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RENEWABLES NOW

RENEWABLES 2021
GLOBAL STATUS REPORT

2021

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REN21 is the only **global renewable energy community** of actors from science, governments, NGOs and industry. We provide up-to-date and peer-reviewed facts, figures and analysis of global developments in technology, policies and markets. Our goal: enable decision-makers to make the shift to renewable energy happen – now.

The most successful organisms, such as an octopus, have a **decentralised intelligence** and "sensing" function. This increases responsiveness to a changing environment. REN21 incarnates this approach.

Our more than **2,000 community members** guide our co-operative work. They reflect the vast array of backgrounds and perspectives in society. As REN21's eyes and ears, they collect information and share intelligence, by sending input and feedback. REN21 takes all this information to better understand the current thinking around renewables and change norms. We also use this information to connect and grow the energy debate with non-energy players.

Our annual publications, the *Renewables Global Status Report* and the *Renewables in Cities Global Status Report*, are probably the world's most comprehensive crowdsourced reports on renewables. It is a truly collaborative process of co-authoring, data collection and peer reviewing.

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FOREWORD

2020 was a year of disruption. The pandemic had a tragic impact on our communities but our health benefited from the extreme drop in fossil fuel use. It was also a year of new norms in the renewable energy sector. Ambition increased at an accelerated pace with a dramatic expansion of net zero emission targets. Increasing pressure from citizens and civil society led courts to force countries to strengthen their own climate plans, while the private sector purchased record amounts of renewable energy.

However, the past teaches us that ambition is not enough. It must be translated into action. While this year's *Renewables 2021 Global Status Report* (GSR) shows continuing progress in the power sector, the share of renewables in heating and transport has barely changed from past levels. Despite all the rhetoric, we are nowhere near the necessary paradigm shift towards a clean, healthier and more equitable energy future.

Clearly, we need a structural shift. It's not just about deploying and installing renewables. It's also about conserving energy, integrating energy efficiency AND leaving fossil fuels in the ground. It's time to stop talking only about gigawatts of installed capacity. We must emphasise how renewables can support development, economic development and a cleaner, healthier environment. If we are to achieve the energy transition, we need to integrate renewables across all economic sectors.

This year's report shows that governments need to act more aggressively and press forward with renewables in all sectors. The window of opportunity is closing and efforts must be ramped up significantly. This will not be easy. The share of fossil fuels in overall final energy demand is as high as it was a decade ago. While renewables grew almost 5% per year from 2009 to 2019, fossil fuel shares remained at around 80% over the same period. And with fossil fuel subsidies in 2019 totalling USD 550 billion – almost double the total investment in renewables – the last 10 years of climate policy promises have shown themselves to be mostly empty words.

One way to accelerate development is to define the uptake of renewable energy as a key performance indicator (KPI). To borrow a business adage, "What gets measured gets done." By measuring our performance, we can close the gap between ambition and target. And how better to measure our progress towards a clean energy transition? We must use the share of renewable energy in final energy consumption as a KPI and link it to every economic activity, every budget, every single purchase. This may sound overly ambitious, but we need urgent action. We cannot afford to make any more commitments that do not produce action. This needs to happen now.

I hope that the pages of this report contain the data and information you need to continue your work in making renewable energy the new norm. I would like to thank all those who have contributed to this year's edition. Particular thanks go to the Research Direction Team of Hannah E. Murdock, Duncan Gibb and Thomas André; Special Advisors Janet L. Sawin, Adam Brown and Lea Ranalder; the many authors; our editors, Lisa Mastny and Leah Brumer; our designers, Caren Weeks, Nicole Winter and Sebastian Ross; and all those who provided data and participated in the peer review process. Once again, this report illustrates the power of a collective process.

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Cascades Inc. diverts three-quarters of the residual materials from its plants away from landfills, using them in biomass boilers or to fertilise farmland, and has committed to achieving 100% renewable electricity by 2030.

EXECUTIVE SUMMARY

01 GLOBAL OVERVIEW

Despite the impacts of the COVID-19 pandemic, renewable energy set a record in new power capacity in 2020 and was the only source of electricity generation to register a net increase in total capacity. Investment in renewable power capacity rose, although slightly, for the third consecutive year, and corporations continued to break records for sourcing renewable electricity. More countries shifted towards renewables for the electrification of heat. Although production of transport biofuels declined, electric vehicle (EV) sales expanded, as did the linking of EVs and renewable power, although to a lesser extent. China was among the countries that strengthened their commitments to action on the climate crisis, setting a carbon-neutral target. The United States re-joined the Paris Agreement in early 2021.

Meanwhile, previous obstacles to progress in the renewable energy sector persisted during 2020. They include the slow increase in the share of renewables in total final energy consumption (TFEC), inadequate innovation in some sectors, the need for infrastructure development, the lack of affordability in some markets, the absence of sufficient policy and enforcement, and ongoing support for fossil fuels.

For the first time, the number of countries with renewable energy support policies did not increase from the previous year. Despite greater interest in net zero targets during 2020, these targets do not necessarily cover all greenhouse gases or sectors, nor do they necessarily lead to increased attention to renewables or to success in meeting renewable energy targets. While such targets are in place in nearly all countries, many countries were not on track to achieve their 2020 targets in multiple sectors, and many had not yet set new targets as their 2020 targets expired. In addition, investments in fossil fuels outlined in COVID-19 recovery packages worldwide were six times greater than the level of investments allocated to renewable energy.

As in past years, the highest share of renewable energy use was in the electricity sector (26% renewables); however, electrical end-uses accounted for only 17% of total final energy consumption. The transport sector, meanwhile, accounted for an estimated 32% of TFEC and had the lowest share of renewables (3.3%). The remaining thermal energy uses, which include space and water heating, space cooling, and industrial process heat, represented more than half (51%) of TFEC; of this, renewables supplied some 11%.

As of 2019, modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11.2% of TFEC, up from 8.7% a decade earlier. Despite tremendous growth in some renewable energy sectors, the share of renewables has increased only moderately each year. This is due to rising global energy demand, continuing consumption of and investment in new fossil fuels, and declining traditional use of biomass (which has led to a shift towards fossil fuels).

This slow progress points to the complementary and fundamental roles of energy conservation, energy efficiency and renewables in reducing the contribution of fossil fuels to meeting global energy needs and reducing emissions. With the concentration of carbon dioxide (CO_2) in the atmosphere still rising to record levels even as emissions have fallen, it has become increasingly clear that a structural shift is needed to reach long-term climate targets.

BUILDINGS

Renewable energy meets a growing portion of final energy demand in buildings, although its share is still less than 15%.

Renewables remained the fastest growing source of energy in buildings, increasing 4.1% annually on average between 2009 and 2019. The highest growth was in electricity use, whereas heating with renewable energy rose more slowly. Modern bioenergy (such as the use of wood-based fuel in efficient stoves) still represented the largest source of renewables in the buildings sector, especially in providing heat, although its growth has been roughly stagnant..

The use of renewable electricity for heat (for example, through electric heat pumps) provided the second largest renewable energy contribution to heat demand and showed the greatest growth in recent years. Solar thermal heat, geothermal heat and district energy networks also have grown quickly, albeit starting from a smaller base. Policies to stimulate renewable energy uptake in buildings remain relatively scarce, although many options exist to improve efficiency in new and existing buildings, expand access to electricity and clean cooking, and encourage the use of renewables.

INDUSTRY

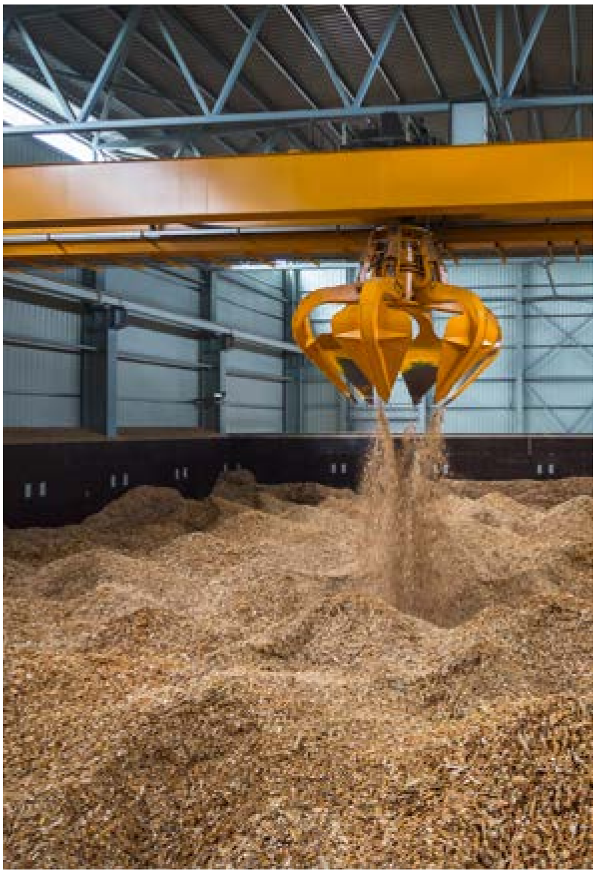
The share of renewables in industrial energy demand remains small, particularly in sectors that require high temperatures for processing.

Renewable energy accounts for only around 14.8% of total industrial energy demand and is used mainly in industries with low-temperature requirements for process heat. In heavy industries – iron and steel, cement, and chemicals – renewables accounted for less than 1% of the combined energy demand in 2018.

Bioenergy (mainly biomass) supplies around 90% of renewable heat in the industrial sector, primarily in industries where biomass waste and residues are produced on-site. Renewable electricity accounts for the second largest share (10%) of renewable industrial heat, although it represented only 1% of total industrial heat consumption in 2019. Solar thermal and geothermal technologies accounted for less than 0.05% of total final industrial energy use in 2018.

The COVID-19 pandemic temporarily reduced industrial energy demand, with global bioenergy use in industry falling 4% in 2020. Measures to promote the uptake of renewables in industries received limited attention in COVID-19 stimulus packages, although some countries announced renewable hydrogen strategies or investment plans to support industrial decarbonisation. By the end of 2020, only 32 countries had at least one renewable heating and cooling policy for industry (all of them economic incentives, such as subsidies, grants, tax credits or loan schemes).

Despite tremendous growth in some renewable energy sectors, the share of renewables has **increased only moderately** each year.



TRANSPORT

After falling initially, transport energy demand rebounded by the end of the year. Trends show rising demand and a stagnant share of renewable energy.

The COVID-19 pandemic had significant impacts on the transport sector and its use of renewable energy. Transport activity and energy demand fell sharply in the early months of 2020 but rebounded by year's end. Longer-term trends have shown that growth in energy demand for transport has far outpaced that for other sectors.

Transport remains the sector with the lowest share of renewables, as oil and petroleum products (and 0.8% non-renewable electricity) continue to meet nearly all global transport energy needs (95.8%). Biofuels and renewable electricity met small shares of those needs (3.1% and 0.3%, respectively). Following a decade of steady growth, biofuel production decreased in 2020 due to the overall decline in transport energy demand, while electric car sales increased 41% during the year. The use of or investment in renewable hydrogen and synthetic fuels for transport increased in some regions but remained relatively minimal.

Overall, the transport sector is not on track to meet global climate targets. Many countries still lack a holistic strategy for decarbonising transport. Such a strategy could greatly decrease energy demand in the sector and thus allow for the renewable share in transport to increase.

POWER

Driven by solar photovoltaic (PV) and wind power, the renewable power sector surged in the second half of 2020 to overcome the pandemic's impacts.

Installed renewable power capacity grew by more than 256 gigawatts (GW) during the pandemic, the largest ever increase. Continuing a trend dating back to 2012, net additions of renewable power generation capacity outpaced net installations of both fossil fuel and nuclear power capacity combined. China again led the world in renewable capacity added, accounting for nearly half of all installations in 2020 and leading the global markets for concentrating solar thermal power (CSP), hydropower, solar PV and wind power.

China added nearly 117 GW, bringing online more renewable capacity in 2020 than the entire world did in 2013 and almost doubling its additions from 2019. By the end of 2020, at least 19 countries had more than 10 GW of non-hydropower renewable capacity, up from 5 countries in 2010. Renewable energy reached a record share – an estimated 29% – of the global electricity mix. Despite these advances, renewable electricity continued to face challenges in achieving a larger share of global electricity generation, due in part to persistent investment in fossil fuel (and nuclear) power capacity.

China

added nearly 117 GW of renewable power, bringing online more capacity in 2020 than the entire world did in 2013.

02 POLICY LANDSCAPE

Despite the COVID-19 crisis, policy support for renewables generally remained strong throughout 2020.

By the end of 2020, nearly all countries had in place renewable energy support policies, although with varying degrees of ambition. Corporate commitments to renewable energy also increased during the year, led by market-based drivers such as action on climate change and the declining costs of renewable electricity.

While the suite of renewable energy policies implemented during the year was affected in part by the COVID-19 pandemic, it also evolved in response to increased action on climate change, falling costs of renewables, evolving network and system integration demands, and the changing needs and realities of different jurisdictions.

RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

2020 was an important year for climate change policy commitments.

Although the COVID-19 crisis was the central political focus of the year, commitments to climate change mitigation stood out. Overall, 2020 was an important milestone for climate change policy, as many countries' greenhouse gas targets for the year expired. Countries set new targets, and many committed to carbon neutrality.

While some jurisdictions enacted climate change policies that indirectly stimulate the uptake of renewable energy, a growing number adopted comprehensive policies directly linking decarbonisation with increased deployment of renewables. Policy mechanisms implemented in 2020 that can indirectly stimulate interest in renewable energy included fossil fuel bans and phase-outs, greenhouse gas emission reduction targets, and carbon pricing and emission trading systems. In addition, at least six regional, national and state/provincial governments adopted comprehensive, cross-sectoral climate policies that include direct support for renewables.

HEATING AND COOLING IN BUILDINGS

Despite the enormous potential for renewable energy in heating and cooling, policy developments in heating and cooling for buildings in 2020 remained limited, outstripped by policies aimed at electricity generation and transport.

Financial incentives were the most common mechanism used to encourage renewable heating and cooling in buildings in 2020. All such policies enacted or revised during the year were in Europe.

Evidence also points to growing interest in electrification of heating and cooling, which can increase the penetration of renewables in the buildings sector if the electricity used is generated from renewable sources. In 2020, policy makers in a number of national and sub-national jurisdictions focused rising attention on policies targeting building heating and cooling electrification. Energy efficiency policies also received international attention.

INDUSTRY

Policy developments related to increasing the share of renewables in industry remained scarce in 2020, compared with policies directed at all other end-use sectors.

Although renewable energy solutions for industrial uses are available, they are not yet competitive with fossil fuels, and policy support remains critical for increasing renewables in this sector. However, such support remained rare in 2020. By year's end, only 32 countries had some form of renewable heating and cooling policy for industry (no change from 2019), with financial incentives being the most common form of policy support.

TRANSPORT

Decision makers are focusing increasingly on expanding the use of renewables in the transport sector, with an emphasis on transport electrification.

Although biofuels continue to be a central component of road transport policy frameworks, the electrification of transport received much of the attention in 2020. Policies aimed at transport electrification are not renewable energy policies in and of themselves, but they offer the potential for greater penetration of renewable electricity in the sector, to the extent that the electricity used for charging vehicles is generated from renewable sources.

As in past years, policy makers focused most of their attention on road transport. EV policies became increasingly popular in 2020, although the vast majority of these continued to lack a direct link to renewable electricity generation. However, the number of countries with EV policies that do have a direct link to renewables increased from two to three during the year.

Rail, aviation and shipping still receive much less policy attention than road transport, even though they are the fastest growing transport sub-sectors and account for a rising share of total final energy use in transport.

EV policies
became increasingly popular in 2020, although the vast majority of these continued to lack a direct link to renewable electricity generation.

POWER

As in previous years, the power (electricity generation) sector continued to receive significant renewable energy policy attention in 2020.

The power sector continued to receive the bulk of renewable energy policy attention in 2020, as in previous years. Targets were the most popular form of intervention: by the end of 2020, 137 countries had some form of renewable electricity target, compared with 166 in 2019.

Although feed-in policies remain a widely used policy mechanism for supporting renewable power, in 2020 the shift continued from feed-in policies (set administratively) to competitive remuneration through tenders and auctions. Despite the continued popularity of net metering policies, some jurisdictions began transitioning away from net metering or modified their programmes to charge customers fees for participating.

Financial incentives, while always an important policy tool, were especially important for the power sector in 2020 as a result of the COVID-19 pandemic.

SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY (VRE)

Many jurisdictions with relatively high shares of renewables are implementing policies designed to ensure the successful integration of VRE into the broader energy system.

The policy push for systems integration of renewables and enabling technologies, such as energy storage, focuses primarily on increasing power system flexibility and control, as well as grid resilience. Policies to advance the integration of VRE focused on market design, improving electricity transmission and distribution system infrastructure, and supporting the deployment of energy storage.

03 MARKET AND INDUSTRY TRENDS

BIOENERGY

Modern bioenergy provided 5.1% of total global final energy demand in 2019, accounting for around half of all renewable energy in final energy consumption.

Modern bioenergy provided 9.5% of the heat required in industry and agriculture in 2019, an increase of around 16% since 2009. Bioenergy also provided 5% of the heat needed for buildings, with this use up 7% over the decade.

Biofuels – mostly ethanol and biodiesel – provide around 3% of transport energy. In 2020, global biofuel production fell 5% due to the impacts of the COVID-19 pandemic on overall transport energy demand. Ethanol production declined around 8%, with an 11% drop in production in the United States, the major producer. Global biodiesel production increased slightly to meet higher blending levels in Indonesia (the world's largest biodiesel producer) and in Brazil, as well as higher demand in the United States.

In the electricity sector, bioenergy's contribution rose 6% in 2020, reaching 602 terawatt-hours (TWh). China remained the largest generator of bio-electricity, followed by the United States and Brazil.

The most notable industry trend was rising investment in hydrotreated vegetable oil (HVO), with a 12% increase in production in 2020. Plans were announced for many additional plants, which could more than quadruple current capacity. HVO production would then exceed that of FAME (fatty acid methyl ester) biodiesel.

GEOTHERMAL POWER AND HEAT

Geothermal electricity generation totalled around 97 TWh in 2020, while direct use of geothermal heat reached about 128 TWh (462 petajoules).

An estimated 0.1 GW of new geothermal power generating capacity came online in 2020, bringing the global total to around 14.1 GW. The year saw relatively little growth in capacity compared to recent years (attributed in part to pandemic-related disruption), with almost all new facilities located in Turkey. The United States and Japan added minor amounts of geothermal power capacity in 2020.

Direct use of geothermal energy for thermal (heat) applications is highly concentrated geographically, with only four countries – China, Turkey, Iceland and Japan – accounting for three-quarters of the energy consumed. Direct use has grown at an average rate of nearly 8% in recent years, with space heating being the primary driver. Some of the most active markets lack access to high-temperature resources and often face higher costs and greater technical challenges to accessing geothermal heat. Countries with noteworthy activity in 2020 included France, Germany and the Netherlands.

The geothermal industry was characterised by project delays and by meagre and highly concentrated market growth. The main focus continued to be on technological innovation, such as new resource recovery techniques and seismic risk mitigation, with the aim of improving the economics, lowering the development risk and strengthening prospects for expanded resource development. However, as in past years, the hopes of expanding geothermal development beyond the relatively few and concentrated centres of existing activity remained largely unmet. High costs and project risks have continued to deter investment in most places, especially in the absence of government support (such as feed-in tariffs and risk mitigation funds), although certain pockets of innovation attracted new investment from established entities in the energy industry.

In 2020, **global biofuel production** fell 5% due to the impacts of the COVID-19 pandemic on overall transport energy demand.

HYDROPOWER

The global hydropower market grew in 2020, but China was responsible for more than half of capacity additions.

Despite a 24% increase in capacity additions, driven mainly by China, the global hydropower market did not recover in 2020 after several years of deceleration. The effects of the COVID-19 pandemic were notable, with the market slowing as construction was halted temporarily, component supply chains were disrupted, and energy demand fell. New capacity was an estimated 19.4 GW, raising the total global installed capacity to around 1,170 GW. Global hydropower generation increased 1.5% in 2020 to reach an estimated 4,370 TWh, representing around 16.8% of the world's total electricity generation.

China added 12.6 GW of hydropower capacity in 2020, its largest addition of the previous five years, and regained the lead from Brazil in commissioning new hydropower capacity, followed by Turkey, India and Angola. Pumped storage capacity increased slightly (up 1.5 GW, or 0.9%), with projects in China and Israel, bringing total capacity to 160 GW. Several large pumped storage projects were in the pipeline, including in Australia, Greece, India, Portugal, Scotland and Turkey, in part to support growth in solar PV and wind power.

The hydropower industry continued to face challenges as well as opportunities, with both of these affected by the pandemic-induced recession. Challenges included operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure. Opportunities for industry expansion included technology improvements and increased performance, the remaining untapped potential of smaller resources, synergies with VRE, and increased needs for grid flexibility.

OCEAN POWER

Ocean power represented the smallest portion of the renewable energy market, yet new targets for ocean power capacity were set during the year.

Ocean power represents the smallest portion of the renewable energy market, with most projects focused on relatively small-scale demonstration and pilot projects of less than 1 megawatt (MW). Net additions in 2020 totalled around 2 MW, with an estimated 527 MW of operating capacity at year's end. Ocean power technologies are steadily advancing towards commercialisation, and tidal turbines continued to demonstrate their reliability. However, consistent policy and revenue support remain critical.

Development activity is concentrated primarily in Europe, and particularly off the coast of Scotland, but has increased steadily in China, the United States and Canada. The resource potential of ocean energy is enormous, but it remains largely untapped despite decades of development efforts.

The ocean power industry experienced delays of planned deployments due to COVID-19, and developers redirected their focus to device and project development. Operational tidal turbines continued to generate power reliably and to move towards commercialisation. Across the sector, financial and other support from governments, particularly in Europe and North America, continued to boost private investments in ocean power technologies, especially tidal stream and wave power devices.

SOLAR PHOTOVOLTAICS (PV)

Solar PV had another record-breaking year, adding as much as an estimated 139 GW, for an estimated total of 760 GW.

Pending policy changes drove much of the growth in the top three markets – China, the United States and Vietnam – but several other countries saw noteworthy expansion.

Favourable economics have boosted interest in distributed rooftop solar PV systems. In 2020, growth in this market share was due mainly to a rush of installations in Vietnam in advance of the expiry of the country's feed-in tariff; however, Australia, Germany and the United States also saw significant increases as homeowners invested in home improvements during the pandemic.

South Australia achieved one of the world's highest levels of solar penetration in 2020. The state's power system has become the world's first large-scale system to approach the point at which rooftop solar PV effectively eliminates demand for electricity from the grid.

The solar PV industry rode a roller coaster in 2020, driven largely by pandemic-related disruptions, as well as by accidents at polysilicon facilities in China and a shortage of solar glass. These disruptions, due in large part to heavy reliance on China as the world's dominant producer, combined with concerns about possible forced labour in polysilicon production, led to calls in many countries for the creation of local supply chains.

Despite the multiple challenges, new actors entered the sector. Competition and price pressures continued to motivate investment to improve efficiencies, reduce costs and improve margins.

The solar PV industry has become the major driver of growth in polysilicon production and accounts for a rising share of demand for other resources and materials, such as glass and silver. In most countries, recycling panels at the end of their useful life – as a means to reclaim these resources and minimise associated environmental impacts – is only starting to gain attention.

CONCENTRATING SOLAR THERMAL POWER (CSP)

Despite declining costs, CSP capacity grew in only one country during 2020.

Global CSP capacity grew a mere 1.6% in 2020 to 6.2 GW, with a single 100 MW parabolic trough project coming online in China. This was the lowest annual market growth in over a decade, the result of increasing cost competition from solar PV, the expiry of CSP incentive programmes and a range of operational issues at existing facilities.

More than 1 GW of CSP projects was under construction in the United Arab Emirates, China, Chile and India during the year. The majority of this capacity is based on parabolic trough technology and is being built in parallel with thermal energy storage (TES). At year's end, an estimated 21 gigawatt-hours of thermal energy storage was operating in conjunction with CSP plants across five continents. Global TES capacity, installed mainly alongside CSP, is almost double that of utility-scale battery storage.

During the 2010s, CSP costs fell nearly 50%, the largest decline for all renewable energy technologies, with the exception of solar PV. In many cases, CSP plants are being retrofitted with TES or co-located with solar PV capacity to lower costs and increase capacity values.

Solar PV had another record year, while only a single CSP project came online in 2020.

SOLAR THERMAL HEATING

An estimated 25.2 gigawatts-thermal (GW_{th}) of new solar thermal capacity was added in 2020, increasing the global total 5% to around 501 GW_{th}.

China again led in new solar thermal installations, followed by Turkey, India, Brazil and the United States. Most large solar thermal markets were constrained by COVID-19-related challenges, and in some cases commercial clients postponed investment decisions. However, the reduction was smaller than expected due to stabilising factors such as ongoing business in the construction sector and higher demand from residential owners, many of whom spent more time at home and invested in infrastructure improvements.

The year was bright for solar district heating in China and Germany, thanks to policy support for green heating technologies. The global solar district heating market also diversified into new markets in Europe (Croatia, Kosovo and Serbia) and Asia (Mongolia). In addition, central solar hot water systems for large residential and commercial buildings sold well in China, Brazil and Turkey. By year's end, at least 471 solar district heating or central hot water systems (at least 350 kilowatts-thermal) were operating worldwide, totalling 1.8 GW_{th} of capacity.

Hybrid, or solar PV-thermal (PV-T), collectors became more popular in several countries. In total, 36 manufacturers worldwide reported PV-T capacity of at least 60.5 megawatts-thermal (MW_{th}) (connected to 24 MW-electric), up sharply from 46.6 MW_{th} in 2019.

More collector manufacturers and project developers began offering solar industrial heat (SHIP) solutions to factories worldwide. At least 74 SHIP systems, totalling 92 MW_{th}, started operation globally in 2020, raising the number of facilities in operation 9% to around 891 SHIP plants. Although many technology suppliers reported delays in installation and construction, some megawatt-scale plants were successfully commissioned during the year, including Europe's largest (10.5 MW_{th}), used to heat agricultural greenhouses.

WIND POWER

The wind power market achieved a record-breaking 93 GW of new installations, bringing total capacity onshore and offshore to nearly 743 GW.

China and the United States led the growth in wind power with record years, driven by pending policy changes at the end of 2020 in both countries. Several other countries also reached installation records, while the rest of the world installed about the same amount as in 2019. Wind power accounted for a substantial share of electricity generation in several countries in 2020, including Denmark (over 58%), Uruguay (40.4%), Ireland (38%) and the United Kingdom (24.2%).

Nearly 6.1 GW of capacity was connected offshore for a global total of 35.3 GW. Interest in offshore wind power is increasing – including among corporations looking to sign power purchase agreements (PPAs) – due to the large scale of generation, high capacity factors, fairly uniform generation profiles and falling costs.

The wind industry continued to face perennial challenges that were exacerbated by the pandemic. Despite selling more turbines, even top manufacturers suffered losses for the year, closed factories and laid off workers as the highly competitive market, together with pandemic-related costs and delays, squeezed profit margins further.

In some markets, governments responded by extending policy deadlines, and new policy commitments helped stimulate record investments. For the first time, global capital expenditures committed to offshore wind power during the year surpassed investments in offshore oil and gas.

To diversify in key markets, turbine manufacturers and project developers continued expanding into new sectors, even as new actors – including oil majors – moved further into the wind sector. Manufacturers focused on technology innovation to continuously reduce costs and achieve an ever lower levelised cost of energy. In addition, they expanded their work with other researchers to increase wind turbine sustainability during production and at the end of useful life.

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS (DREA)

Distributed renewables have continued to enable energy access, reaching electricity generation shares as high as 10% in some countries.

By the end of 2019, 90% of the global population had gained access to electricity, although one-third (2.6 billion people) still lack access to clean cooking, relying on mostly traditional use of biomass. Renewables-based electric power systems and clean cooking solutions have played an increasingly important role in improving energy access rates, especially in rural and remote areas where such access remains low. Stand-alone solar systems and renewables-based mini-grids are often the most cost-effective way of electrifying off-grid areas in the developing world, providing power for households and productive uses. Options that help reduce the health and environmental impacts of the traditional use of biomass include improved biomass stoves and fuels, biogas, ethanol, solar cookers and, increasingly, renewables-based electric cooking.

After several years of strong growth, the market for renewables-based energy access systems was negatively impacted by the COVID-19 pandemic. Global sales of off-grid solar systems fell 22% in 2020, with the greatest regional decline in South Asia (51%), while sales in East Africa, the largest market, dipped 10%. Despite the drop in sales, financing for off-grid solar companies increased slightly by 1%. While equity funding fell significantly, debt and grant funding increased.

Although many planned renewables-based mini-grid projects were delayed due to the pandemic, new solar mini-grids were commissioned in several countries specifically to power healthcare facilities as an emergency response to the crisis. By late 2020, new financing deals were signed for several larger mini-grid developments across Africa.

The clean cooking sector has seen less funding and private sector involvement than the electricity access sector. However, funding for the 25 largest clean cooking companies increased 68% in 2019, to USD 70 million. In 2020, several new large-scale funding initiatives were announced for clean cooking in Africa, where the clean cooking deficit remains the largest. Policy makers in several countries also have focused on clean cooking, setting new targets and developing financial support packages.

05 INVESTMENT FLOWS

Global investment in renewable energy capacity increased 2% in 2020, resisting the COVID-19-induced economic crisis.

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) totalled USD 303.5 billion in 2020. Developing and emerging economies surpassed developed countries in renewable energy capacity investment for the sixth year running, reaching USD 153.4 billion (a smaller margin than in previous years). Investments for the year rose 13% in developed countries and fell 7% in developing and emerging countries.

Investment in renewables continued to focus on wind and solar power, with solar representing nearly half of global renewable energy investment in 2020, at USD 148.6 billion (up 12%). Investments fell in all renewable technologies except solar power, with wind power falling 6% to USD 142.7 billion (47% of the total). The remaining technologies continued their downward trend, with investment in small hydropower falling to USD 0.9 billion, geothermal to USD 0.7 billion and biofuels to USD 0.6 billion.

COVID-19 economic recovery packages included significant spending to stimulate further investment in renewables. Around 7% of the USD 732.5 billion total announced by 31 governments to support all types of energy was allocated directly to policies favouring the production or consumption of renewables. However, renewable energy investments outlined in recovery packages were still only around one-sixth the level of investments allocated to fossil fuels.

Energy projects represented nearly 60% of all climate finance in 2017 and 2018, averaging USD 337 billion. Climate finance flows from developed to developing countries reached USD 78.9 billion in 2018, of which USD 12.5 billion was allocated to projects targeting energy generation from renewable sources. Multilateral climate funds and multilateral development banks play an important role in providing direct support to developing countries, while climate finance instruments, such as green bonds, hit record levels for a second consecutive year, up 1.1% in 2020 to USD 269.5 billion.

The divestment movement continued its upward trend in 2020, with more than 1,300 institutional investors and institutions worth nearly USD 15 trillion committing to divesting partially or fully from fossil fuel-related assets. Investors increasingly have aligned their portfolios with the emission reduction goals of the Paris Agreement. However, investment in fossil fuel-related companies also has grown, and it is difficult to establish a direct link between divesting from fossil fuels and investing in renewables.

06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

Wind and solar reached record levels in the electricity mix in 2020, while sales of heat pumps, electric vehicles and energy storage grew strongly despite the COVID-19 pandemic.

In the power sector, the installed capacity and penetration of variable renewable electricity sources – mainly solar PV and wind power – have grown rapidly in many countries. Several power systems reached record-high shares of instantaneous VRE in 2020 due to lower costs of these renewable technologies and to the effects of COVID-19 containment measures on electricity markets.

The wider digitalisation of transmission and distribution grids continued, as did growth in "behind-the-meter" systems. In addition, electricity markets were adapted during 2020 to allow for the participation of ancillary services from wind, solar and battery storage. Flexibility services were procured increasingly from VRE power plants, flexible sources of demand and virtual power plants.

Grid infrastructure constraints have become a significant bottleneck for the integration of renewables in several locations. Large transmission projects also have faced regulatory hurdles. Despite this, major projects were advanced in 2020, driven by demand for grid capacity from VRE generators.

In contrast to the power sector, shares of renewables in global transport and heating systems remained low in 2020. Integration of renewable energy into road-based transport was advanced mainly through vehicle electrification, while heat pumps offer untapped potential to enable the use of renewables in the heating and cooling sector. Along with energy storage, the enabling technologies of heat pumps and EVs support the integration of renewables and contribute to greater flexibility in power systems. Sales of all three technologies increased in 2020, despite the onset of the COVID-19 pandemic.

In 2020, heat pump uptake slowed in the Asia-Pacific region, while it continued to increase in North America and Europe. The heat pump industry was characterised by company acquisitions, technological developments in refrigerants that have low global warming potential, and the emergence of new solutions integrating heat pumps with other energy devices.

At least nine countries **generated more than 20%** of their electricity from solar PV and wind in 2020.

While global car sales decreased in 2020, sales of electric cars (including both battery electric vehicles and plug-in hybrids) resisted the COVID-19-induced downturn with nearly 3 million units sold, up 41% from 2019. The share of electric cars in new car sales worldwide reached 4.6% in 2020, surpassing the 2019 record of 2.7%. Meanwhile, around one-third of the two- and three-wheelers sold were electric, nearly all of them in China. Notable activity in the EV industry during the year included significant reductions in battery costs and automakers' announcements that they would shift, partially or fully, to electric production.

The global market for energy storage of all types reached 191.1 GW in 2020. Mechanical storage in the form of pumped hydropower accounted for the vast majority of this capacity, followed by roughly 14.2 GW of electro-mechanical and electrochemical storage, and around 2.9 GW of thermal energy storage. The energy storage industry saw significant cost reductions, innovation in battery technologies and increased collaboration in the production of renewable hydrogen.

07 ENERGY EFFICIENCY, RENEWABLES AND DECARBONISATION

Integrating renewable energy deployment and energy efficiency measures remains crucial for decarbonising end-use sectors and the energy system as a whole.

Renewable energy and energy efficiency have long been known to provide multiple benefits to society, such as lowering energy costs, improving air quality and public health, and boosting jobs and economic growth. Increasingly, renewables and efficiency are viewed as crucial to reduce carbon emissions. Energy production and use account for more than two-thirds of global greenhouse gas emissions. Together, renewables and energy efficiency have made significant contributions to limiting the rise in CO_2 emissions.

Trends in carbon intensity – measured as energy-based CO_2 emissions per unit of gross domestic product (GDP) – help to better understand the full impact of both energy efficiency and renewables on the transition to more efficient and cleaner energy production and use. Unlike overall emissions, the carbon intensity of GDP reflects technical or structural improvements in various sectors.

Together, renewables and energy efficiency have made significant contributions to **limiting the rise in CO_2 emissions.**

Between 2013 and 2018, global energy-related CO_2 emissions grew 1.9%, to nearly 38 gigatonnes. The increase occurred during a period of economic growth – global GDP grew 23% during the five-year period – but was slowed by improvements in the overall carbon intensity of GDP. These improvements were due in part to increased renewable electricity production and, to a greater extent, to improved energy efficiency; this occurred despite an overall decline in energy efficiency improvements that began in 2015 and that was reinforced by the COVID-19 crisis and low energy prices.

Some measures that apply to end-use sectors – such as building energy codes and the deployment of distributed renewables, heat pumps, and technologies for electrification – impact carbon intensity as they can have both an energy efficiency and a renewable energy component. Other energy efficiency measures can play a role in each sector, including digitalisation in the buildings and industry sectors, and vehicle fuels and emission standards in the transport sector. In 2020, the COVID-19 pandemic impacted the energy efficiency of all end-use sectors.

08 FEATURE: BUSINESS DEMAND FOR RENEWABLES

Businesses are increasing their uptake of renewable energy across power, heating and cooling, and transport needs. Company membership in business coalitions promoting renewable energy procurement surged across all sectors.

Several factors incentivise business demand for renewables. Government policy continues to play a key role, but company-level factors also are becoming prominent. Environmental and ethical considerations encourage companies to adopt renewable energy as part of their broader sustainability or emission reduction goals. Renewables also are increasingly associated with lower costs and a variety of risk mitigation opportunities, thereby driving business demand. Surging membership in coalitions, such as RE100 and EV100, that promote business demand for renewables is also driving corporate uptake.

Businesses source their electricity from renewables in multiple ways, including by generating it themselves (either on- or off-site); procuring it from utilities through direct billing; purchasing environmental attribute certificates from energy suppliers; and signing long-term power purchase agreements with producers. Despite a challenging business year, the new renewable energy capacity that businesses sourced through PPAs increased 18% in 2020, across nearly all regions. North America accounted for the majority of the new capacity procured, and Amazon was the leading corporate power purchaser. Policies to enable cross-border PPAs were under development in Europe. In the Asia-Pacific region, ongoing challenges to corporate sourcing included regulatory and market barriers and limited or no availability of corporate sourcing mechanisms.

Corporations meet their needs for low-temperature thermal energy through renewables-based electrification, renewable gases, procurement of renewable district heat, and the direct use of geothermal heat, solar thermal heat and modern bioenergy. By the end of 2020, nearly 900 solar thermal systems were supplying industrial process heat, with new projects concentrated in China, Mexico and Germany. In most cases, corporations produce and consume on-site the energy they need for heating and cooling, rather than sourcing it from elsewhere.

Corporations in energy-intensive industrial sectors – such as iron and steel, cement, and chemicals production – use smaller shares of renewables to meet their energy needs. Still, interest in renewable energy procurement in these sectors has grown, and business coalitions emerged on both the demand and supply sides in 2020.

Businesses source renewable energy for their transport needs mainly from biofuels, renewables-based electricity, and renewable hydrogen across the road, rail, maritime and aviation sectors. Electrification of fleet vehicles has become increasingly popular, especially among companies operating in the more than 300 zero-emission zones in cities worldwide. However, the COVID-19 pandemic contributed to a 20% drop in sales and investment in hydrogen-powered transport in 2020, as the demand for hydrogen fuel cell buses fell.

Declining costs have made biofuels an increasingly viable option for corporate procurement in maritime shipping, although their use in this sector is marginal. Interest in renewable hydrogen and ammonia also increased in the maritime transport sector. In 2020, several aviation companies committed to sourcing more-sustainable aviation fuels, while others showed interest in developing electric and hydrogen aircraft.

City Developments Limited has mapped a pathway to reach its goal of net zero carbon emissions by 2030, including investing heavily in energy efficiency and targeting 100% renewable energy.

01 GLOBAL OVERVIEW

KEY FACTS

- Despite the impacts of the COVID-19 pandemic, **renewable energy set a record in new power capacity in 2020** and was the only source of electricity generation to register a net increase in total capacity.
- Renewables continued to meet low shares of final energy demand in the buildings, industry and transport sectors, where **policy support remains crucial** to spurring uptake but is insufficient.
- For the first time, the **number of countries with renewable energy support policies did not increase** from the previous year. While renewable energy targets are in place in nearly all countries, **many countries were not on track to achieve their 2020 targets** in multiple sectors, and many had not yet set new targets as their 2020 targets expired.
- With the atmospheric concentration of CO_2 rising to record levels even as emissions have fallen, it has become increasingly clear that **a structural shift is needed to reach long-term climate and development goals.**

The renewable energy story during a crisis year was one of resilience and adaptation, yet significant challenges remain. During the year, restrictions on movement and goods as well as the introduction of COVID-19 recovery packages all had an impact on the production and use of renewable energy.

Despite suffering during the onset of the pandemic, renewable energy saw a record increase of new power capacity in 2020 globally and was the only source of electricity generation to experience a net increase in total capacity. Investment in renewable power capacity increased (albeit slightly) for the third consecutive year, and corporations continued to break records for sourcing renewable electricity. More countries are turning towards electrification of heat with renewables, and although production of transport biofuels decreased, sales of electric vehicles (EVs) expanded as did the linking of EVs to renewable power (to a lesser extent). A wave of commitments to action on the climate crisis included a carbon-neutral[i] target by China, while the United States re-joined the Paris Agreement in early 2021.

At the same time, obstacles that have slowed progress in the renewables sector in past years persisted during 2020. For the first time ever, the number of countries with renewable energy support policies did not increase from the previous year. While renewable energy targets are in place in nearly all countries, many countries were not on track to achieve their 2020 targets in multiple sectors, and many had not yet set new targets as their 2020 targets came to term. Moreover, in COVID-19 recovery packages, investment in fossil fuels was six times greater than for renewable energy.

i See Glossary.

RENEWABLES IN 2020

As governments worldwide instituted lockdowns in 2020 to slow the spread of COVID-19 and to respond to the resulting global health crisis, economies ground to a halt and **energy demand** plummeted. Overall, primary energy demand worldwide fell around 4% during the year, resulting in a 5.8% drop in global energy-related carbon dioxide (CO_2) **emissions** – the largest percentage decrease since World War II.[1]

Renewable energy reached its highest recorded share in the global electricity mix in 2020 – an estimated 29% – due in large part to low operating costs and preferential access to electricity networks during periods of low electricity demand.[2] Data for countries representing more than one-third of global electricity demand showed that every month of full lockdown during the pandemic reduced electricity demand 20% on average, or more than 1.5% on an annual basis.[3]

In the meantime, more than 256 gigawatts (GW) of **renewable power capacity** was added globally during the year, surpassing the previous record by nearly 30%.[4] (→ *See Table 1.*) While the renewables sector proved to be notably robust during this period, the fossil fuel industry largely struggled – especially the global coal and oil industries – due to decreased demand as well as difficulties for the oil industry in reaching production agreements within the Organization of the Petroleum Exporting Countries (OPEC)+ alliance[i].[5]

Costs of producing electricity from wind and solar energy have dropped significantly in recent years. In 2020, the global weighted average levelised cost of electricity from utility-scale solar photovoltaics (PV) declined 85% since 2010, while onshore wind power costs fell 56% during the same period. (→ *See Sidebar 6 in Market and Industry chapter.*) These declines mean that for most of the world's population, electricity production from new renewables is more cost effective than from new coal-fired power plants.[6] In a growing number of regions, including parts of China, the European Union (EU), India and the United States, it has already become cheaper to build new wind or solar PV plants than to operate existing coal-fired power plants.[7] Renewables also are outcompeting new natural gas-fired power plants on cost in many locations, and are the cheapest sources of new electricity generation in countries across all major continents.[8]

In contrast to previous years, which had seen some growth, the share of renewables in the transport sector remained constant.[9] Although biofuels have continued to dominate the renewable energy contribution in transport, the global EV stock has grown significantly, increasing opportunities to integrate renewables in road transport.[10] The global market share of EVs remains low overall, however.[11]

The uptake of modern renewables for heating and cooling progressed at a slow pace. Consumption of renewable heat suffered during the pandemic, and electrification of heating in buildings (and to some extent in industry) attracted policy-maker attention.[12] However, the uptake of renewables in both heating and transport remains constrained by insufficient policy support and enforcement and by slow developments in new technologies (such as advanced biofuels).[13]

Distributed renewables for **energy access** (DREA) systems proved invaluable in many rural and remote communities during the early phases of the pandemic, notably in Africa, powering health facilities and other essential services through solar PV mini-grids.[14] However, measures to contain the virus hindered companies, delayed projects and held back end-customers from purchasing new systems.[15] Sales of solar lanterns, in particular, fell 30% in 2020 compared to 2019 even though they rebounded in the second half of the year.[16]

The global population without access to electricity continued to shrink, although 771 million people (10% of the world's population) still lacked electricity access in 2019 (latest data available), nearly 75% of them in sub-Saharan Africa.[17] However, estimates for 2020 suggest that the pandemic led to reversals in this trend for the first time since 2013: in Africa, 2% fewer people (13 million people) had access to electricity in 2020.[18] Meanwhile, the global population lacking access to clean cooking[ii] increased slightly in 2019 to around 2.6 billion people, with few signs of progress.[19] In addition, the pandemic further worsened the inequities of lack of energy access, as populations without access were more heavily affected during the year.[20]

i Established in 2016, OPEC+ includes the 14 OPEC members as well as 10 additional oil and gas producing countries.

ii The REN21 Global Status Report (GSR) refers to clean and/or efficient cook stoves or fuels as per the methodology of the Multi-Tier Framework.

Although analysts widely expected the economic blow in 2020 to decrease **renewable energy investment** as much as 10%, the opposite ended up being true.[21] Due to a combination of factors including policy support, low interest rates, fluctuating oil and gas prices, and longer-term investor perspectives, global investment in new renewable energy capacity (excluding large hydropower projects) increased 2% from the previous year, reaching USD 303.5 billion.[22] In 2020, global investment in new renewable power and fuel capacity was estimated to be more than twice the investment in coal, gas and nuclear power generating plants combined.[23] However, considering all types of energy investment[i], investment in fossil fuels far outweighed that of renewables.[24]

At least two countries **withdrew support for fossil fuel exploration.** Denmark will cease all new oil and gas exploration as part of a larger plan to stop extracting fossil fuels entirely (overseas and domestic) by 2050.[25] The United Kingdom announced its intentions to end support for oil, gas and coal projects overseas "as soon as possible".[26] Japan also was considering withdrawing support for overseas exploration.[27] Multilateral development banks dedicated more than USD 13 billion to "clean[ii]" energy, but at the same time they committed over USD 3 billion to fossil fuels.[28] By early 2021, numerous private banks, pension funds and insurers also had committed to ending or seriously restricting support for fossil fuels.[29]

Businesses continued to purchase more and more renewable electricity. Corporate sourcing of renewable power set a record in 2020, increasing 18% and reaching more than 23 GW of power purchase agreements (PPAs) signed during the year.[30] Most of the installed capacity was solar PV, followed by wind power.[31]

By early 2021, more than 300 leading global corporations had joined the RE100 initiative – committing to using 100% renewable electricity – up from 167 corporations a year before.[32] EV100 and EP100 both saw growth in membership in 2020, while SteelZero was launched in December.[33]

Companies also are meeting their heating, cooling and transport needs with renewable energy, although these activities are at a much smaller scale. (→ *See Feature chapter.*) In some manufacturing industries, such as pulp and paper and food processing, firms supply relatively high shares of their heat demand with renewables (mostly bioenergy), while those in energy-intensive industries, such as steelmaking, are exploring activities to decarbonise their energy use with renewable hydrogen.[34] (→ *See Box 1.*) By early 2021, at least 2,360 companies had committed to net zero targets, a more than four-fold increase since 2019.[35]

The ongoing shift among major **energy companies** to invest in renewable energy highlights both the cost-competitiveness and public appeal of renewables, in addition to political and investor pressure. The world's largest oil and gas companies continued to invest in the renewable energy sector in 2020 (as well as to acquire companies already active in the sector) and to invest in technologies such as electric mobility and energy storage as well as hydrogen production and distribution (although often not renewable hydrogen).[36] Even so, major fossil fuel companies still invested heavily in oil and gas extraction projects, and only a minor share of their overall investments goes to the renewable energy sector, with some companies expected to miss their own "green energy" investment targets.[37] (→ *See Sidebar 1.*)

BOX 1. Renewable Hydrogen in the GSR

In 2020, policy, industry and civil society attention to the use of renewable hydrogen to reduce demand for fossil fuels grew rapidly around the world. REN21's *Renewables Global Status Report* (GSR) treats (renewable) hydrogen as an energy storage technology that is capable of converting primary renewables into useful forms of energy in key sectors, including certain industrial processes, maritime shipping and aviation. As such, readers will find information on renewable hydrogen distributed throughout the report, most prominently in the Policy Landscape chapter (Sidebar 5 and Table 5) and in the Energy Systems Integration and Enabling Technologies chapter (pages 213 and 215).

i Including upstream/downstream oil, gas and coal supply.

ii "Clean" energy in this case includes renewable energy, energy efficiency, active transport (e.g., walking and cycling) and electric vehicles, but also may include hydrogen that is produced from fossil fuels.

Beyond cost competitiveness and public appeal, awareness of the multiple co-benefits of renewables increased during the year, including improved public health through reduced pollution, increased reliability and resilience, access to modern energy services and job creation.[38] (→ *See Sidebar 2.*)

Awareness also increased surrounding equality and inclusiveness in the energy sector, and the strong business case was reaffirmed for increasing gender equality and cultural and ethnic diversity in companies.[39] An increasing number of companies joined the Equal by 30 campaign, aiming for more gender equality in the "clean energy" sector, specifically through equal opportunities, pay and leadership.[40] By early 2021, the campaign counted at least six countries among its signatories (Canada, Finland, Japan, the Netherlands, Sweden and the United Kingdom).[41]

Overall, **commitments towards climate action** greatly increased during 2020. At least 21 countries and the EU committed to greenhouse gas emission reduction targets during the year[i] – covering around 48% of global emissions – including at least 9 countries committing to net zero emission targets and 9 committing to carbon-neutral targets in numerous significant markets, such as China, the EU, the Republic of Korea and Japan.[42] (→ *See Table 4 in Policy Landscape chapter.*) By the end of 2020, around 800 cities had committed to net zero emissions – up sharply from the 100 cities with such commitments by the end of 2019.[43] (→ *See Box 2.*)

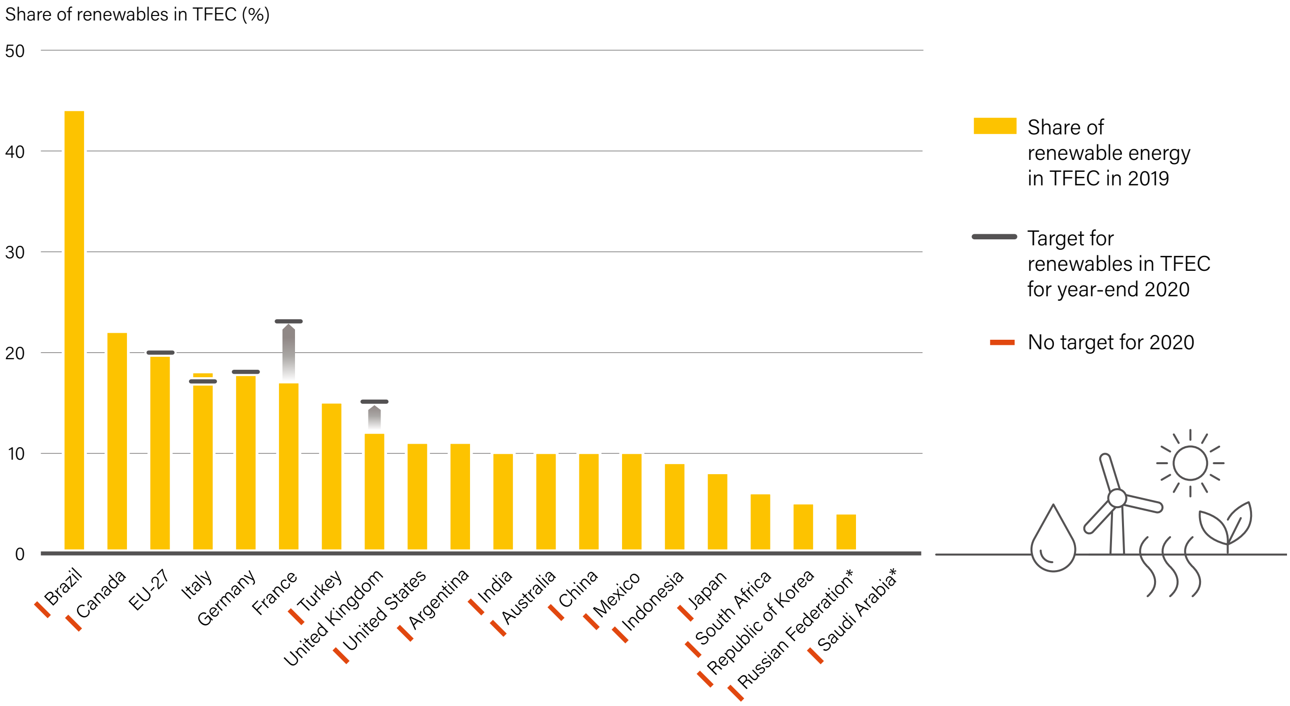
STRUCTURAL SHIFT NECESSARY TO REACH CLIMATE AND DEVELOPMENT GOALS

Even as global emissions decreased in 2020, the concentration of CO_2 in the atmosphere continued to rise to record levels, highlighting that a **structural shift** is necessary to reach long-term climate targets.[44] This was vividly demonstrated at year's end when it became clear that, despite the lockdowns and drop in economic activity, particularly early in 2020, there was no real lasting dent in global emissions as some estimates had anticipated.[45] Already by year's end, while most countries continued to grapple with the pandemic, CO_2 emissions had strongly rebounded from their earlier lows, rising in December to levels that were 2% higher than a year prior.[46]

Despite more interest in net zero targets in 2020, these targets do not necessarily cover all greenhouse gases or all sectors, nor do they necessarily lead to greater attention to renewables or to success in meeting renewable energy targets. Only five of the world's largest member economies in the Group of Twenty (G20) – the EU-27, France, Germany, Italy and the United Kingdom – had set 2020 targets to achieve a certain share of renewables in final energy use.[47] Of them, several were clearly not on track to achieve these targets by year's end.[48] (→ *See Figure 1.*)

i In 2019, 77 countries joined the Climate Ambition Alliance with an aspirational commitment to net zero carbon emissions by 2050; by early 2021, the country total reached 121, although not all commitments have been backed by domestic action. The increased ambition and awareness among governments and companies alike also is being reflected by international organisations, notably the International Energy Agency, which in early 2021 recommended under its new net zero scenario no further investment in new fossil fuel supply projects and no further final investment decisions for new "unabated coal plants". See endnote 42 for this chapter.

FIGURE 1.
Renewable Energy Shares and Targets, G20 Countries, 2019 and 2020



Note: TFEC = Total final energy consumption. Data for Russian Federation and Saudi Arabia are for 2018 and 2017 respectively.
Source: See endnote 48 for this chapter.

ONGOING CHALLENGES TOWARDS A RENEWABLES-BASED WORLD

The developments during 2020 highlighted some of the key ongoing challenges impeding the widespread adoption of renewable energy. They include the slow increase of renewables in total final energy consumption (TFEC), the need for more innovation in some sectors, the need for infrastructure development and increased affordability in some markets, the lack of sufficient policy support and enforcement, and persistent support for fossil fuels.

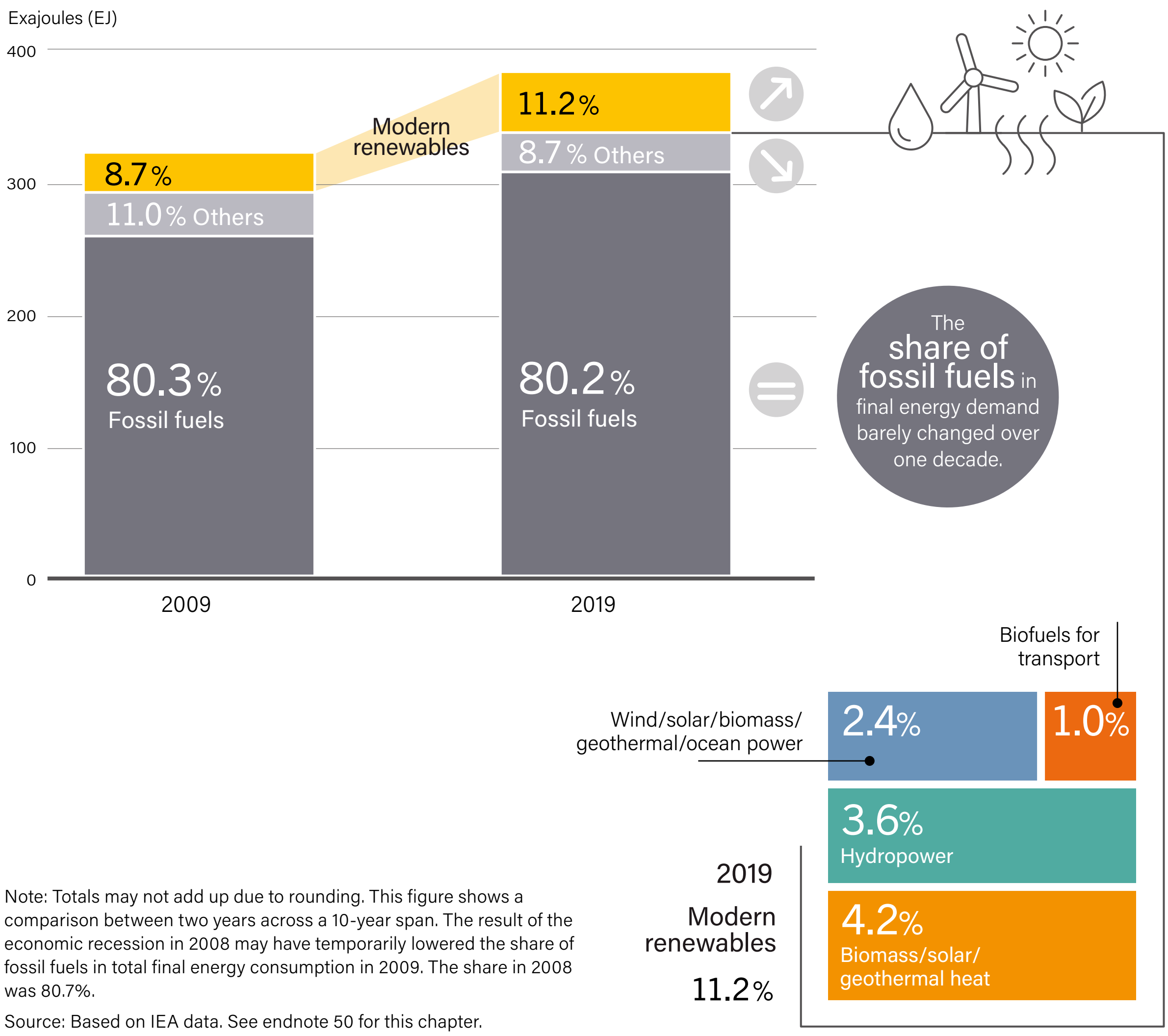
The share of renewables in TFEC has increased only moderately due to:

- rising global energy demand;
- continuing consumption of and investment in new fossil fuels, resulting in fossil fuels meeting most of the increasing demand, and
- declining traditional use of biomass, which although a positive development due to sustainability and health concerns (→ *see Box 3*) has meant that as people shift towards modern sources of energy, much of this is via fossil fuels.[49]

As of 2019[i], modern renewable energy (excluding the traditional use of biomass) accounted for an estimated 11.2% of TFEC, up from 8.7% a decade earlier.[50] (→ *See Figure 2.*) The largest portion was renewable electricity (6.0% of TFEC), followed by renewable heat (4.2%) and transport biofuels (1.0%).[51]

i At the time of publication, global data for TFEC and the contribution of energy sources to meet energy demand were available for the year 2018; values for 2019 are estimates.

FIGURE 2.
Estimated Renewable Share of Total Final Energy Consumption, 2009 and 2019



Note: Totals may not add up due to rounding. This figure shows a comparison between two years across a 10-year span. The result of the economic recession in 2008 may have temporarily lowered the share of fossil fuels in total final energy consumption in 2009. The share in 2008 was 80.7%.

Source: Based on IEA data. See endnote 50 for this chapter.

BOX 2. Renewable Energy in Cities

REN21's *Renewables in Cities Global Status Report* is an annual stock-taking of the global transition to renewable energy at the city level. City governments around the world have taken action to accelerate the global uptake of renewables, driven by air pollution concerns, public pressure and the need to create clean, liveable, climate-resilient and equitable communities.

Cities are home to 55% of the global population and growing, and they account (directly or indirectly) for more than 80% of global GDP. Urban energy use also has grown significantly in recent decades due to global population growth, urbanisation and urban economic activity. By 2018, cities accounted for around three-quarters of global final energy use, and cities release a similar share of global energy-related CO_2 emissions. This makes cities high-impact areas for climate action, including for decarbonising the energy system and accelerating renewable energy investments, which help cities achieve their own objectives as well as global goals.

Urban commitments to directly support renewables are increasing. By the end of 2020, more than 1 billion people – 25% of the world's urban population – lived in a city that had a renewable energy target and/or policy (for a total of over 1,300 cities), and during the year around 260 cities set new targets or passed new policies. This includes more than 830 cities in 72 countries that had adopted targets for renewables, with more than 600 cities setting targets for 100% renewable energy (with varying target dates).

Commitments to decrease greenhouse gas emissions also can result indirectly in greater use of renewables citywide. By 2020, more than 10,500 cities had adopted targets to reduce their greenhouse gas emissions, and around 800 cities had committed to net zero emissions, with the number of such net zero targets increasing roughly eight-fold from 2019. To achieve these targets, city governments have been leading by example, scaling up on-site renewable energy generation (mostly solar PV) and/or procurement for public buildings and municipal fleets.

Achieving urban renewable energy targets depends not only on political commitment and municipal investment in renewables, but also on the city's ability to enable the uptake of renewables city-wide, by other actors. Contrary to the slow pace at the national level, momentum has been growing for city-level policies that move beyond the power sector to support renewables in heating and cooling, the transport sector, and integrated policy approaches. These include both direct and indirect support policies, municipal codes and mandates for new buildings, incentives for retrofitting existing buildings, and bans and restrictions on fossil fuel use for both the buildings and transport sectors.

→ *See Renewables in Cities 2021 Global Status Report, along with the report's city case studies and cities data pack at https://www.ren21.net/cities.*

Source: See endnote 43 for this chapter.

BOX 3. Sustainability in the GSR

Much of the support for renewables to-date has focused on the social and economic acceptance of the energy transition, including the roles of political leadership, financial measures and market confidence. Accelerating the scale-up of renewables also means fostering public acceptance of renewable energy systems and investigating the key challenges to acceptance that they are facing. The sustainability of renewable energy technologies, infrastructure and supply chains is a key emerging issue. While there is no one definition of sustainability within the renewable energy context, this concept is usually determined by environmental, social and economic dimensions.

Even though the development of renewable energy is understood as essential for tackling climate change, the recent and planned expansion of renewables has raised notable sustainability concerns. Some of these issues have a longer history, such as considerations around the impacts that hydropower reservoirs and dams have on ecosystems and host communities and, in recent years, the debate on the role of bioenergy, especially in the context of the unsustainable use of biomass. More recently, as solar and wind power projects have become more numerous, issues around their long-term sustainability have come into the spotlight[i]. In addition, the resource requirements and lifecycle emissions of renewable energy technologies have received increasing attention.

Critically examining the environmental, social and economic impacts of renewables along the value chain, using a comprehensive approach and having an informed and transparent debate is necessary to address perceived tensions and challenges in shifting to a renewable-based energy system. Future editions of the GSR will address the topic more holistically, as will additional projects from REN21.

i See, for example, L. Bennun et al., *Mitigating Biodiversity Impacts Associated with Solar and Wind Energy Development* (Gland, Switzerland: IUCN, 2021), https://portals.iucn.org/library/sites/library/files/documents/2021-004-En.pdf.

Source: See endnote 49 for this chapter.

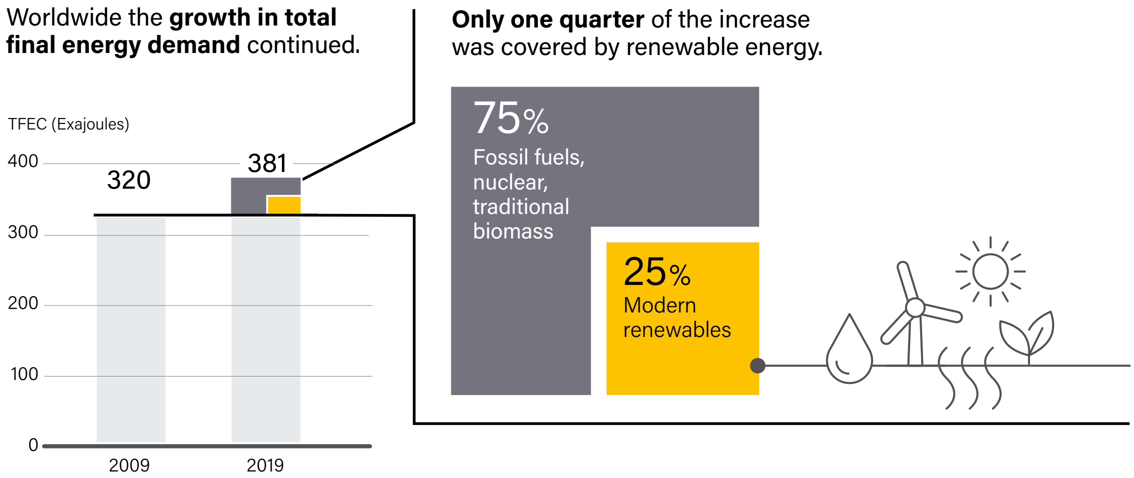
Renewable energy accounted for **only one-quarter** of the total increase in energy demand between 2009 and 2019.

The share of renewable energy has increased only moderately each year despite tremendous growth in some renewable energy sectors. Total demand for modern renewables grew strongly (15.1 exajoules, EJ) during the 10-year period 2009-2019, rising around 4.4% annually.[52] Total final energy consumption grew 60.9 EJ, or around 1.8% annually.[53] Thus, renewable energy increased at more than twice the rate of TFEC, accounting for 25% of the total increase in energy demand.[54]

However, this means that other energy sources (mainly fossil fuels, which grew 1.7% annually) accounted for 75% of the total increase in energy demand during this period, highlighting the challenge that renewables faced in gaining greater TFEC shares.[55] (→ *See Figure 3.*) This slow progress points to the complementary and fundamental roles of energy conservation, energy efficiency and renewables in reducing the contributions of fossil fuels in meeting global energy needs and reducing emissions.

Efficiency and conservation reduce overall demand for (additional) energy to achieve the same energy services, making it easier for renewables to attain a larger share of the total. However, energy efficiency also faced challenges in 2020. The rate of energy intensity improvements had been declining since 2015, and in 2020 the global crisis coupled with low energy prices resulted in only an estimated 0.8% improvement in energy intensity – half the rate of the previous two years.[56]

FIGURE 3.
Estimated Growth in Modern Renewables as Share of Total Final Energy Consumption Between 2009 and 2019



Source: Based on IEA data. See endnote 55 for this chapter.

As in past years, the highest share of renewable energy is in electrical applications (excluding electricity for heating, cooling and transport), such as lighting and appliances.[57] However, these end-uses account for only 17% of TFEC.[i,58] Energy use for transport represents some 32% of TFEC, and has the lowest share of renewables (3.4%).[59] The remaining thermal[ii] energy uses, which include space and water heating, space cooling and industrial process heat, accounted for more than half (51%) of TFEC; of this, some 10.2% was supplied by renewables.[60] Increasing the renewable share in transport and thermal end-uses is necessary to reach a higher share of renewable energy in overall TFEC.[61] (→ *See Figure 4.*)

Although costs for most renewable energy technologies have fallen (some precipitously, such as for solar PV and onshore wind power), **innovation** is still needed to enable the widespread adoption of renewables in harder-to-decarbonise sectors, such as energy-intensive industrial processes and long-haul transport.[62] The integration of variable renewable energy sources (such as solar and wind) into existing power systems could be further enabled by expanded and modernised grid **infrastructure**, further cost declines in energy storage, and advances in new business models and market design that allow electricity supply to flexibly meet demand.[63] In addition, **affordability** in some markets can be hampered by various elements, such as higher labour costs, permitting costs, land constraints, availability of renewable resources, lack of favourable policy frameworks and infrastructure issues.[64]

Another key reason for the low penetration of renewables is the persistent lack of **supporting policies and policy enforcement**, particularly in the transport and heating and cooling sectors. Targets for renewables are not only more numerous but also more ambitious for the power sector. While renewable energy targets are in place in nearly all countries, many countries were not on track to achieve their 2020 **targets** in multiple sectors, and many had not yet set new targets as their 2020 targets were coming to term.

Targets also were more often achieved and set for the power sector than for heating and cooling or transport. (→ *See Figure 11 in Policy Landscape chapter.*) However, many jurisdictions announced emission reduction targets during the year, which could support increasing the renewable share in these sectors where the targets are economy-wide.[65] Also, many countries have submitted more ambitious climate pledges across sectors for 2030 through their updated Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.[66]

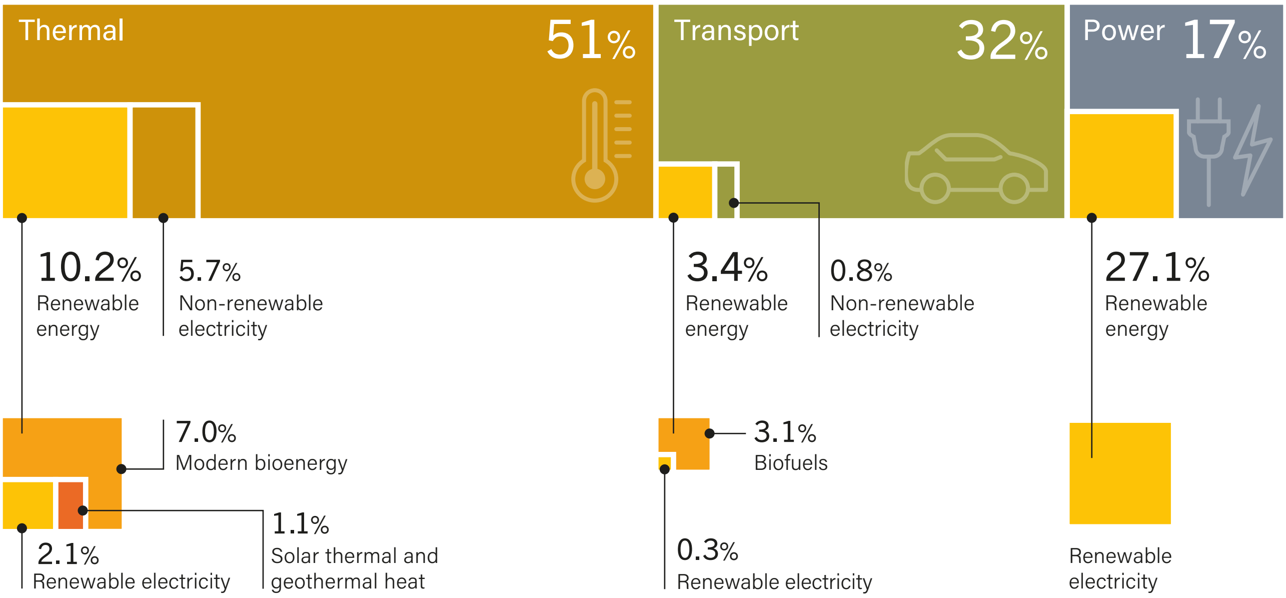
In contrast to previous years, the number of countries with renewable energy **support policies** did not increase in 2020[iii,67] The number of countries with mandates for renewable heat also did not grow, and policy examples for renewable energy support in industry remained scarce. No new countries added regulatory incentives or mandates for renewables in transport, although some countries that already had mandates added new ones or strengthened existing ones. Only three countries had a policy directly linking renewables and EVs by year's end, with Japan newly joining Austria with a similar incentive for charging EVs with renewable electricity, alongside Germany with its policy supporting renewable-based charging infrastructure.[68] Policies supporting renewable hydrogen also remained rare. (→ *See Table 5 in Policy Landscape chapter.*)

i Electrical applications account for a higher portion of *primary* energy consumption. See Glossary for definitions.

ii Applications of thermal energy include space and water heating, space cooling, refrigeration, drying and industrial process heat, and any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

iii However, policy support increased at the local level, where city governments have continued to take action to accelerate the global uptake of renewable energy to create clean, livable and equitable cities and have had a particular impact in the uptake of renewables in buildings and transport. Overall, more than 1 billion people lived in a city with a renewable energy target and/or policy in 2020. (→ *See Box 2.*)

FIGURE 4.
Renewable Energy in Total Final Energy Consumption, by Final Energy Use, 2018



Note: Data should not be compared with previous years because of revisions due to improved or adjusted methodology.
Source: Based on IEA data. See endnote 61 for this chapter.

In addition, **fossil fuel subsidies** remain a persistent challenge for renewable energy. Despite calls by world leaders, leading economists, international organisations and non-governmental organisations for governments to use COVID-19 recovery efforts to advance the phase-out of fossil fuel subsidies, this support remained in the hundreds of billions of dollars (nearly USD 500 billion as of 2019), far above the support for renewables.[69] In many countries, **investment in new fossil fuel production** and related infrastructure continued. Although some countries were phasing out coal, others invested in new coal-fired power plants, both domestically and abroad. Similar to the previous year, in 2020 many coal-fired plants announced closures in Europe and the United States, where almost no new plants had been planned for a few years and decommissioning has been accelerating, although some new plants began operating during the year[i].[70] Most of the still-operating, new and planned coal plants were located in developing and emerging Asia.[71]

During the first half of 2020, global net coal power capacity fell for the first time in history, as decommissioning outpaced new installations.[72] However, by year's end a steep increase in **new coal capacity** in China offset global retirements, resulting in the first annual increase in global coal capacity since 2015.[73] In line with past years, public finance from China funded by far the largest amount of coal capacity in other countries, followed by funding from Japan, the Republic of Korea, France, Germany and India, nearly all of which was directed towards developing and emerging countries.[74] Funding from private banks for fossil fuel projects also has increased annually since the signing of the Paris Agreement in 2015, totalling USD 2.7 trillion between 2016 and 2019.[75]

Despite international calls to "build back better"[ii] from the COVID-19 crisis, the majority of energy-related **recovery** funds were either directly or indirectly in support of fossil fuels.[76] (→ *See Figure 49 in Investment chapter.*) Governments around the world announced at least USD 732.5 billion in energy-related stimulus during 2020, and some stimulus packages included incentives for renewables; however, as of April 2021 only around USD 264 billion (36%) of the total amount provided by governments globally was for renewables, whereas more than USD 309 billion was allocated to fossil fuels, although the shares of funds for "clean" energy versus fossil fuels varied by region and country.[77] In some cases, coal was explicitly supported in recovery packages, such as in Poland, which seeks to maintain coal operations until 2049.[78]

The following sections discuss key developments in renewable energy in the sectors of buildings, industry and transport, followed by a discussion on renewable power capacity and renewable electricity generation.

i For example, in the Czech Republic and in Germany.
ii "Build back better" was a term adopted by the international community in the Sendai Framework for Disaster Risk Reduction 2015-2030.

SIDEBAR 1. Oil and Gas Suppliers and the Renewable Energy Transition

The year 2020 was challenging for the oil and gas industry. Demand disruption due to the COVID-19 crisis and an oil price war between OPEC and the Russian Federation combined to create oversupply and plunging prices. Conventional oil and gas suppliers increasingly are feeling the impetus to participate in the renewable energy transition in order to remain competitive, and due to pressure from energy users and investors.

In many parts of the world, public sentiment is rapidly turning against fossil fuels. Public and private investors alike are pulling money out of fossil fuel companies, with institutional investors worth nearly USD 15 trillion committed to divestment as of early 2021. (→ *See Investment chapter.*) While the transition away from fossil fuels is most visible in the power sector, it has been much slower in harder-to-decarbonise sectors such as industrial heat and heavy-duty transport, where oil and gas are more heavily embedded.

Major oil and gas companies have used a variety of strategies to try to position themselves as key players in the energy transition. Many have sought to signal a shift in priorities through their communications and public relations activities, including rebranding efforts. BP spearheaded the trend when it rebranded itself as "Beyond Petroleum" from "British Petroleum" in 2001. A host of other companies followed suit: GDF (Gaz de France) Suez became ENGIE in 2015, Danish Oil and Natural Gas (DONG Energy) became Ørsted in 2017, Statoil became Equinor in 2018, Gas Natural Fenosa became Naturgy in 2018, and Total became TotalEnergies in 2021. In a similar vein, the chief executive officer of Royal Dutch Shell communicated to investors in 2018 that the company is no longer an oil and gas company, but rather an "energy transition company".

While Ørsted has gone further than name change, transitioning from an oil and gas company to a large player in renewable power (predominantly offshore wind), others are still at early stages in their transitions. By the end of 2020, European majors BP, Eni, Equinor, Repsol, Shell and Total had all announced net zero emission targets for 2050, albeit with vast differences in coverage and ambition. While BP, Eni and Equinor have committed to absolute reductions in emissions, Repsol, Shell and Total aim to cut their emission intensities instead, making it possible for them to meet their targets without having to actually cut fossil fuel production. Reflecting these differences, BP announced in 2020 that it aims to slash oil and gas production 40%[i] by 2030 from 2019 levels, while Shell revealed in early 2021 that it had committed far more to oil and gas exploration and production than to renewables. However, in May 2021, Shell was ordered by a Dutch court to reduce carbon dioxide emissions (including emissions arising from the use of its products) 45% by 2030, relative to 2019 levels.

Each of these companies also has intermediate targets to invest in renewables or to expand their own renewable energy (mostly power) capacities. BP aims for 50 GW by 2030, Total plans to install 35 GW of renewable power capacity by 2025, Eni and Repsol are both targeting 15 GW by 2030, Equinor is targeting 12-16 GW by 2035 and Shell has an annual investment target of USD 2-3 billion in renewable energy and hydrogen (although not necessarily produced from renewables). Some companies – such as Repsol, Shell and Total – also link executive remuneration to emission reduction measures. On the other hand, US-based oil and gas giants Chevron and ExxonMobil do not have any renewable energy targets, and the emissions intensity reduction targets they do have are short-term and less ambitious[ii]. The difference in their approaches reflects the divergent policy priorities and shareholder interests in the United States and Europe so far, although these trends may be changing. In May 2021, 61% of Chevron shareholders voted to cut Scope 3 emissions – emissions arising from the use of the company's products – and ExxonMobil lost two board seats to a climate activist hedge fund.

Oil and gas companies can help advance the energy transition by reallocating their significant capital to address the investment gap facing the renewable energy sector. However, some companies still hesitate to diversify much into renewable energy and remain more inclined to protect their core businesses. Chevron, ExxonMobil and Shell, for example, have started sourcing renewable electricity to power their oil and gas operations by signing long-term PPAs with renewable energy companies, a move that lowers their emission intensities but may not greatly impact their absolute emissions. Chevron and ExxonMobil also are mostly allocating their energy transition funds (roughly 3-4% of their total capital expenditures) to research and development of technologies like carbon capture and storage, nuclear fusion reactors, EV charging infrastructure, battery storage and advanced biofuels.

At the same time, other oil and gas majors have invested in renewables either by acquiring stakes in renewable energy companies or by diversifying their core businesses towards renewables. For example, in 2011 Total purchased a 60%

majority stake in US solar company SunPower in a USD 1.4 billion deal. In 2017, BP acquired a 43% stake in European solar developer Lightsource to create Lightsource BP, and later increased its stake to 50% in 2019. In 2018, Shell acquired 44% of US solar power firm Silicon Ranch and made an equity investment of USD 20 million in India's distributed renewable utility company Husk Power Systems.

In terms of installed renewable energy capacity, Total and BP led in 2020 with 3 GW and 2 GW respectively, followed by Repsol at 1.3 GW, Shell at 0.9 GW, Equinor at 0.5 GW and Eni at 0.2 GW. Companies such as BP, Chevron, Equinor, Total and Unocal have begun making forays into the geothermal energy and offshore wind power sectors, which are readily accessible by oil and gas majors and present organic growth opportunities.

Despite changing headwinds, many forces motivate oil and gas companies to continue with business as usual. As of 2019, these companies had collectively invested less than 1% of their total capital expenditure in activities outside their core business areas[iii], with the leading companies spending on average around 5% on projects outside core oil and gas supply. (→ *See Figure 5.*) Companies like BP and Shell maintain membership in industry associations that lobby against climate action. Moreover, provisions of international trade pacts like the Energy Charter Treaty[iv] protect the fossil fuel industry at the expense of the renewable energy sector, and global post-COVID recovery packages have tended to favour fossil fuel industries over renewables. (→ *See Sidebar 3 in Policy Landscape chapter.*)

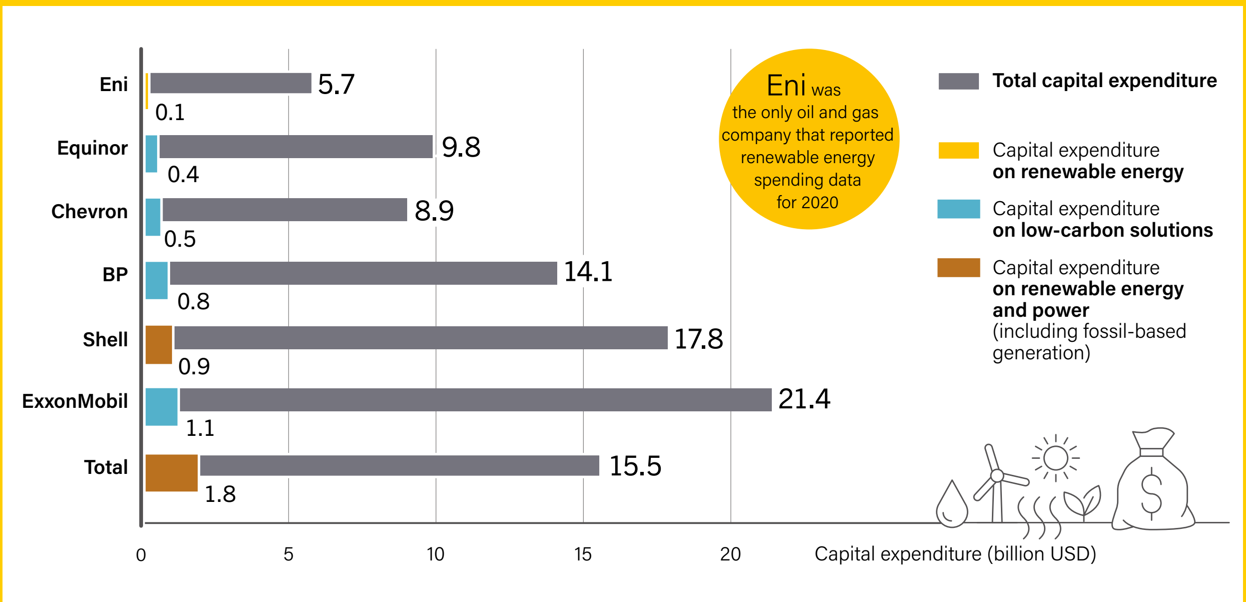
i BP's commitment does not, however, include production from Rosneft, the Russian oil and gas company of which it holds a major share. This means that nearly 30% of BP's carbon emissions (Rosneft's share of emissions in 2019) would remain unaffected by its net zero ambition. See endnote 37 for this chapter.

ii Chevron has a 40% emissions intensity reduction target in oil production and 26% in gas production by 2028 (relative to the 2016 baseline), while ExxonMobil has a 15-20% upstream emissions intensity reduction target by 2025.

iii Activities outside core business areas may include any ventures outside exploration and production for oil and gas companies, with the exact definition differing across companies. Renewable energy projects are likely to form a small proportion of such activities, however the exact proportion is unknown due to lack of disaggregated reporting by oil and gas majors.

iv The Energy Charter Treaty is a multilateral agreement for energy co-operation, enforced under international law since 1998. One of its provisions protects foreign investments from policy changes in host countries, and effectively allows fossil fuel companies to sue national governments for climate action and seek compensation when their interests are threatened. Talks on reforming the treaty are ongoing. For details, see sources in endnote 37 for this chapter.

FIGURE 5.
Spending on Renewable Energy versus Total Capital Expenditure, Selected Oil and Gas Companies, 2020



Note: Oil and gas companies do not explicitly report on renewable energy spending in their financial statements. Eni was the only company that provided this number for 2020. Equinor, Chevron, BP and ExxonMobil conflate renewable spending with environmental or low-carbon spending in general. Total and Shell conflate renewable spending with spending on power generation, including fossil-based generation.

Source: See endnote 37 for this chapter.

TABLE 1.
Renewable Energy Indicators 2020

		2019	2020
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	298.4	**303.5**
POWER			
Renewable power capacity (including hydropower)	GW	2,581	**2,838**
Renewable power capacity (not including hydropower)	GW	1,430	**1,668**
Hydropower capacity[2]	GW	1,150	**1,170**
Solar PV capacity[3]	GW	621	**760**
Wind power capacity	GW	650	**743**
Bio-power capacity	GW	137	**145**
Geothermal power capacity	GW	14.0	**14.1**
Concentrating solar thermal power (CSP) capacity	GW	6.1	**6.2**
Ocean power capacity	GW	0.5	**0.5**
HEAT			
Modern bio-heat demand (estimated)[4]	EJ	13.7	**13.9**
Solar hot water demand (estimated)[5]	EJ	1.5	**1.5**
Geothermal direct-use heat demand (estimated)[6]	PJ	421	**462**
TRANSPORT			
Ethanol production (annual)	billion litres	115	**105**
FAME biodiesel production (annual)	billion litres	41	**39**
HVO biodiesel production (annual)	billion litres	6.5	**7.5**
POLICIES[7]			
Countries with renewable energy targets	#	172	**165**
Countries with renewable energy policies	#	161	**161**
Countries with renewable heating and cooling targets	#	49	**19**
Countries with renewable transport targets	#	46	**35**
Countries with renewable electricity targets	#	166	**137**
Countries with heat regulatory policies	#	22	**22**
Countries with biofuel blend mandates[8]	#	65	**65**
Countries with feed-in policies (existing)	#	83	**83**
Countries with feed-in policies (cumulative)[9]	#	113	**113**
Countries with tendering (held during the year)	#	41	**33**
Countries with tendering (cumulative)[9]	#	111	**116**

1 Data are from BloombergNEF and include investment in new capacity of all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately; all ocean power projects; and all biofuel projects with an annual production capacity of 1 million litres or more. Total investment values include estimates for undisclosed deals as well as company investment (venture capital, corporate and government research and development, private equity and public market new equity).

2 The GSR strives to exclude pure pumped storage capacity from hydropower capacity data.

3 Solar PV data are provided in direct current (DC). See Methodological Notes for more information.

4 Includes bio-heat supplied by district energy networks and excludes the traditional use of biomass. See Reference Table R1 in the GSR 2021 Data Pack and related endnote for more information.

5 Includes glazed (flat-plate and vacuum tube) and unglazed collectors only. The number for 2020 is a preliminary estimate.

6 The estimate of annual growth in output is based on a survey report published in early 2020. The annual growth estimate for 2020 is based on the annualised growth rate in the five-year period since 2014. See Geothermal section of Market and Industry chapter.

7 A country is counted a single time if it has at least one national or state/provincial target or policy. See Table 6 and Reference Tables R3-R11 in the GSR 2021 Data Pack.

8 Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 6 and in Reference Table R8 in the GSR 2021 Data Pack.

9 Data reflect all countries where the policy has been used at any time up through the year of focus at the national or state/provincial level. See Reference Tables R10 and R11 in the GSR 2021 Data Pack.

Note: All values are rounded to whole numbers except for numbers <15, biofuels and investment, which are rounded to one decimal point.
FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil.

TABLE 2.
Top Five Countries 2020

Annual Investment / Net Capacity Additions / Production in 2020

Technologies ordered based on total capacity additions in 2020.

	1	2	3	4	5
Solar PV capacity	China	United States	Vietnam	Japan	Germany
Wind power capacity	China	United States	Brazil	Netherlands	Spain or Germany
Hydropower capacity	China	Turkey	Mexico	India	Angola
Geothermal power capacity	Turkey	United States	Japan	–	–
Concentrating solar thermal power (CSP) capacity	China	–	–	–	–
Solar water heating capacity	China	Turkey	India	Brazil	United States
Ethanol production	United States	Brazil	China	Canada	India
Biodiesel production	Indonesia	Brazil	United States	Germany	France

Total Power Capacity or Demand / Output as of End-2020

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	China	United States	Brazil	India	Germany
Renewable power capacity (not including hydropower)	China	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydropower)[1]	Iceland	Denmark	Sweden	Germany	Australia
Bio-power capacity	China	Brazil	United States	Germany	India
Geothermal power capacity	United States	Indonesia	Philippines	Turkey	New Zealand
Hydropower capacity[2]	China	Brazil	Canada	United States	Russian Federation
Solar PV capacity	China	United States	Japan	Germany	India
Concentrating solar thermal power (CSP) capacity	Spain	United States	China	Morocco	South Africa
Wind power capacity	China	United States	Germany	India	Spain
HEAT					
Modern bio-heat demand in buildings	United States	Germany	France	Italy	Sweden
Modern bio-heat demand in industry	Brazil	India	United States	Finland	Sweden
Solar water heating collector capacity[2]	China	Turkey	India	Brazil	United States
Geothermal heat output[3]	China	Turkey	Iceland	Japan	New Zealand

1 Per capita renewable power capacity (not including hydropower) ranking based on data gathered from various sources for more than 70 countries and on 2019 population data from the World Bank.

2 Solar water heating collector ranking for total capacity is for year-end 2020 and is based on capacity of water (glazed and unglazed) collectors only. Data from International Energy Agency Solar Heating and Cooling Programme.

3 Not including heat pumps.

Note: Most rankings are based on absolute amounts of investment, power generation capacity or output, or biofuels production; if done on a basis of per capita, national GDP or other, the rankings would be different for many categories (as seen with per capita rankings for renewable power not including hydropower and solar water heating collector capacity).

BUILDINGS

Buildings historically have accounted for around 33% of final energy use, a share that was relatively stable in the decade leading up to 2020.[79] Renewable energy meets a growing share of final energy demand in buildings, although it remains less than 15% and has risen slowly overall.[80] Increases in renewable energy consumption are most noticeable in electricity use, whereas heating with renewables is rising more slowly.[81] Bioenergy remains the global front-runner in supplying renewable heat to buildings, while the use of renewable electricity to meet heating loads (i.e., electrification) is rising rapidly and already covers the full renewable contribution to cooling demand.[82]

The COVID-19 pandemic impacted energy use in the buildings[i] sector – at their peak in April 2020, partial or full stay-at-home orders were active in countries responsible for around 55% of global primary energy demand.[83] As a result of these restrictions, millions of people began working from home. This shifted energy use, particularly electricity demand, away from industrial activity, transport and commercial buildings and towards residential buildings.[84] The global impact on energy demand in 2020 was not known at the time of publication; however, first estimates suggest that remote work could have contributed to a net reduction in building energy consumption in 2020.[85]

The sector is a significant contributor to global energy-related CO_2 emissions.[86] Prior to the pandemic, this share was 28%, with significant regional variations, and was increasing steadily, driven mainly by growth in indirect emissions from electricity generation and from production of heat consumed in buildings.[87]

Population and building floor area are typical indicators that have propelled past trends in global building energy use.[88] In the decade leading to 2020, growth in both indicators exceeded any reductions in demand resulting from energy efficiency measures, leading to around a 1% annual increase in building energy consumption.[89] However, growth in both energy demand and CO_2 emissions was lower than the rise in population and building floor area, underlining a gradual decoupling and overall improvement in the energy and carbon intensity of building operations.[90] Increased use of renewables was responsible for an estimated 15% of this improvement across all sectors.[91]

Renewables are the fastest growing energy source for buildings, rising 4.1% annually on average between 2009 and 2019[ii].[92] Despite this growth, renewables met only an estimated 14.3% of total energy demand in buildings in 2019, up from 10.5% in 2009.[93] Energy use in buildings can be split into two basic needs. Thermal energy[iii] needs – including space heating and

cooling, water heating and cooking – account for around 77% of global final energy demand in buildings.[94] The remaining 23% is electrical end-uses, which comprise lighting, appliances and other uses unrelated to heating or cooling.[95]

Already, most of the world's cooling demand is supplied by electricity.[96] Meanwhile, the demand for cooling has continued to grow rapidly in emerging countries, notably in Sub-Saharan Africa and in Southeast Asia.[97] However, the world's average cooling load is met mainly by less-efficient models of air conditioner compared to the most efficient technology available.[98]

Electricity also meets a rising proportion of the world's heat demand in buildings, having increased from around 9.6% in 2009 to 11.7% in 2019.[99] As the share of renewable electricity in the global power system continues to grow, electrification has increasingly emerged as the preferred route to decarbonise heating systems in buildings.[100]

Total energy demand for **heating and cooling** grew at around the same rate as building energy use (1% per year) between 2009 and 2019.[101] It was outpaced by the growth of renewable heating and cooling in buildings over the same period (around 6%).[102] Chief among the factors for this increase was the use of renewable electricity for heating (and cooling), while modern bioenergy[iv] use has stayed relatively stable.[103] However, the renewable energy share of heating demand grew from only around 8% to nearly 11% over the same decade, underscoring the importance of energy efficiency in enabling higher shares of renewables.[104] (→ *See Figure 6.*)

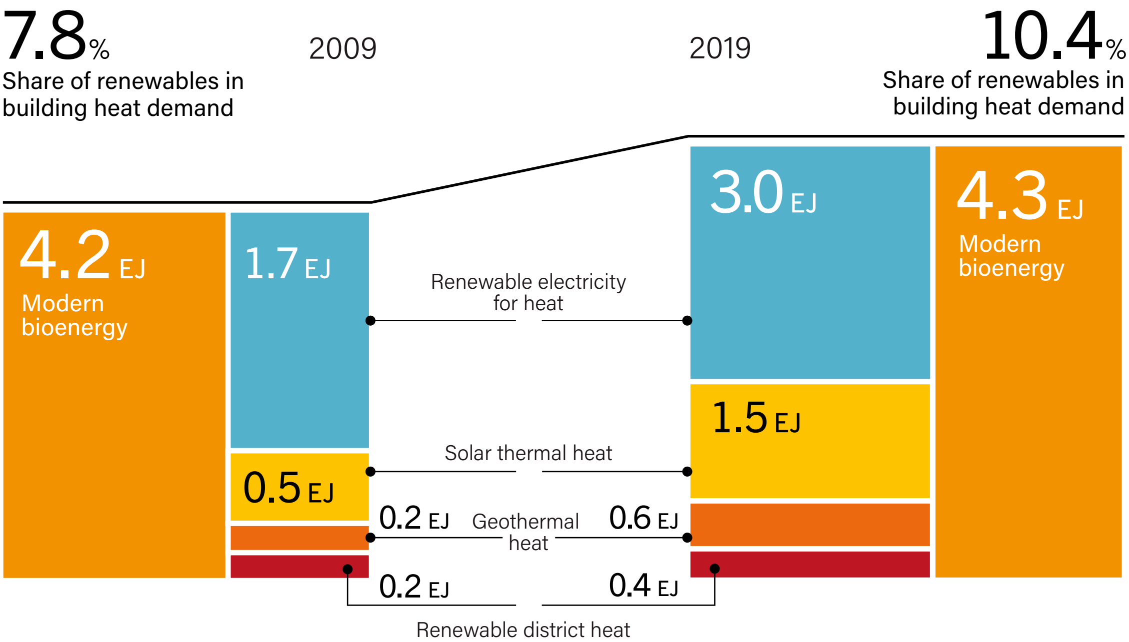
i "Buildings" in the GSR refers to the activities and energy used in building operation and maintenance, and does not include manufacturing, transport or use of building materials, or energy use in construction activities.

ii Due to data availability and publication dates for comprehensive datasets, the most recent data available for energy consumption are in the year 2018. Throughout this section, estimates are made for the year 2019.

iii Includes electricity for heating and cooling. The GSR considers all electricity used for heating and cooling to contribute to the final heating and cooling demand in each end-use sector, rather than to the respective final electricity demand. In order to determine total electricity consumption, demand of electrical end-uses and electricity for heating and cooling should be summed. See Methodological Note.

iv The traditional use of biomass for heat involves burning woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies. Modern bioenergy is any production and use of bioenergy that is not classified as "traditional use of biomass".

FIGURE 6.
Renewable Energy Contribution to Heating in Buildings, by Technology, 2009 and 2019



Note: Energy demand is reported in exajoules (EJ). Includes space heating, space cooling, water heating and cooking. Renewable district heat is virtually all supplied by bioenergy. Totals may not add up due to rounding.

Source: Based on IEA data. See endnote 104 for this chapter.

Although the global renewable heating and cooling share in buildings remains low, some countries and regions have achieved relatively higher shares. In the EU, a global leader in this area, renewable energy accounted for more than 21% of total heating and cooling needs (including industrial process heat) in 2018 (latest data available).[105] Certain Baltic and Nordic countries[i] supply more than 50% of their building heat demand with renewables.[106]

Demand for cooling is the most rapidly growing energy end-use in buildings.[107] Sales of cooling devices are growing fastest in developing and emerging countries.[108] As most cooling is supplied by electric devices, the contribution of renewables to meeting this demand depends largely on the prevailing electricity fuel mix; however, significant regional variations exist.[109]

The global mix of renewable energy technologies supplying heat to buildings is gradually shifting. **Modern bioenergy** has long delivered the largest amount of renewable heat to buildings, responsible for around half of all renewable heat consumption.[110] Bioheat typically is produced in wood-burning furnaces or combusted and delivered via district energy networks.[111] In 2019, bioheat met around 4.6% of total heat demand in buildings[ii,112] Its role is shrinking, however, as solar thermal heat, geothermal heat and renewable electricity for heat are expanding and gaining shares.[113]

Solar thermal and **geothermal energy** together contributed some 2.2% of heat demand in buildings in 2019, up from 0.8% in 2009.[114] Globally, demand for new solar thermal systems contracted slightly in 2020, and the impact of existing policy had a greater effect than the general impact of the pandemic, notably in China (the global leader).[115] China was similarly the world's largest and fastest-growing market for direct consumption of geothermal heat in buildings, growing 21% annually during 2015-2020, while the runners-up (Turkey, Iceland and Japan) grew 3-5%.[116] Overall, consumption of solar and geothermal heat sources has grown more rapidly (each up around 11% per year) than bioenergy use in recent years, although starting from a small base.[117]

After bioenergy, the use of **renewable electricity for heat** provided the second largest renewable energy contribution to building heat demand at around 3.2% in 2019, up from 2.0% in 2009.[118] Over this period, electricity contributed more than one-third of the overall demand growth for renewable building heat – the most of any renewable energy source.[119] However, most of the increase was due to the growing share of renewables in the global electricity supply, rather than to rising electrification of heating in buildings.[120] In total, the global share of all electricity use in final energy consumption of buildings grew from 28% in 2009 to an estimated 32% in 2019, an increase in global share even as final energy consumption rose.[121]

i As of 2019, these included Iceland, Sweden, Latvia, Finland and Estonia. See endnote 106.
ii When accounting for bioenergy delivered by district heating networks, the share rises to around 5%.

Renewable electricity supplies heat to buildings in various ways, notably through electric radiators or highly efficient electric heat pumps. Major global markets for electric heat pumps in China, Japan, Europe and the United States grew in 2020, continuing a multi-year acceleration.[122] Government policy related to heat pumps also is expanding, with several countries setting targets for installations of the technology while also pledging to increase their renewable power capacities.[123]

Total electrification of heating is garnering increasing policy attention as well. In 2020, **electrification of heat** was prominently pursued in the United States, continuing a trend from 2019.[124] US states such as Colorado, Maine, Michigan, Nevada and New Jersey released plans to address climate change that targeted "all-electric" buildings, mandated heat pump installations and/or cited electric heating as a way to achieve their climate goals.[125] In Australia, the Australian Capital Territory committed to supporting numerous all-electric residential and business developments, some of which included the choice to participate in community solar projects.[126]

During the year, attention grew on the use of **hydrogen for heating buildings**. Communities in Canada and the United Kingdom announced pilot projects to blend hydrogen with fossil gas in gas distribution networks to provide heat to buildings.[127] As part of its Hydrogen Strategy, the EU is conducting pilot projects to analyse the potential to replace fossil gas boilers with hydrogen boilers.[128] At the same time, numerous studies from research organisations and think tanks found that using hydrogen for home heating could be less energy efficient and more cost intensive than electrification, most notably with electric heat pumps.[129] Moreover, in early 2021 a coalition spanning businesses and civil society organisations sent a letter to the European Commission asking it to prioritise renewables and energy efficiency over hydrogen for building heat.[130]

District energy networks can efficiently meet urban heating and cooling needs; however, these systems currently account for just 6.7% of heat demand in buildings.[131] Moreover, the low global share of renewable energy in these networks (5.6%) means that only 0.4% of the world's heat demand in buildings was met by renewables in district networks in 2018.[132] Nevertheless, some European countries have achieved relatively high shares of renewables in the district heat supply (more than 50%[i] in at least six countries in recent years[ii]).[133] In 2020, solar thermal systems for district heating were brought online in China, Denmark and Germany, and these markets have continued to grow.[134]

The use of traditional biomass for **cooking** – predominantly in open fires or inefficient indoor stoves – leads to significant health problems, particularly in developing and emerging economies.[135] In these countries, the use of gaseous fuels[iii] reached 37% of the population in 2019 (compared to 35% for the traditional use of biomass).[136] At the same time, the share of electricity for cooking rose to 10% in 2019; due to its use mostly in urban areas, the use of renewable electricity for cooking is dependent on the overall renewable share in national power grids.[137] Use of solar energy for cooking is also rising: by early 2021, more than 14 million people had benefited from the 4 million solar cookers that had been distributed around the world.[138]

Policies subsidising the use of fossil fuels for heating continue to clash with those that encourage the uptake of renewables.

Electricity is the fastest growing energy source in buildings, with demand up 2.2% annually between 2009 and 2019.[139] Renewable electricity is delivered to buildings both from centralised plants by the electricity grid, and by distributed systems, depending on the location.[140] Although the penetration of distributed systems is growing, the global contribution of renewables to electricity demand in buildings is largely dependent on the prevailing local electricity mix in the grid.[141] In 2020, the renewable share of electricity production was around 29%, up from 20% in 2010.[142] (→ *See Power section in this chapter.*)

Distributed renewables also provide **electricity access** to growing shares of the population in developing and emerging economies.[143] As of mid-2020, more than 100 million people had gained access to basic residential electricity services through the use of solar lighting and solar home systems alone.[144] In addition, as of March 2020, 87% of operational mini-grids were providing renewables-based electricity access, with solar PV as the fastest growing technology for mini-grids.[145]

Policy attention to stimulate renewable energy uptake in buildings is lacking on a global scale, particularly related to heating end-uses.[146] New or updated financial incentives in 2020 were introduced only in Europe, and included the Netherlands' incentive scheme that was expanded to include renewable heat and the United Kingdom's extension of its funding programme to retrofit buildings with renewables-based heating systems.[147] At the city level, policy trends for buildings include energy codes that mandate the use of renewables for heating (or electricity).[148] Such codes typically apply to new buildings, while renewables for existing buildings often are encouraged through financial and fiscal incentives.[149]

An enabling policy measure becoming increasingly prevalent is bans and restrictions on some types of fossil fuels in new and existing buildings. Examples of this trend are present in more than 50 cities in 10 countries (and at least 7 national governments).[150] Numerous cities in Asia, North America (especially the US state of California), Europe and Oceania have introduced policies to phase out the use of fossil fuels for space and water heating in new and/or existing buildings.[151] Policies subsidising the use of fossil fuels for heating continue to exist and clash with those that encourage the uptake of renewables.[152]

i These statistics often include waste heat as a "renewable" source of district heat.

ii The six countries are, in descending order, Iceland, Norway, Sweden, Lithuania, Denmark and France.

iii Gaseous fuels refer to liquefied petroleum gas (LPG), natural gas and biogas, with LPG comprising the majority. Although not all renewable, these fuels – in addition to electricity and improved biomass – combined with their related stoves are considered "clean cooking" facilities as per the guidelines of the World Health Organization (WHO) for indoor air quality linked to household fuel combustion. See WHO, *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion* (Geneva: 2014), https://www.who.int/airpollution/guidelines/household-fuel-combustion/en.

Efforts to restrict use of fossil fuels (mostly fossil gas) for heating have met heavy resistance from the incumbent industry in many regions, notably in the United Kingdom, the EU and the United States.[153] In the United States, fossil gas companies and industry associations launched public relations campaigns and spent millions of dollars in 2020 attempting to sway public opinion against electrification.[154] In the state of California, a consumer protection agency recommended that the largest US fossil gas utility pay USD 255 million in fines after misusing public funds to oppose local fossil gas bans.[155]

The emergence of targets towards achieving net zero emissions, as well as rising interest in **net and nearly zero energy buildings**[i], also are spurring increased use of renewables in buildings.[156] In late 2020, 18 new signatories signed the Net Zero Carbon Buildings Commitment to bring the total to 6 states and regions, 28 cities, and 98 businesses and organisations that had agreed to achieve net zero emissions in their operations by 2030.[157] Beginning in 2021, the EU's Energy Performance in Buildings Directive mandated that all new public buildings in the region be "nearly zero energy buildings".

In addition to improving the performance of new buildings, addressing the **existing building stock** is expected to be an important step towards meeting climate targets. The EU's Renovation Wave strategy, announced in 2020, aims to support the decarbonisation of heating and cooling by strengthening regulations, providing incentives for private financing and introducing minimum energy performance standards, among other objectives.[158] Mandatory building performance standards were introduced and strengthened in the United States in 2020 and early 2021.[159] By the end of 2020, 67 countries had mandatory or voluntary building energy codes at the national level, although no new requirements for renewables in building energy codes were introduced during the year.[160]

INDUSTRY

Industrial energy use accounts for around 34% of total final energy consumption, growing at an annual rate of around 1%.[161] In certain energy-intensive sub-sectors such as chemicals and non-ferrous metals processing, the annual growth in energy demand nears 4%.[162] Around three-quarters of the energy used in industry is for direct thermal or mechanical end-uses that involve combustion, as well as the use of electricity to meet thermal energy needs.[163] Overall, these processes include the generation of industrial process steam as well as drying and refrigeration by use of thermally driven chillers. The remaining share is for electrical end-uses, including the operation of machinery and lighting.[164] Direct energy-related industrial CO_2 emissions (excluding agriculture and land use) comprise around 24% of the global total.[165]

The COVID-19 pandemic and related economic slowdown led to curtailed demand for industrial output worldwide and to a temporary reduction in industrial energy demand in 2020.[166] As a result, global industrial bioenergy consumption fell 4% for the year.[167] Measures to promote the uptake of renewables in industries received limited attention in stimulus packages implemented in response to the pandemic. Some countries – notably Australia, Chile, Germany, the Netherlands, Norway and the United Kingdom – announced renewable hydrogen strategies or investment plans to support efforts in harder-to-decarbonise sectors including heavy industry. (→ *See Sidebar 5 and Table 5 in Policy Landscape chapter*). By the end of 2020, only 32 countries had at least one renewable heating and cooling policy for industry, all of them in the form of economic incentives such as subsidies, grants, tax credits and loan schemes. (→ *See **Reference Table R9** in GSR 2021 Data Pack.*)

i Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on- or off-site renewable energy. See endnote 156 for this chapter.

The industrial sector relies heavily on fossil fuels, with renewables accounting for only around 14.8% of total industrial energy demand.[168] Around 90% of the renewable heat in the sector is supplied by bioenergy (mainly biomass), and mostly in industries where biomass waste and residues are produced on-site, such as pulp and paper, food, forestry and wood products.[169] Uptake of bioenergy also is rising in the cement industry due to increasing use of municipal waste in China and the EU.[170] Bioenergy use for industrial heating is concentrated in countries with large bio-based industries, such as Brazil, China, India and the United States.[171] In 2019, Brazil was the world's largest user of bioenergy for industrial heat, with an estimated 1.6 EJ, followed by India (1.4 EJ) and the United States (1.3 EJ).[172]

Renewable electricity accounts for the second largest share (10%) of renewable industrial heat, although it represented only 1% of the total industrial heat consumption in 2019.[173] It is used mainly for processes such as drying, refrigeration, and packaging and hardening for metal production.[174] Solar thermal and geothermal technologies also increasingly supply direct renewable heat for low-temperature industrial applications (20 degrees Celsius (°C) to 300°C), although they still accounted for less than 0.05% of total final industrial energy use in 2018.[175]

As of 2020, 98% of the geothermal industrial process heat was used in China, New Zealand, Iceland, the Russian Federation and Hungary.[176] Geothermal heat is used mainly in the food and beverages, pulp and paper processing, and chemical extraction industries.[177] For solar thermal industrial heat, as of early 2020, the leading countries in total installed capacity were Oman (300 megawatts-thermal (MW_{th}), Chile (25 MW_{th}) and China (24 MW_{th}), while Mexico and India led in the number of installations with 77 and 44 systems respectively.[178] The mining sector had the largest share of installed solar thermal capacity (75%), followed by food and beverages (10%) and textiles (5.6%).[179]

Three key industrial sectors that have low-temperature process heat requirements, and where renewable energy is used, are pulp and paper, food and beverages, and mining. The **pulp and paper** industry uses the highest share of renewables in industrial process heat, with bioenergy and other renewable fuels accounting for 30% of the sector's total energy use.[180] This industry is located mainly in North America, Europe, East Asia and Brazil.[181] In particular, renewable energy provides low-temperature heat for chemical pulping, the predominant mode of paper production.[182] In 2020, Navigator Company (Portugal) invested EUR 55 million (USD 68 million) in a new biomass boiler plant at its pulp and paper complex in the city of Figueira da Foz.[183] Renewables also provide electricity for producing paper through mechanical pulping.[184] In Eastern Croatia, a paper mill operated by sustainable packaging company DS Smith announced in 2020 that it was shifting to renewable electricity to power its paper-making process.[185]

The **food and tobacco** industry ranks second, with renewables supplying more than a quarter of the energy supply for industrial process heat.[186] Here, the renewable heat is supplied by heat pumps, solar thermal heat and electric heating.[187] In Cyprus, a solar thermal system designed for continuous operation was installed at a Kean Juices facility as part of a demonstration project in mid-2020.[188] Renewable electrification also was a popular option during the year. McCain Foods (Australia) began building an 8.2 MW renewable energy system at its food processing facility in Ballarat using a combination of ground-mounted solar PV and a co-generation anaerobic digester that uses food waste to generate energy.[189] In India, SunAlpha Energy installed 12 MW of solar PV capacity for the food processing sector and announced plans to exceed 30 MW at facilities across the country by 2030.[190]

The **mining** industry accounts for around 6.2% of the world's energy consumption and 22% of global industrial CO_2 emissions.[191] Electricity represents 32% of the energy consumed by mines, presenting an opportunity for direct use of renewable power.[192] However, renewables comprise less than 10% of energy consumption in the sector, a share that has been constant for some five decades.[193] This share is higher in Australia, a leading region in the use of renewables in mining.[194]

Progress towards renewable electrification in mining also continued in some regions in 2020, with several major mining companies building on-site renewable power plants in Australia, Chile, Saudi Arabia and South Africa.[195] Additionally,

Around 90% of the renewable heat in the industry sector is **supplied by bioenergy,** most of which comes from biomass produced on-site.

Australia-based iron ore mining giant Fortescue Metals announced plans to build over 235 GW of renewable capacity to become a supplier of renewable power and hydrogen while also decarbonising its own energy consumption.[196]

In more energy-intensive industries, renewables face limitations in meeting the requirements for high-temperature process heat (> 400°C). Three heavy industries in particular – chemicals, iron and steel, and cement – require vast quantities of energy, together accounting for 60% of industrial energy use and 70% of industrial emissions.[197] The penetration of renewables in these heavy industries remains low, comprising less than 1% of their combined energy demand in 2018.[198] In the face of reduced demand due to the COVID-19 crisis, both energy use and emissions in heavy industries declined around 5% in 2020.[199]

Renewable hydrogen[i] can potentially play a key role in decarbonising heavy industries.[200] In 2020, the world's largest developers[ii] of **renewable hydrogen** came together to form the Green Hydrogen Catapult initiative, aiming to greatly reduce costs to stimulate a more rapid energy transition in the most carbon-intensive industries.[201] Government support for renewable hydrogen increased during the year, and by year's end at least 10 countries globally had adopted some kind of renewable hydrogen support policy. (→ *See Sidebar 5 and Table 5 in Policy Landscape chapter.*)

The **chemicals and petrochemicals** industry is the largest industrial energy user worldwide, consuming 46.8 EJ in 2017 and producing 5% of total global energy- and process-related CO_2 emissions.[202] Only 3% of the industry's energy demand comes from renewables.[203] Energy in this industry is used as feedstock (primarily oil, natural gas, and coal) and for providing high-temperature process heat (close to 1,000°C).[204] Renewables could meet this energy demand in two main ways: using biomass to replace fossil fuels as a feedstock, and using renewable hydrogen for process heat or as a feedstock.[205]

Some companies already have begun using renewable hydrogen for these purposes. In late 2020, in Western Australia, YARA and Engine formed a partnership to develop a renewable hydrogen project to provide feedstock for ammonia[iii] production.[206] Also during the year, BioMCM and four partners won an EUR 11 million (USD 13.5 million) European grant for a renewable hydrogen project based in the Netherlands to produce renewable methanol.[207] Additionally, BioBTX, an innovative technology that converts biomass into chemicals, secured financing to operationalise its first commercial plant by 2023.[208]

The **iron and steel** industry consumed 32 EJ of energy in 2017 and contributed 8% of total global energy- and process-related CO_2 emissions, making it the largest emitter among heavy industries.[209] Renewables accounted for only 4% of the industry's energy consumption in 2017.[210] Nearly three-quarters (almost 72%) of global steel is produced via the blast furnace / basic oxygen furnace (BF-BOF) route, using metallurgical coal as the chemical reducing agent, where the potential for renewables use is limited.[211]

By the end of 2020, at least 10 countries had adopted a **renewable hydrogen** support policies.

However, the remaining production occurs mostly through direct reduction of iron ore or scrap steel using electric arc furnaces, where renewable penetration is possible if renewable hydrogen is used as the reducing agent and renewables are used to power the furnaces.[212]

The "green steel" concept received considerable attention from industry players in 2020, mainly in Europe.[213] Sweden's HYBRIT green steel venture, which aims to replace coking coal with fossil-free electricity and hydrogen, began operations at its pilot plant.[214] LKAB, one of the partners in the HYBRIT initiative, also became the world's first producer of fossil-free iron ore pellets during the year.[215] Another Swedish start-up, H2 Green Steel, drew significant investments to build the world's largest hydrogen electrolyser to produce green steel starting in 2024.[216] Germany's largest steelmaker, Thyssenkrupp, announced plans to build a direct reduced iron plant running on renewable hydrogen by 2025.[217]

The **cement and lime** industry consumed 15.6 EJ of energy in 2017 and accounted for 6.7% of total global energy- and process-related CO_2 emissions.[218] However, the bulk of the CO_2 emissions in this industry are not energy-related but are a by-product of the chemical process used to produce clinker, the main constituent of cement.[219] Remaining emissions come mainly from the combustion of fossil fuels to supply process heat for this reaction. The only feasible entry point for renewables in this industry is through fuel switching for process energy from coal to biomass, waste fuels, renewable hydrogen or direct electrification.[220] By 2017, renewables accounted for around 6% of energy use in the cement and lime sector, the largest share of renewables among heavy industries.[221]

Regional and global cement industry associations around the world announced carbon neutrality targets and roadmaps in 2020, outlining the role of renewable heat, electricity and renewable hydrogen, notably in the Dominican Republic, Europe and the United Kingdom.[222] Additionally, the Mineral Products Association secured a GBP 6 million (USD 8.2 million) grant from the UK government to conduct fuel switching trials into hydrogen, biomass and plasma technology to decarbonise cement and lime production.[223] In February 2021, Hanson UK installed a renewable hydrogen demo unit at its cement facility in Wales to partially replace natural gas in the kiln combustion system.[224]

i Renewable hydrogen is electrolytic hydrogen produced with renewable electricity.

ii Founding partners of the initiative include ACWA Power (Saudi Arabia), CWP Renewables (Australia), Envision (China), Iberdrola (Spain), Ørsted (Denmark), Snam (Italy) and Yara (Norway).

iii Ammonia is predominantly used to produce fertilisers. It also is used as a refrigerant gas and for purification of water supplies, as well as in the manufacture of household and industrial-strength cleaning products, plastics, explosives, textiles, pesticides, dyes and other chemicals. There has been growing interest in ammonia as a transport fuel.

TRANSPORT

For the transport sector, the year 2020 was marked by impacts from COVID-19, which also had an impact on the use of renewable energy in the sector. Transport activity and energy demand fell sharply early in the year as lockdowns were put in place, while sales and use of both standard and electric bikes rose dramatically in many places as hundreds of emergency measures were implemented to support cycling and walking infrastructure.[225] Aviation saw a 60% drop in traffic during the year, rail demand fell by up to an estimated 30%, and maritime trade declined an estimated 4.1%.[226] Public transport demand dropped in 2020 and remained low in many countries as of early 2021 due to fears of COVID-19 contagion from being on crowded buses or trains, while people turned to private vehicles and non-motorised or "active" transport (e.g., walking and cycling) in some areas.[227]

While EV sales increased around 41% during 2020, global passenger vehicle sales plummeted 14%.[228] The number of electric and plug-in hybrid passenger cars on the road surpassed 10 million in 2020, while the number of e-buses increased to 600,000, and electric two-/three-wheelers totalled around 290 million.[229] Although sport utility vehicle (SUV) sales decreased, SUVs were the only area globally across all sectors – even beyond transport – to see their emissions increase in 2020 due to their much higher average fuel consumption, their continued growth in popularity and the fact that in most cases they are not electric.[230]

The transport sector accounts for around 60% of global oil demand, which dropped sharply in 2020.[231] While oil demand in transport fell an estimated 8.8% during the year, it had nearly rebounded to pre-pandemic levels by mid-2021, and longer-term trends have shown that the growth in energy demand for transport has far outpaced other sectors.[232] Energy use for transport accounted for around one-third (32%) of total final energy consumption globally in 2018.[233] Road transport represented the bulk of the sector's energy demand (74%), followed by aviation (12%), maritime transport (9.6%) and rail (2%).[234] Transport remains the sector with the lowest share of renewable energy: in 2018, the vast majority (95.8%) of global transport energy needs were met by oil and petroleum products (including 0.8% non-renewable electricity), with small shares met by biofuels (3.1%) and renewable electricity (0.3%).[235]

Despite continued gains in energy efficiency, particularly in road transport, global energy demand[i] in the transport sector increased 2.2% annually on average between 2008 and 2018.[236] This was due mostly to the growing number and size of vehicles on the world's roads (and increases in tonne-kilometres and passenger-kilometres travelled), to a reduction in average passenger-kilometres travelled per person for buses, and to a lesser extent to rising air transport.[237] Passenger transport activity increased 74% between 2000 and 2015, almost entirely in developing and emerging countries, while surface freight (road and rail) activity increased 40% during this period.[238] However, while passenger transport energy intensity fell 27%, road freight transport energy intensity declined only 5% during these years.[239]

Because nearly all of the increases in energy demand in transport have been met by fossil fuels, the result has been a general trend of rising[ii] greenhouse gas emissions from the transport sector across all modes except rail, which remains the most highly electrified sub-sector.[240] Nearly three-quarters (74%) of all transport emissions are from road vehicles, 12% from aviation, 11% from maritime shipping and 1% from rail.[241]

Renewables can meet energy needs in the transport sector through the use of biofuels in pure (100%) form or blended with conventional fuels in internal combustion engine vehicles; biomethane in natural gas vehicles; and renewable electricity in battery electric[iii] and plug-in hybrid vehicles, and converted to renewable hydrogen through electrolysis for use in fuel cell vehicles, or used to produce synthetic fuels and electro-fuels.[242]

Following a decade of steady growth, **biofuels** production[iv] fell 5% in 2020 due to the overall decline in transport energy demand during the year.[243] Nevertheless, they remained by far the largest contributor of renewable energy to the transport sector. Ethanol volumes fell significantly during the year (down 8%), while biodiesel production and use was much less affected.[244] At the same time, production of HVO and HEFA fuels[v] grew sharply.[245] (→ *See Bioenergy section in Market and Industry chapter.*)

In contrast, the share of **renewable electricity** in the transport sector remained stable compared to 2019.[246] Greater electrification of transport can help to dramatically reduce CO_2 emissions in the sector, particularly in countries that are reaching high renewable shares in their electricity mix.[247] EVs also offer the potential for significant final energy savings, as they are inherently more efficient than comparable internal combustion engine vehicles.[248] Investments in charging infrastructure can further enable the electrification of transport, with some infrastructure relying on 100% renewable electricity.[249] (→ *See Systems Integration chapter.*)

Some regions, particularly China, Japan and the Republic of Korea, also saw increases in the fuel cell electric vehicle market, and in

i At the same time, the carbon intensity of transport (i.e., the CO_2 emitted per vehicle-kilometre) has improved in many countries due mainly to the implementation of fuel economy or emission standards for light-duty vehicles. (→ *See Transport section in Energy Efficiency chapter.*)

ii Transport CO_2 emissions increased 19% between 2008 and 2018, at an average annual rate of 1.8%. Emissions from SUVs alone tripled between 2010 and 2020 due to the increasing number and larger sizes relative to other passenger vehicles. The sector as a whole accounted for nearly one-quarter of global energy-related greenhouse gas emissions in 2018 (latest available data). While emissions from transport decreased an estimated 15% in 2020 due to the pandemic, they are expected to rebound. See endnote 240 for this chapter.

iii See Glossary.

iv This section concentrates on biofuel production, rather than use, because available production data are more consistent and up-to-date. Global production and use are very similar, and much of the world's biofuel is used in the countries where it is produced, although significant export/import flows do exist, particularly for biodiesel.

v HVO is hydrotreated vegetable oil and HEFA is hydrogenated esters of fatty acids. These fuels often are described as renewable diesel, especially in North America. See Bioenergy section in Market and Industry chapter.

the use of or investment in **renewable hydrogen**[i] **and synthetic fuels for transport**, but these remained relatively minimal.[250] (→ *See Box 1 and Table 5 in Policy Landscape chapter.*)

Overall, the transport sector is not on track to meet global climate targets for 2030 and 2050.[251] The majority of countries worldwide have acknowledged the transport sector's role in mitigating emissions by including transport in their NDCs under the Paris Agreement.[252] However, just 10% of the NDCs as of 2020 included measures for renewables-based transport.[253]

Many countries still lack a **holistic strategy** for decarbonising transport, although cities often are well placed to take more comprehensive action – and many are already doing so.[254] Such strategies include reducing the overall demand for transport; transitioning to more efficient transport modes, such as (renewables-based) public transport and rail or non-motorised/ active transport (e.g., walking and cycling); and improving vehicle technology and fuels, such as through higher fuel efficiencies and emission standards along with greater incorporation of renewables. Together, these strategies – commonly referred to as Avoid-Shift-Improve[ii] – can greatly decrease energy demand and associated greenhouse gas emissions in the sector and thus allow for the renewable share in transport to increase.[255]

Overall, the
transport sector is not on track
to meet global climate targets for 2030 and 2050.

TRENDS BY TRANSPORT MODE

Road transport accounted for around 75% of global transport energy use in 2019, with passenger transport representing about two-thirds of this.[256] Biofuels continue to comprise nearly all (91%) of the renewable energy share in road transport energy use.[257] By the end of 2020, at least 65 countries had blending mandates for conventional biofuels (a number unchanged since 2017), and several countries with existing mandates strengthened them or added new targets; at least 17 countries had mandates or incentive programmes for advanced biofuels.[258]

Although rarely linked directly to renewable sources, the use of **electric vehicles** continued to expand during the year. EVs became more commonplace in more countries, often as a result of policies and targets adopted in prior years.[259] Global electric car sales remained strong despite the COVID-19 crisis, due in part to support policies and falling costs; however, the overall share of electricity in the transport sector remains low and has increased little in recent years.[260]

Only limited examples exist of direct policy linkages between EVs and renewable electricity. During 2020, one additional country adopted an e-mobility policy directly linked to renewables, bringing the total to three countries globally with such policies (Austria, Germany and Japan).[261] Nevertheless, at least 9 states/ provinces, 33 countries, and the EU had independent targets both for EVs and for renewable power generation, which could facilitate greater use of renewables in transport.[262]

Policies restricting the use of fossil fuels can help increase renewable energy shares in the sector. By early 2021, at least 19 jurisdictions (national and state/provincial) had committed to banning sales of new fossil fuel vehicles or internal combustion engine vehicles in favour of lower-emission alternatives (sometimes explicitly EVs) by 2050 or before, up from 17 jurisdictions a year before.[263] At least 6 cities had adopted such bans, while at least 225 cities had already partially restricted the circulation of fossil fuel vehicles through the use of low-emission zones.[264]

i Almost all hydrogen production globally is from fossil fuels.

ii These actions seek to address broader concerns among policy makers in the transport sector at the national and sub-national levels, such as environmental and health impacts (e.g., congestion, pollution, road safety), transport security and equity in access to mobility.

Partly in response to these and other policy developments, an increasing number of private companies have begun increasing the use of renewables in their fleets[i]. (→ *See Transport section in Feature chapter and Box 2 in GSR 2020 Policy Landscape chapter.*) An increasing number of auto manufacturers also committed to moving away from fossil fuel-powered vehicles during the year, including General Motors, Nissan and Ford, while Volvo and Daimler announced a new joint venture aimed at developing, producing and commercialising hydrogen fuel cells for the heavy-duty vehicle industry.[265]

Although many challenges remain for scaling up EVs, further electrification of road transport has the potential to ease the integration of solar PV and wind power by providing balancing and flexibility services to the grid[ii].[266] Vehicle-to-grid (V2G)[iii] is still relatively in its infancy, but during 2020 more companies invested in the technology and numerous new projects continued to be launched.[267] For example, ENGIE and Fiat-Chrysler began construction on the world's largest V2G project in Turin, Italy to provide 25 MW of renewable energy storage using batteries from 700 EVs.[268]

Road freight consumes around half of all diesel fuel and is responsible for 80% of the global net increase in diesel use since 2000, with the increase in road freight activity having offset any efficiency gains.[269] Fuel economy standards push manufacturers to seek to improve fuel efficiency and facilitate the adoption of alternative drivetrains based on low-carbon solutions, including renewable energy.[270] Although fuel economy standards apply to 80% of light-duty vehicles globally, only five countries apply them to heavy-duty vehicles – Canada, China, India, Japan and the United States – covering just over half of the global road freight market.[271] Moreover, no new countries have adopted such standards since 2017[iv]. In 2019, the EU adopted the first-ever CO_2 emission standards for heavy-duty vehicles.[272]

The larger the vehicles and the longer the range, the more challenging it is to find cost-effective alternatives to diesel.[273] However, both public and private entities have supported renewable alternatives. In 2020, the US state of California became the first jurisdiction worldwide to require truck manufacturers to transition from diesel trucks and vans to "near-zero-emission vehicles", such as electric or biomethane[v] vehicles.[274] Finnish state-owned gas company Gasum expanded its liquefied biogas (LBG)[vi] filling station network in Finland, Sweden and Norway.[275] In the private sector, Volvo Trucks (Sweden) reported seeing increased interest in LBG during the year, while Finnish freight firm Posti increased investment in LBG trucks.[276]

The overall share of **electricity in the transport sector** remains low and has increased little in recent years.

A few local governments and companies are using renewable energy in their **bus fleets**. While many cities have been using biofuels in buses for some time, an increasing number are linking renewable electricity to e-bus charging (such as charging the buses with solar power), notably in Europe, the United States and China.[277] Many more cities are running public urban **rail systems** on electricity, sometimes directly linked to renewable electricity and in other cases using biofuels.[278] By the end of 2020, just two countries (France and India) had enacted new policies and targets to advance the use of renewables in the rail sector.[279]

As the most highly electrified transport sector, rail transport accounts for around 2% of the total energy used in transport.[280] Renewables contribute an estimated 11% of global rail-related energy consumption.[281] Some jurisdictions have increased the share of renewable energy in rail transport to well above its share in their power sectors.[282] In 2020, at least two railway companies set net zero targets: Indian Railways for 2030 and UK-based Network Rail for 2050.[283]

Maritime transport[vii] consumes around 10% of the global energy used in transport – with around 0.1% estimated to be renewable – and is responsible for around 2.9% of global greenhouse gas emissions.[284] Although renewables do not feature significantly in the maritime fuel mix, some advances occurred during 2020. The Netherlands was the only country to advance the use of renewable energy in shipping, announcing plans obliging suppliers of heavy fuel oil and diesel for inland shipping to take part in its renewable fuel scheme.[285]

At the international level, the International Chamber of Shipping (the global shipping trade association) announced plans to invest USD 5 billion in research and development related to alternative fuels, with a goal of reducing the sector's greenhouse gas emissions 50% by 2050 (from 2008 levels).[286] Also, stricter energy efficiency targets and new fuel and emission standards adopted by the International Maritime Organization in 2019 began being implemented in 2020, and the organisation set goals with the Global Industry Alliance to reduce emissions in the ship-port interface.[287]

i This trend also continued in some new mobility service companies, including micro-mobility services such as electric sidewalk/"kick" scooters and dockless bicycles (both electric and traditional), as well as electric moped-style scooters and ridehailing and car-sharing services. (→ *See Box 2 in GSR 2020 Global Overview chapter.*)

ii EVs could ease the integration of variable renewable energy provided that market and policy settings ensure the effective harmonisation of battery charging patterns and/or hydrogen production with the requirements of the electricity system.

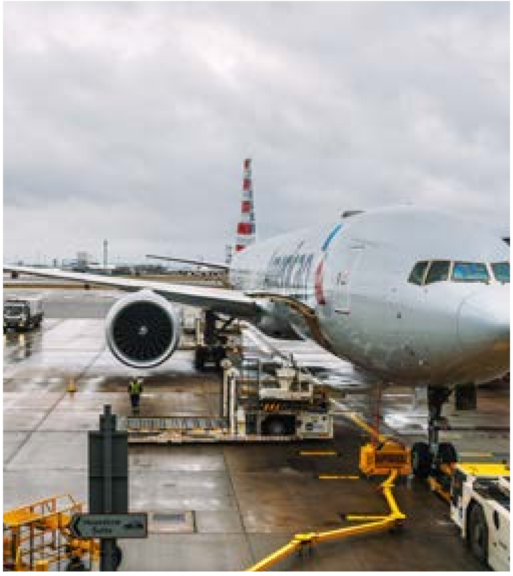
iii Vehicle-to-grid (V2G) is a system in which EVs – whether battery electric or plug-in hybrid – communicate with the grid in order to sell demand response services by returning electricity from the vehicles to the electric grid or by altering their rate of charging.

iv Heavy-duty vehicles are the fastest growing source of oil demand worldwide and the fastest growing emitter of CO_2 emissions. Even though they account for less than a quarter of total freight activity, they account for three-quarters of the energy demand and CO_2 emissions from freight. See endnote 240 for this chapter.

v Also called renewable natural gas or RNG.

vi Also called liquefied biomethane or bio-LNG.

vii The transport of goods or people via sea routes, including inland and coastal shipping.



In addition to the use of biofuels and other renewable-based fuels for propulsion, maritime transport has the possibility to directly incorporate wind power (via sails) and solar energy.[288] Some fleets already have moved to 100% renewable fuels, while others have moved to hybrid systems with energy storage (although not always operating on renewable energy).[289] In 2020, Finnish firms began testing LBG as a shipping fuel.[290] By early 2020, trials also had begun on the use of ammonia as a shipping fuel, with the potential to produce it using renewable electricity.[291] By year's end, discussions had begun on using green hydrogen in ferries and short-distance shipping.[292] At a smaller scale, electric outboard engines increasingly are being used in many markets and can be charged directly with renewable energy; some governments, such as Sweden, have offered incentives for electric models.[293]

By early 2021, at least one new **port** (Valenciaport, Spain) had joined the World Ports Climate Action Program, bringing the membership to 12 ports committed to advancing reductions in maritime transport emissions in support of the Paris Agreement.[294] In 2020, Valenciaport committed to building 8.5 MW of solar PV at two of its ports on Spain's coast for its own operations.[295] Also during the year, Portugal and the Netherlands signed a memorandum of understanding to connect Portugal's renewable hydrogen project with the Dutch Port of Rotterdam.[296]

Aviation accounts for around 12% of the total energy used in transport – less than 0.1% of which is renewable – and for around 2% of global greenhouse gas emissions.[297] Despite the more than 50% decrease in carbon emissions per passenger-kilometre between 1990 and 2019 (due to fuel efficiency improvements), global demand for air travel increased significantly leading up to 2020, with emissions growing more rapidly than expected.[298] However, air travel plummeted with the onset of the pandemic.[299]

Support for and use of renewable fuels in the aviation sector made slight progress during 2020. Belarus, Ethiopia and Qatar submitted voluntary State Action Plans to the International Civil Aviation Organization, bringing to 120 the total number of member states[i] supporting the production and use of "sustainable alternative"[ii] aviation fuels, specifically drop-in fuels[iii],[300] Meanwhile, as of early 2021, more than 315,000 commercial flights had flown on blends of alternative fuels, up from 200,000 a year before.[301] However, this is still a negligible share of the tens of millions of flights performed each year.[302] At least 9 airports had regular distribution of blended alternative fuel, up from 8 the year before, while at least 13 airports had batch deliveries of such fuels.[303] During 2020, as in the previous year, some companies announced targets for their own aircraft to run on biofuels and were developing planes made specifically to do this.[304]

Although interest in the electrification of aviation is increasing, as of May 2021 only electric drones or small planes had been developed. Some companies were planning fully electric airlines to carry more than 120 passengers, while others have aimed for hydrogen-powered electric planes.[305] A few "solar at gate"[iv] pilot projects have been developed in recent years in Cameroon, Jamaica and Kenya, although none were added in 2020.[306] Several airports announced during the year that their operations would be partly powered by solar power, including at all airports in Ghana, three French airports and major airports in the cities of Edmonton (Canada), Melbourne (Australia) and New York (US).[307]

i Representing 97.4% of global air traffic, up from 94.3% a year earlier.

ii The International Civil Aviation Organization (ICAO) considers such fuels to be a sustainable alternative when they are produced from three families of bio-feedstock: the family of oils and fats, or triglicerides, the family of sugars and the family of lignocellulosic feedstock. See ICAO, "Alternative fuels: Questions and answers", https://www.icao.int/environmentalprotection/Pages/AltFuel-SustainableAltFuels.aspx, viewed 14 April 2021.

iii Drop-in biofuels are produced from biomass, including different types of organic waste, and have properties enabling them to replace fossil fuels directly in transport systems, or to be blended at high levels with fossil fuels.

iv Using solar power for air conditioning and other services while a plane is at the airport gate.

POWER

The renewable power sector experienced a turbulent first half of 2020 during the onset of the COVID-19 pandemic. Supply chain disruptions, restrictions on the movement of labour and goods, postponed or cancelled auctions, and other factors led to levels of new additions and investment that were markedly lower than in the same period in 2019.[308] Pandemic-related restrictions led to project developers facing significant labour shortages and delays in the supply chain as they rushed to complete projects on time.[309]

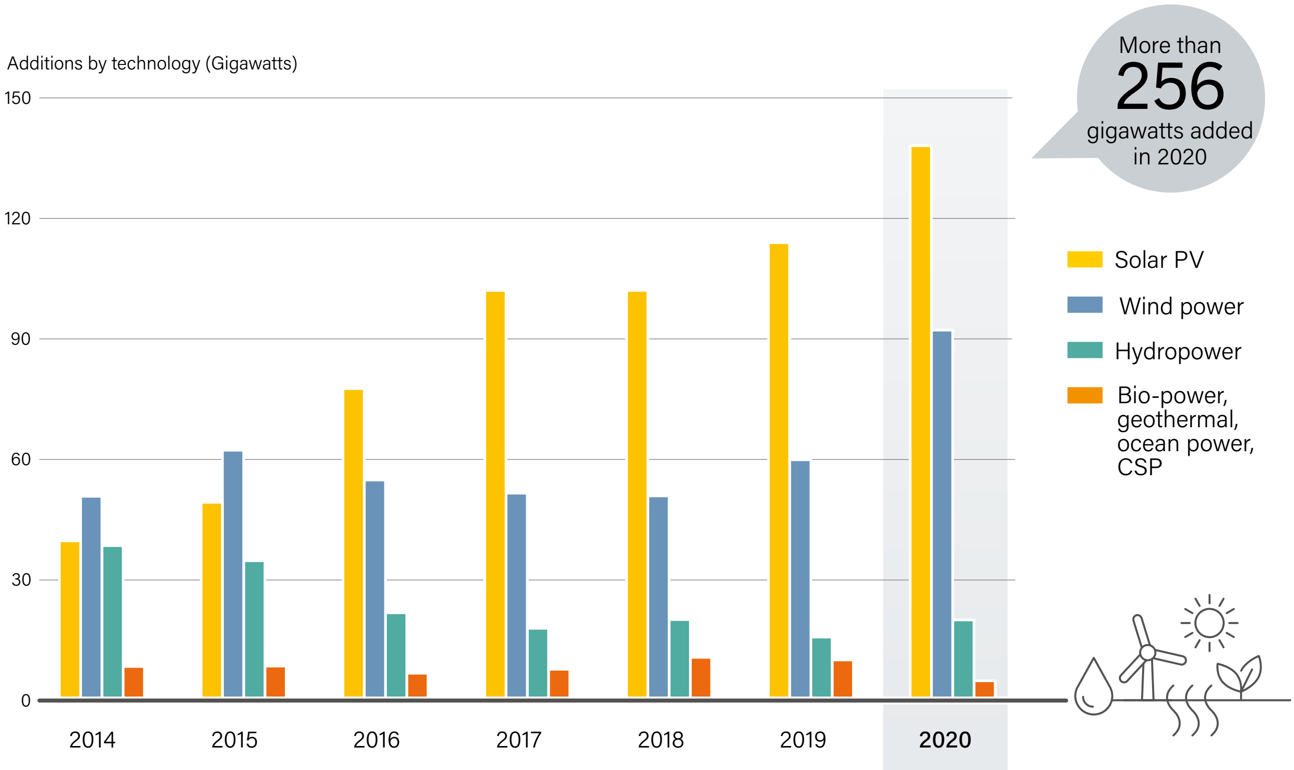
However, the solar PV and wind power sectors rebounded in the second half of 2020, and by year's end these two technologies each had installed a record amount of new capacity, steering the renewable power sector to an all-time high of more than 256 GW of added capacity.[310] Worldwide, total installed renewable power capacity grew almost 10% to reach 2,839 GW.[311] (→ *See Figure 7 and* ***Reference Table R1*** *in GSR 2021 Data Pack.*)

Continuing a trend going back to 2012, most of the newly installed power capacity in 2020 was renewable. Even as the fossil fuel and nuclear power sectors struggled, renewables reached 83% of net power capacity additions.[312] (→ *See Figure 8.*) As in recent years, solar PV and wind power made up the bulk of new renewable power additions. Around 139 GW of solar PV[i] was added, comprising more than half of the renewable additions, while 93 GW of installed wind power capacity made up some 36%.[313] Almost 20 GW of hydropower capacity was brought online, and the remaining additions were from bio-power, with ocean, geothermal and concentrating solar thermal power (CSP) adding only marginal net capacity.[314]

Once again, China led in capacity added during the year, accounting for almost half of new installations and leading global markets for bio-power, CSP, hydropower, solar PV and wind power.[315] With more than 116 GW added, China brought online more capacity in 2020 than the entire world did in 2013, and it nearly doubled its own additions of the previous year.[316] Countries

i For consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC). See endnotes and Methodological Notes for further details.

FIGURE 7.
Annual Additions of Renewable Power Capacity, by Technology and Total, 2014-2020



Note: Solar PV capacity data are provided in direct current (DC). Data are not comparable against technology contributions to electricity generation.
Source: See endnote 311 for this chapter.

outside of China added around 140 GW of capacity, up around 5% from 2019 and led by the United States (36 GW) and Vietnam (11 GW).[317] China also remained the global leader in cumulative renewable energy capacity (908 GW) at year's end, followed by the United States (313 GW), Brazil (150 GW), India (142 GW) and Germany (132 GW).[318] (→ *See Table 2.*)

By the end of 2020, at least 34 countries had more than 10 GW of renewable power capacity in operation, up from 20 countries in 2010.[319] The shift is even more impressive when excluding hydropower, as markets for both solar PV and wind power have grown dramatically in recent years. At least 19 countries had more than 10 GW of non-hydropower renewable capacity at the end of 2020, up from 5 countries[i] in 2010.[320]

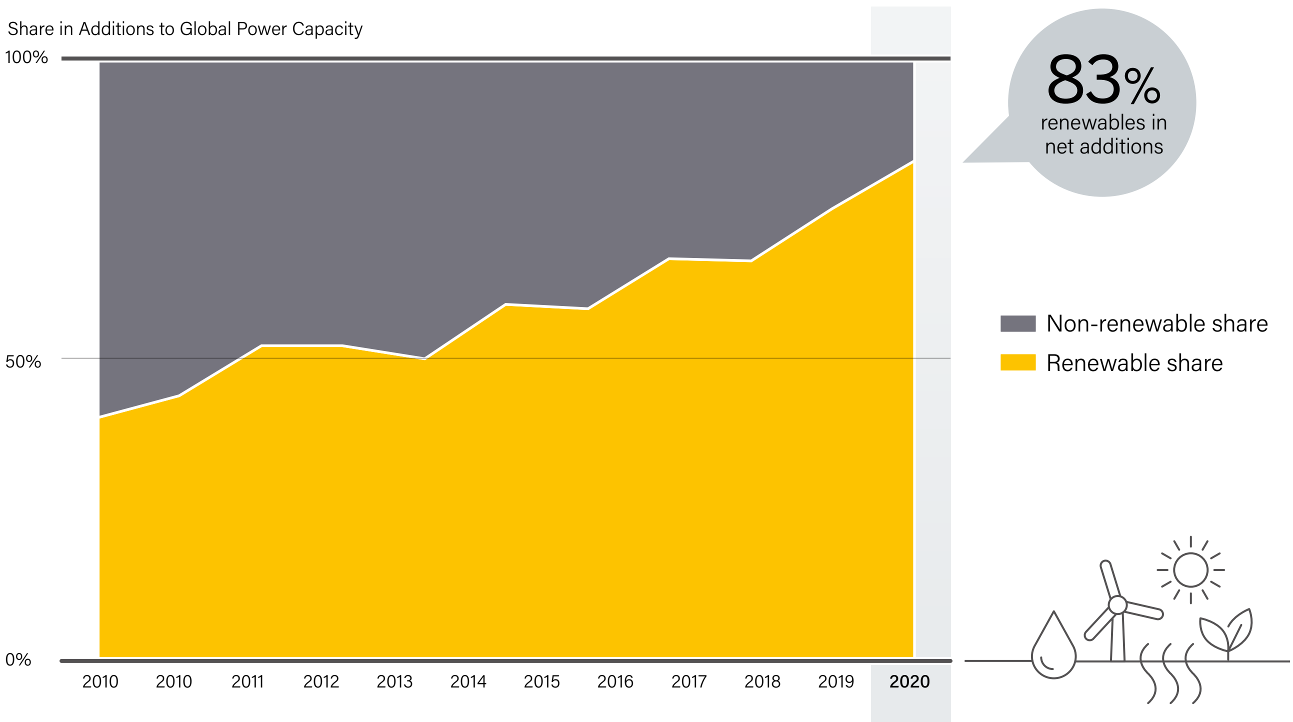
The top countries for non-hydro renewable power capacity per person were unchanged from previous years: Iceland, Denmark, Sweden, Germany and Australia.[321] (→ *See **Reference Table R2** in GSR 2021 Data Pack.*)

Driven by government policy and low costs, **major markets for leading renewable energy technologies** withstood the worst effects of the economic shocks in 2020. During the second half of the year, activity accelerated dramatically as developers sought to make up for delays and to take advantage of expiring incentives in Vietnam and the United States as well as expiring subsidies in China, which led to an installation rush (particularly for solar PV and wind power but also for hydropower).[322] In solar PV markets, rapid growth in rooftop solar projects compensated for a smaller increase in the utility-scale market, while growth in the wind power sector rose sharply in the second half of the year, driven mainly by onshore wind installations in China.[323] The global offshore market was stagnant compared to 2019.[324]

The global market for hydropower, still the leading technology in renewable electricity generation, grew significantly (24%) in 2020 due to the commissioning of several large projects in China.[325] CSP and geothermal power markets both declined during the year, with only a handful of countries accounting for most of the

i In 2010, China, India, Germany, Spain and the United States exceeded 10 GW of non-hydro renewable power capacity. As of 2020, Australia, Brazil, Canada, Italy, France, Japan, the Republic of Korea, Mexico, the Netherlands, Poland, Sweden, Turkey, the United Kingdom and Vietnam also joined this list.

FIGURE 8.
Shares of Net Annual Additions in Power Generating Capacity, 2010-2020



Source: See endnote 312 for this chapter.

new installations.[326] Ocean power was still disadvantaged by a lack of policy support and of sufficient technological innovation to reduce costs significantly; however, the EU passed a new target for 1 GW of ocean power by 2030 and 40 GW by 2050.[327]

Auctions and tenders for renewable power have become one of the most common market support mechanisms for new projects.[328] In the first half of 2020, 13 countries awarded nearly 50 GW in new capacity, breaking a record for auctioned capacity.[329] The total number of countries that held renewable power auctions decreased during the year (from 41 to at least 33), but several new countries held auctions for the first time.[330] In some markets, the shift to auctions also has reduced the diversity of participants, notably the involvement of community energy groups.[331]

Alongside significant and ongoing cost reductions in solar PV and wind power, the growth of auctions has created a highly competitive bidding environment that has placed strong downward pressure on price levels for renewable power projects. In 2020, developers around the world continued to submit bids for tenders at record-low prices for utility-scale solar PV and wind power.[332] However, low bid prices in tendering processes do not necessarily reflect overall costs, as prices depend on resource availability, local labour and land prices and costs of financing, while tendering conditions might include the provision of grid connection to developers, among other incentives.[333]

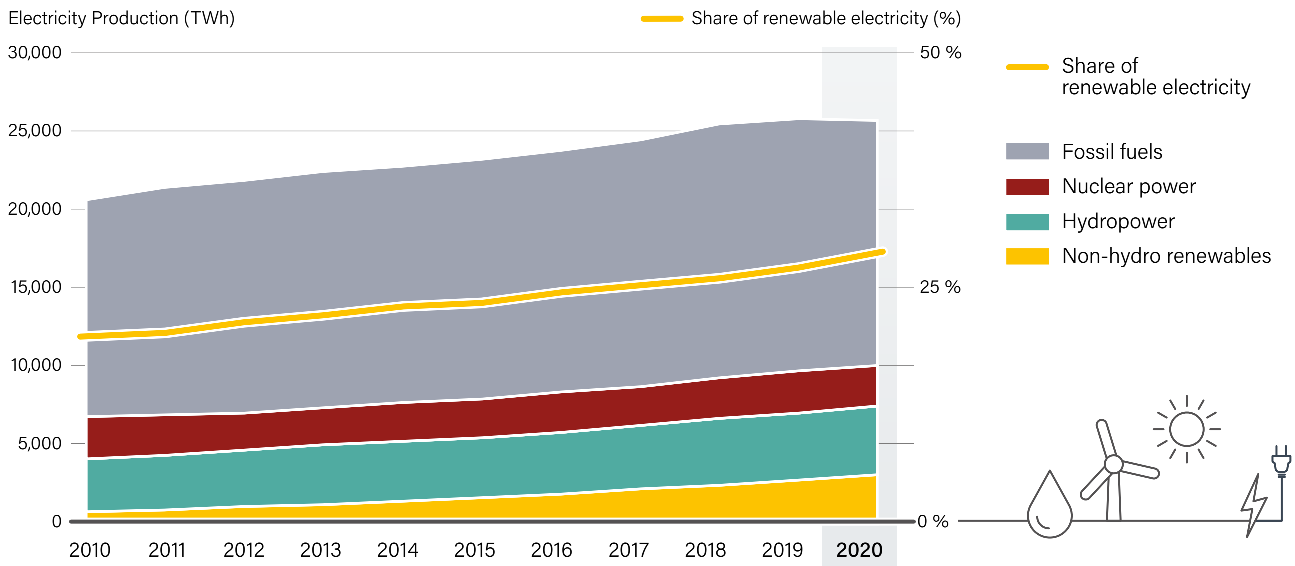
The amount of renewable electricity from **power purchase agreements** has grown substantially in recent years, with a record 23.7 GW sourced from corporate PPAs in 2020.[334] The United States remained the world's leading market for corporate PPAs despite declining 16%, while the record additions were driven by a combined tripling in Europe, the Middle East and Africa.[335] US companies that successfully closed PPAs in the United States have shown growing interest in expanding their efforts to Europe.[336]

Renewables generated an estimated
29% of global electricity
in 2020.

In early 2020, **global electricity demand** dropped sharply in the wake of the COVID-19 pandemic.[337] However, demand rebounded by year's end, resulting overall in a slight decline of around 2%, the first annual decline since the global economic crisis of 2008/2009.[338] Production of electricity from renewables was favoured under these low-demand circumstances due to its inherent low operating costs, as well as the dispatch rules in many countries that prioritise renewable electricity.[339]

Each year for the past decade, renewables have met a higher share of global electricity demand than in the previous year.[340] This trend accelerated in 2020 amid the lower demand and favourable conditions for renewable power. For the second consecutive year, electricity production from fossil fuels was estimated to decline, driven mainly by a 2% decrease in coal power generation.[341] Overall, renewables generated an estimated 29.0% of global electricity in 2020, up from 27.3% in 2019.[342] (→ *See Figure 9.*)

FIGURE 9.
Global Electricity Production by Source, and Share of Renewables, 2010-2020



Source: Ember. See endnote 342 for this chapter.

The progress in renewable energy, and the decline in fossil fuels (especially coal), has been especially pronounced in certain countries and regions. Wind power, hydropower, solar power and bioenergy became the EU-27's main source of electricity in 2020, growing from 30% of generation in 2015 to 38%.[343] Electricity generation from these renewable sources grew 23% as production from coal power fell by half over this period.[344] Similarly, in the United Kingdom, renewables grew to a 42% share of generation to become the main source of electricity in 2020, beating out fossil gas and coal at a combined 41%.[345]

In the United States, renewable energy reached nearly 20% of net electricity generation by year's end, with solar and wind energy accounting for more than half of this; meanwhile, coal's share fell from around 24% in 2019 to less than 20% in 2020.[346] More than 19% of Australia's electricity came from wind and solar energy in 2020, and, overall, renewable energy represented nearly 28% of the country's generation, up from 24% in 2019.[347] In China, electricity from hydropower, solar energy and wind energy provided more than 27% of production, up from around 26% in 2019.[348]

The share of electricity generated by **variable renewable electricity** (wind power and solar PV) continued to rise in several countries around the world. While variable renewables contributed more than 9% of global electricity in 2020, in some countries they met much higher shares of production, including in Denmark (63%), Uruguay (43%), Ireland (38%), Germany (33%), Greece (32%), Spain (28%), the United Kingdom (28%), Portugal (27%) and Australia (20%).[349]

The cost-effective **integration** of variable renewable electricity has spurred industry players and governments to make efforts to increase the flexibility of their energy technologies and systems. Some countries expanded or modernised transmission infrastructure specifically to adapt their systems to rising shares of variable renewables.[350] Manufacturers of wind turbines and solar PV modules are working to make their technologies more flexible so that they provide services[i] to the grid, as well as better facilitate their own integration into the energy system.[351] Governments have introduced policies to support demand flexibility measures such as time-of-use pricing, incentive payments and penalties to influence the electricity use of consumers.[352]

Hybrid systems, consisting of at least two renewable energy technologies and/or energy storage, are able to provide flexibility to the grid as well as to decrease costs and deliver technical benefits (including higher capacity factors) due to co-localisation.[353] In 2020 and early 2021, hybrid projects combining solar PV, wind and/or energy storage were announced or commissioned in many countries, including India where a massive 30 GW solar-wind project began construction in Gujarat.[354] Markets for hybrid solar thermal collectors[ii] grew in China, France, Germany, Ghana and the Netherlands during 2020.[355]

i Grid services include the ability to provide operating reserve, voltage support and black start capabilities. (→ See Systems Integration chapter.)

ii Also known as PV-T, or photovoltaic-thermal collectors, these systems convert solar radiation into both electrical and thermal energy.

In 2020, **wind power and solar PV** generated more than 20% of electricity in nine countries.

SIDEBAR 2. Impacts of COVID-19 on Renewable Energy-Related Jobs in 2020

A variety of factors shape employment trends in the renewable energy sector. They include costs and investments as well as labour, industry and trade policies. The intensity of labour changes as technologies mature, as the scale and complexity of operations grow and as automation takes hold. Gender disparities also persist in the sector, with women accounting for less than one-third of the overall renewable energy workforce in 2018. In addition to these factors, the COVID 19 pandemic had unprecedented impacts on renewable energy-related employment in 2020.

Although renewables fared better than expected compared with conventional energy sources (in terms of new capacity additions), the sector faced uncertainties and disruptions during the year. Lockdowns and other restrictions on movement put pressure on supply chains and constrained economic activity. In many countries, project delays early in 2020 were followed by surges of activity by year's end, reflecting cycles of rising and falling COVID-19 infections. The year-end surge was driven in part by developers rushing to meet permitting deadlines (some of which were extended in response to pandemic delays) or reacting to impending changes in policies, such as expiring tax credits, subsidy phase-outs or cuts in feed-in tariff rates. In a sense, the pandemic amplified the business cycle fluctuations typically seen in the sector.

As a result, employment in renewables fluctuated considerably over the year. Depending on labour market policies and industry practices in different countries, workers were furloughed, had their work hours reduced or were laid off (and, in some cases, rehired later). The ability of governments, companies and industries to cope with disruptions by switching to remote working arrangements or to comply with social distancing requirements in the workplace differed enormously.

COVID-19's impacts on employment also varied by renewable energy technology, end-use sector and value chain segment. (→ *See Table 3.*) Disruptions in the supply of inputs and raw materials were common. For example, the supply of balsa, a key component of wind turbine blades, was affected by the lockdown in Ecuador, which supplies 95% of the wood globally. As a result, production was shifted to other countries (including Papua New Guinea), and other materials (such as PET plastic) were substituted – resulting in job losses in Ecuador.

TABLE 3.
COVID-19's Impacts on Employment in Segments of the Renewable Energy Supply Chain

Value chain segment	Magnitude of impact	Comments
Distributed renewables for energy access	Very high	Demand affected by reduced incomes and by social distancing requirements.
Transport and logistics	High (medium term)	Greatly affected by temporary parts shortages, social distancing measures, quarantines and border controls.
Construction and installation	High	Strongly affected by lockdowns and delays, limits on the numbers of workers allowed on-site and social distancing requirements. Less impact in the second half of 2020.
Biofuels	High	Drop in demand due to the decline in transport volumes and to cheaper fossil-based diesel, but this was moderated in some countries by increases in blending mandates.
Manufacturing and procurement	High (short term)	Heavy effects on factory workers, technicians and engineers due to temporary factory closures.
Operations and maintenance	Low to medium	Travel to some project sites affected by border closures and quarantine rules; however, energy generation is an essential service and the physical space available at wind and solar farms often allows for social distancing.
Project planning	Low	Many jobs can be performed remotely.

Source: IRENA. See endnote 38 for this chapter.

Experience also diverged widely across countries, affecting local employment trends. Some countries (such as China) witnessed substantial growth in new renewable power capacity additions in 2020, while in other countries (such as India), renewables stagnated. However, new installations did not always translate into job growth. For example, the United States added record amounts of solar energy in 2020, but one survey found that US employment in the sector dropped 6.7% during the year, to around 231,500 workers. This could be due to a decline in labour intensity, given that large utility-scale projects accounted for three-quarters of new installations, as well as to fewer in-person sales, which shifted to online marketing to comply with social distancing requirements. By mid-2020, the US solar industry had lost as many jobs as it had added in the past five years, due primarily to a shift away from door-to-door sales.

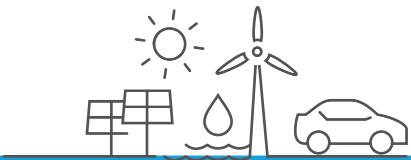
Meanwhile, energy use in the transport sector collapsed in early 2020. This affected biofuel demand in two ways: directly through reduced demand for fuels and indirectly due to falling crude oil prices, which made biofuels less competitive. During the year, employment rose in biodiesel while it fell in ethanol. In Brazil, the world's largest biofuels employer, the increase in the blending mandate drove biodiesel production up: jobs in this sector climbed from 294,900 in 2019 to 323,800 in 2020. In contrast, jobs in ethanol have continued to fall as increasing mechanisation reduces the need for manual labour in feedstock operations, declining from an estimated 574,400 in 2018 to an estimated 547,300 in 2019.

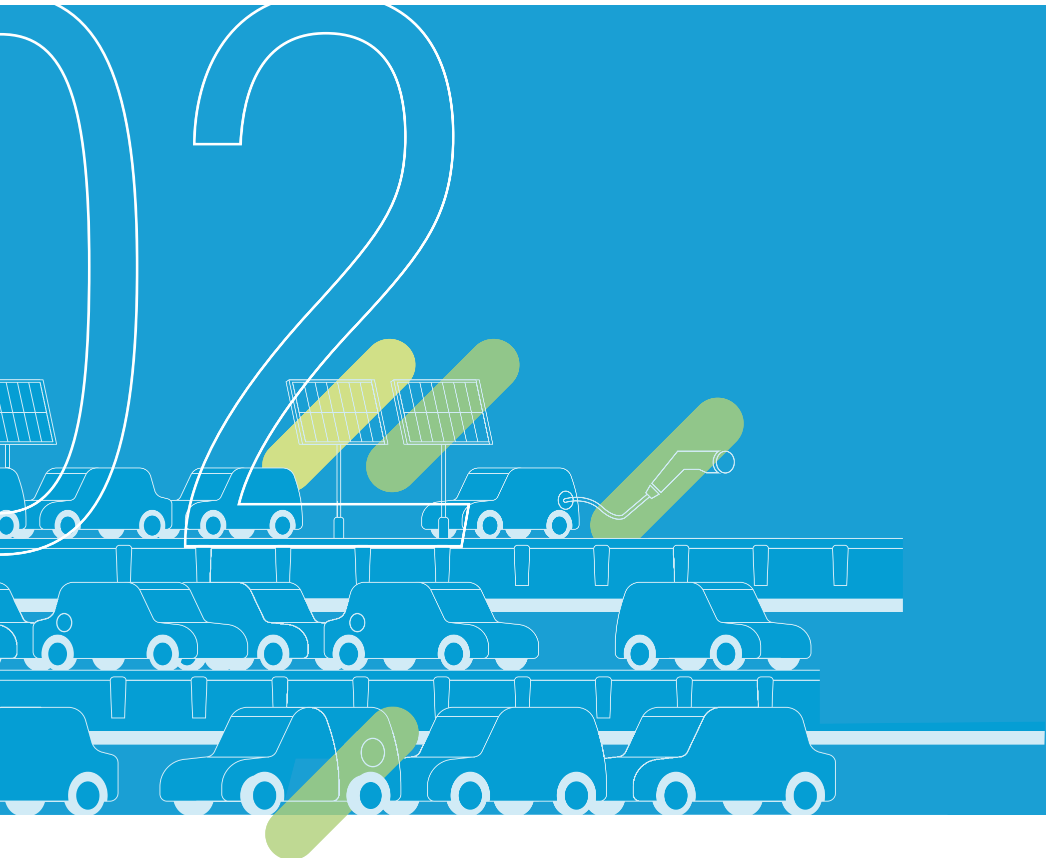
In Indonesia, another major biodiesel producer, employment remained virtually unchanged in 2020 at around 475,000 jobs. Although COVID-19 restrictions reduced overall diesel fuel consumption, the government raised the biodiesel blending mandate from 20% to 30%, substantially increasing domestic biodiesel consumption and, thus, supporting employment. However, the country's exports collapsed as a result of unfavourable prices compared to conventional diesel and countervailing duties imposed by the European Union in 2019.

In the off-grid power sector, COVID-19 slowed the pace of new capacity additions and electricity access considerably in many countries in 2020. This was especially true for sales of off-grid solar lighting products. The finances of off-grid solar companies were constrained due to reduced equity funding, while reductions in income restricted households' abilities to afford cash purchases. (→ *See Distributed Renewables chapter.*) Consequently, employment in the sector suffered. Jobs plummeted from an estimated 339,000 in 2019 to just 187,500 in 2020. COVID-19 also heavily impacted women's employment and livelihoods in the off-grid sector, since women are more often employed in small businesses and segments of the informal economy that already faced challenges to energy access.

Source: IRENA. See endnote 38 for this chapter.

Since 2020, the BMW Group has used 100% renewable energy sources for its operations globally. It also aims to increase electric vehicle sales to one-fifth of all sales by 2023.





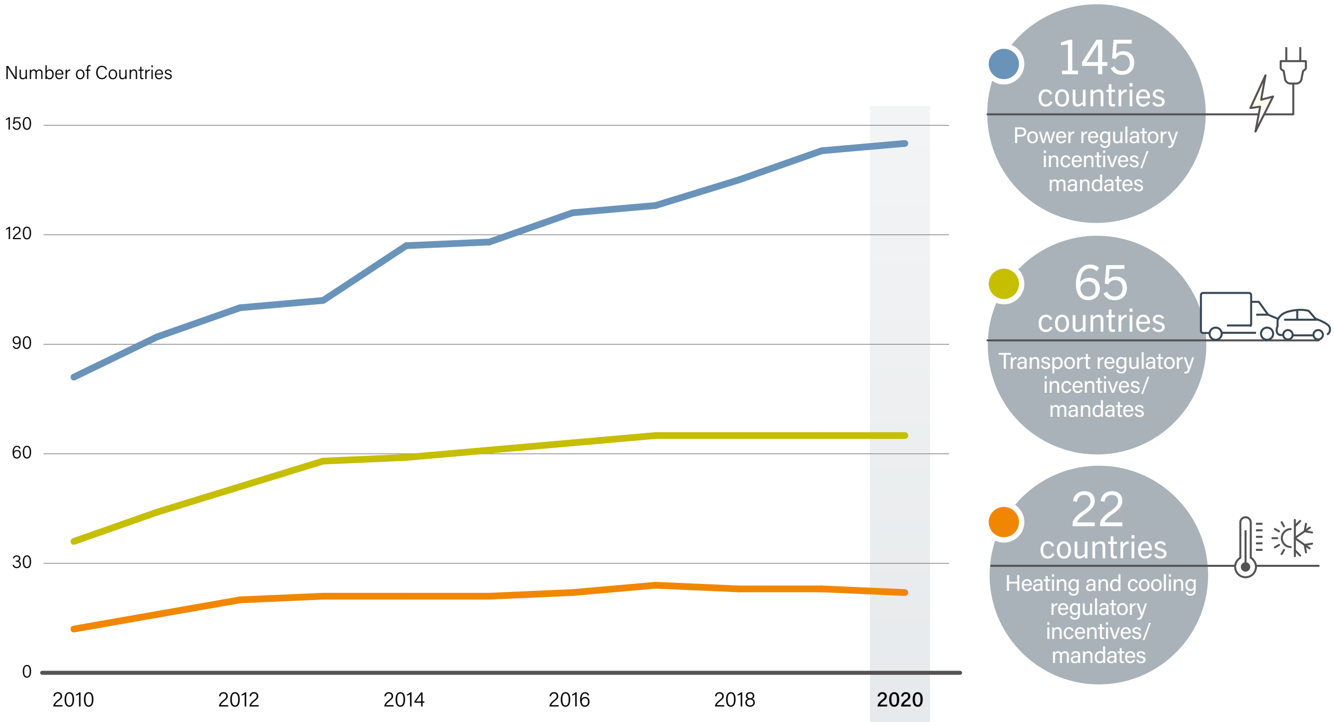
02 POLICY LANDSCAPE

KEY FACTS

- Despite the COVID-19 crisis, **policy support for renewables remained strong** throughout 2020.
- Many **countries were not on track to achieve their 2020 targets**, and many had not yet set new targets for future years.
- **Policy related to heating and cooling in buildings and industry remained scarcer** than policies directed at electricity generation and transport.
- EV policies became increasingly popular in 2020, but **most continued to lack a direct link to renewable electricity.**
- Many jurisdictions with **high shares of variable renewable electricity** implemented policy to ensure successful integration.
- 2020 saw important **climate change policy commitments** in some major markets.

Government policies continue to play a crucial role in accelerating the adoption and deployment of renewable energy technologies, particularly in sectors other than power generation. Policies also continue to be critical for achieving renewable energy cost reductions and innovation.[1] By the end of 2020, nearly all countries worldwide had in place renewable energy support policies, although with varying degrees of ambition.[2] (→ *See Figure 10 and Table 6.*) In addition, renewable energy deployment continued to expand outside of government policies in the form of corporate commitments to renewables and utility-led activities. This was driven by market-based factors such as corporate action on climate change and the declining costs of renewable electricity.[3] (→ *See Feature chapter.*)

FIGURE 10.
Number of Countries with Renewable Energy Regulatory Policies, 2010–2020



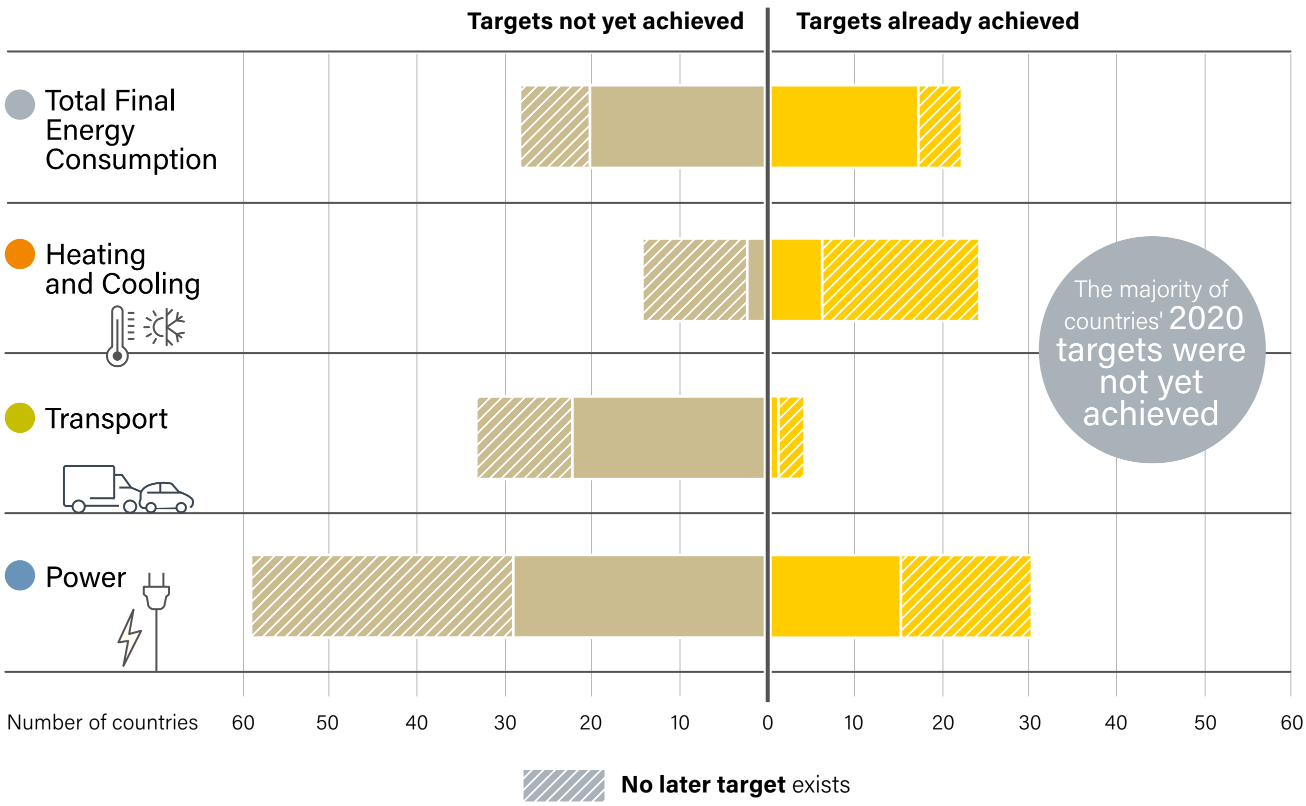
Note: Figure does not show all policy types in use. In many cases countries have enacted additional fiscal incentives or public finance mechanisms to support renewable energy. A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial-level policy in place. Power policies include feed-in tariffs (FITs) / feed-in premiums, tendering, net metering and renewable portfolio standards. Heating and cooling policies include solar heat obligations, technology-neutral renewable heat obligations and renewable heat FITs. Transport policies include biodiesel obligations/mandates, ethanol obligations/mandates and non-blend mandates. For more information, see Table 6 in this chapter and Reference Tables R8-R10 in GSR2021 Data Pack.

Source: REN21 Policy Database.

The year 2020 was critical for assessing progress on renewable energy targets. Worldwide, 165 countries had in place targets to increase uptake of renewables in various sectors by year's end.[4] Most of these targets were for the power sector, followed by targets for total final energy consumption, heating and cooling, and transport. However, success in actually being on track to meet the 2020 targets varied widely: overall, some 80 targets were achieved, while the majority (134) were not yet achieved according to the latest data available (ranging from 2017 to 2020). While some countries were close to achieving their targets, others were far from being on track. Moreover, as countries' 2020 targets were coming to term at the end of the year, as many as 30 countries had not yet set new targets for future years (compared to 67 that had). Many of the achieved targets were for power, heating and cooling, and total final energy consumption, while very few were in the transport sector. (→ *See Figure 11 and* ***Reference Tables R3-R8*** *in GSR 2021 Data Pack*[i].)

i See www.ren21.net/gsr-2021.

FIGURE 11.
Status of Countries in Meeting Their 2020 Renewable Energy Targets and Setting New Ones



Note: Figure includes only countries with targets in these sectors that are for a specific share from renewable sources by a specific year, and does not include countries with other types of targets in these sectors.

Source: REN21 Policy Database. See Reference Tables R3-6 in GSR 2021 Data Pack.

Continuing a trend of the past decade – and despite the COVID-19 crisis – policy support for renewables generally remained strong throughout 2020. In some countries, economic recovery policies and funding packages related to the pandemic included explicit support for renewables, although, overall, far more support was allocated to fossil fuels.[5] (→ *See Sidebars 3 and 4.*) While the global health and economic disruptions affected the suite of renewable energy policies implemented during the year, such measures also evolved in response to greater action on climate change, the falling costs of renewables, evolving grid and system integration demands, and the changing needs and realities of different jurisdictions.

In jurisdictions with high shares of installed renewable energy, decision makers typically focused policy development on ensuring that support for renewables was cost effective, and on the technical and market integration of renewables. (→ *See Systems Integration section in this chapter.*) In less-mature renewable energy markets and in some developing and emerging economies, policy efforts prioritised outcomes such as boosting renewable energy capacity and generation to meet demand, promoting energy security and providing increased access to energy.[6] (→ *See Distributed Renewables chapter.*)

Policies to advance the production and use of renewables can be targeted at any and all end-use sectors, including buildings, industry, transport and electricity generation. Most renewable energy policy in 2020 continued to focus on a single sector, although at least five countries unveiled comprehensive climate change policies that included support for renewables across multiple sectors. Trade policy also continued to have an impact on the production, exchange and development of renewable energy products, as well as on the demand for renewables within specific countries.[7] (→ *See Box 4.*)

A significant amount of renewable energy policy making continued to occur at the municipal level. However, this chapter covers mainly policy enacted at the regional, national and state/provincial levels of governance. Municipal policy is discussed in detail in the REN21 *Renewables in Cities Global Status Report*[i].

i See www.ren21.net/cities.

SIDEBAR 3. Renewable Energy in COVID-19 Stimulus Packages

In response to the COVID-19 crisis, governments around the world announced more than USD 12 trillion in financial stimulus, including at least USD 732.5 billion in energy-related support. Although some stimulus packages included incentives for renewables, as of April 2021 this comprised only around USD 264 billion of the total amount provided by governments globally, compared to more than USD 309 billion in fossil fuel stimulus. (→ *See Figure 49 in Investment chapter.*) Direct support for coal included India's USD 6.75 billion coal infrastructure support package and the Republic of Korea's USD 2.5 billion bailout of Doosan Heavy Industries, a coal plant manufacturer. Direct support for oil and gas included USD 4.4 billion in loans and loan guarantees to a Canadian pipeline and GBP 1.3 billion (USD 1.7 billion) in low-interest loans to oil and gas companies in the United Kingdom.

Nevertheless, examples of "green recovery" efforts did emerge. At a regional level, around 30% of the European Union's (EU) EUR 750 billion (USD 921 billion) COVID-19 stimulus package was dedicated to "clean recovery" and renewables, including renewable electricity generation, energy retrofits of buildings, renewable heat, renewable hydrogen and electric vehicles (EVs)[i]. China, India and the Republic of Korea also committed to renewable energy investments, although those countries also supported coal in their recovery plans. Colombia's plan included raising COP 16 billion (USD 4.6 million) to accelerate 27 renewable energy and related transmission projects.

In the power sector, governments provided around USD 95 billion in response to COVID-19. This was largely to ensure the continuation of services and to reduce consumers' bill burdens rather than to incentivise renewables[ii], although several countries provided funds for new renewable power capacity. Israel's recovery plan included a commitment of ILS 6.5 billion (USD 2 billion) to build 2 gigawatts (GW) of new solar PV capacity. Nigeria's stimulus plan allocated around USD 620 million for a programme to install solar PV home systems for 5 million households. In the United States, the USD 900 billion relief package included extensions of the production and investment tax credits for solar PV and onshore wind power, a new tax credit for offshore wind power, USD 1.7 billion for low-income homeowners to install renewable energy, and USD 4 billion in research and development (R&D) funding for solar power, wind power, hydropower and geothermal energy.

In the buildings and industry sectors, the largest share of energy-related stimulus aid was aimed at spurring investments in renewable heat in buildings and raising the energy efficiency of existing buildings. France's COVID-19 stimulus package included EUR 7 billion (USD 8.6 billion) to support building renovations – including those encouraging renewable heat – as part of a wider target to renovate the country's entire building stock by 2050.

In the transport sector, aviation was the largest stimulus recipient, but only three countries – Austria, France and Sweden – included "green" conditions for aviation stimulus[iii]. At least four countries provided COVID-19 relief for electric transport and hydrogen for transport, although not necessarily linked to renewable energy. The Republic of Korea's recovery package included KRW 2.6 trillion (USD 2.4 billion) in support of EVs and hydrogen cars. France's plan allocated EUR 11 billion (USD 13.5 billion) for EVs, including support for charging stations. Germany's stimulus package included EUR 5.9 billion (USD 7.3 billion) in subsidies for EVs and charging infrastructure as well as EUR 7 billion (USD 8.6 billion) for renewable hydrogen for decarbonising heavy transport and industry. Part of Spain's EUR 3.8 billion (USD 4.6 billion) aid package for the auto industry included measures to electrify public transport, a target to increase the number of EV charging points to 50,000 by 2023 and 800,000 by 2040, funding for EV charging and subsidies for purchasing low-emission cars.

i Member States are expected to invest funds in the seven priority areas of: clean energy technologies; energy-efficient building renovations; sustainable transport; broadband roll-out; digitalisation of public administration; cloud computing capacities; and mainstreaming digital skills into education systems. In line with the European Green Deal, EU countries have agreed to explicitly include clean energy transitions at the heart of their economic recovery.

ii Excluding the EU plan for economic recovery, new renewable electricity plants, mostly wind and solar PV, received only around USD 10 billion from announced stimulus packages.

iii Austria required Austrian Airlines to abolish air routes that can be reached by train in far fewer than three hours and to commit to additional emission reduction goals, France's USD 7.7 billion support for Air France required 50% emission reduction and a minimum of 2% renewable fuel by 2030, and Sweden imposed conditions of 25% emission reduction by 2025 on Scandinavian Airlines.

Source: See endnote 5 for this chapter.

BOX 4. Trade Policy, Local Content Requirements and Renewables

In 2020, several jurisdictions unveiled policies to stimulate the local production of renewable energy equipment. In Africa, Mali exempted equipment such as solar panels, wind turbine blades and pump turbines from paying value-added tax (VAT). Burkina Faso launched a Solar Cluster initiative to establish a domestic solar PV industry by offering long-term financial backing for solar PV projects and providing networking and training opportunities for the country's solar industry. Uganda's revised draft National Energy Policy committed to formulating innovative financing mechanisms for geothermal and solar PV through different financial interventions, including income tax deductions, exemptions from VAT and customs tax, and accelerated depreciation tax incentives.

India put forward an expedited manufacturing plan to incentivise domestic solar cell manufacturing capacity and planned to impose new tariffs of 40% on imports of solar modules and 25% on solar cells starting in April 2022. The Indian government also approved a "production-linked incentive" plan to enhance the country's manufacturing capabilities and exports, including domestic high-efficiency solar PV module manufacturing and advanced chemistry cell batteries.

Turkey's new regulations for solar panel imports (which require calculating the import duty on solar modules per kilogram rather than by square metre) are perceived to favour Turkish manufacturers of solar PV panels, as high-efficiency modules generally are heavier than they were a few years ago. Saudi Arabia announced a plan to increase local content in domestic renewable energy industry chains.

Other jurisdictions eased import requirements for renewable energy equipment in 2020. The Brazilian government introduced a measure to remove a 12% levy for some solar equipment (modules, inverters and trackers). The government of Bangladesh added EUR 200 million (USD 246 million) during the year to its Green Transformation Fund, which offers loans for the import of "environmentally friendly" products and energy efficiency components from Europe. In Senegal, to accelerate the electrification of rural areas, the government exempted equipment[i] for the production of solar PV power from the VAT.

i The exempted products include solar panels, inverters, solar thermal collectors, batteries, solar lamp kits, solar water heaters and charge regulators. Packages comprising a battery, solar panel, and a lantern or a solar panel, a water pump and controller also are included among the VAT-exempted products.

Source: See endnote 7 for this chapter.

RENEWABLE ENERGY AND CLIMATE CHANGE POLICY

Policies enacted to help mitigate climate change can directly or indirectly stimulate renewable energy deployment by mandating a reduction or elimination of greenhouse gas emissions, phasing out or banning the use of fossil fuels and/or increasing the costs of energy from fossil fuels relative to renewables. Climate change policies that indirectly support renewables include targets to reduce greenhouse gas emissions, the development of and participation in carbon pricing and emission trading programmes, and fossil fuel bans or phase-outs. In some cases, climate change policies also are designed to directly stimulate the deployment of renewables.

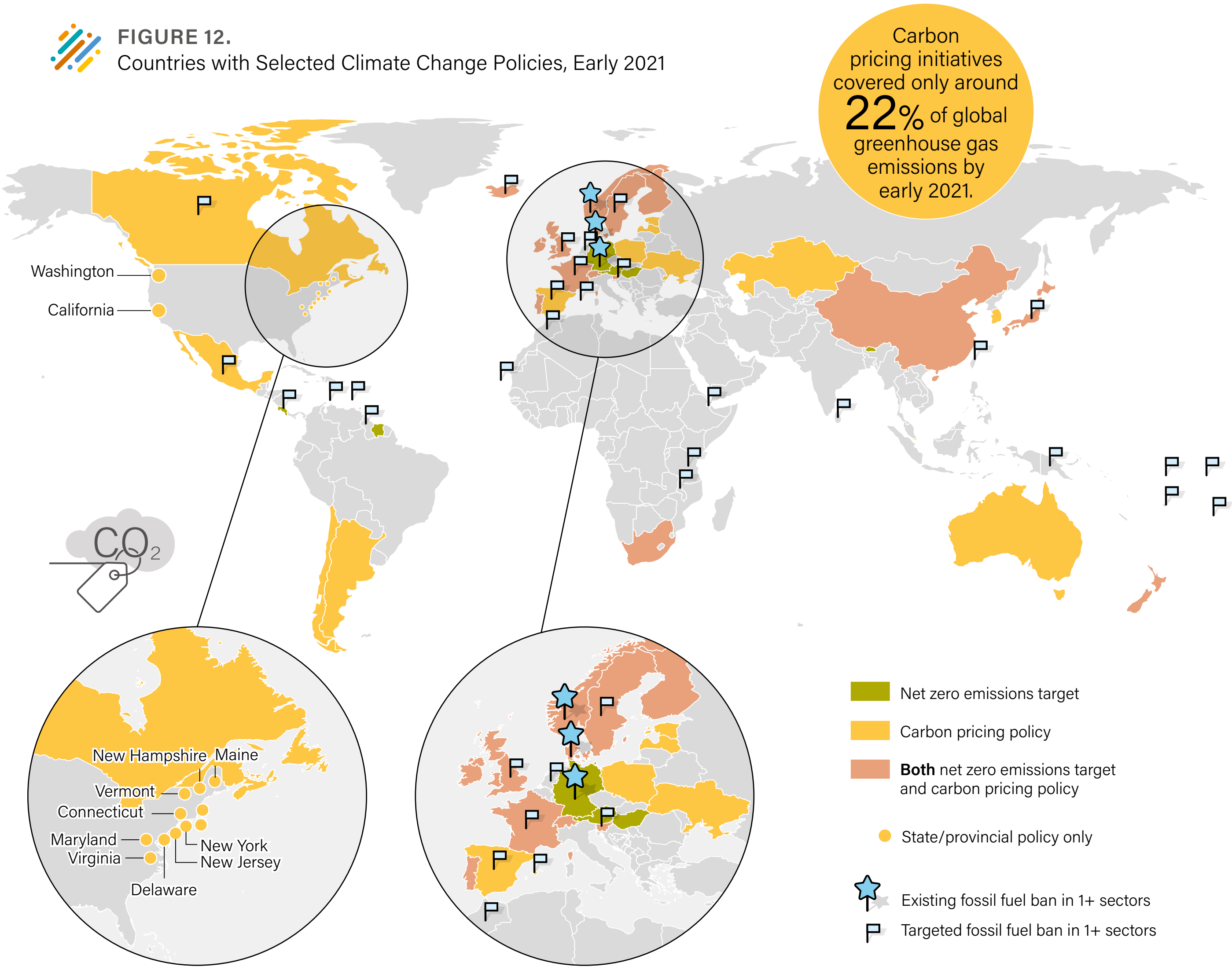
CLIMATE POLICIES THAT INDIRECTLY SUPPORT RENEWABLES

Although the COVID-19 crisis was the central political focus of 2020, commitments to climate change mitigation also were prominent during the year. Overall, 2020 was an important milestone for climate change policy, with many countries' greenhouse gas targets for the year expiring, countries setting new targets, and numerous countries committing to carbon neutrality. For example, signatories to the Paris Agreement were supposed to submit updated (or new) Nationally Determined Contributions (NDCs)[i] towards reducing emissions by the end of 2020, and at least 40 countries plus the EU met this deadline.[8]

Numerous countries worldwide also implemented additional climate change policies during 2020, including setting greenhouse gas emission targets, adopting carbon pricing or emission trading programmes, and announcing fossil fuel bans or phase-outs. (→ *See Figure 12.*)

i Nationally Determined Contributions (NDCs) describe efforts by each country to reduce greenhouse gas emissions and adapt to the impacts of climate change. Article 4 of the Paris Agreement requires each Party to prepare, communicate and maintain successive NDCs that it intends to achieve. By the end of 2020, countries with an initial NDC covering the period to 2025 were required to produce an NDC that extends to 2030, and those that already contained a 2030 target were required to update their NDCs. In 2020, 44 countries plus the EU met this deadline.

FIGURE 12.
Countries with Selected Climate Change Policies, Early 2021



Note: Carbon pricing policies include emission trading systems and carbon taxes. Net zero emissions targets shown are binding and include those that are in law or policy documents, as well as those that have already been achieved. Fossil fuel ban data include both targeted and existing bans across the power, transport and heating sectors. Jurisdictions marked with a flag have some type of fossil fuel ban in one or more sector. See GSR 2021 Data Pack for details. Not all cities with policies are shown; see REN21 *Renewables in Cities 2021 Global Status Report* for more comprehensive city policies.

Source: Based on World Bank, Energy Climate Intelligence Unit, IEA Global Electric Vehicle Outlook and REN21 Policy Database. See Reference Tables R4, R6 and R9 in GSR 2021 Data Pack. See endnote 8 for this chapter.

Greenhouse gas emission targets mandate a reduction in overall emissions and can include net zero and "carbon-neutral" targets[i]. During 2020, new emission reduction commitments were spread across nearly all continents, covering around 47% of total global emissions.[9] (→ *See Table 4.*) Some of the most significant carbon neutrality pledges occurred in Asia, with China aiming to become carbon neutral by 2060, Japan by 2050 and the Republic of Korea by 2050 (including a pledge to replace coal with renewables).[10]

i "Net zero" refers to achieving a net balance between greenhouse gas emissions produced and those removed from the atmosphere. In contrast, a gross zero target would reduce emissions from all sources to zero. In a net zero scenario, emissions are "allowed" as long as they are offset by removals. Reaching net zero emissions may be linked to activities such as carbon offsetting and carbon capture and storage and thus does not necessarily include the use of renewables. "Carbon-neutral" means having a balance between emissions of carbon and the absorption of carbon from the atmosphere (by way of carbon sinks).

TABLE 4.
New Net Zero Emission and Carbon-Neutral Targets Set by Countries/Regions in 2020

Net zero emission targets

Country/region	2019 CO_2 emissions (kilotonnes)	2019 CO_2 emissions (% of world total)	Target year	Legal status
EU-27	**2,939,069**	7.73%	2050	Proposed
Austria	72,363	0.19%	2040[1]	In law/policy document
Canada	584,846	1.54%	2050	Proposed
Hungary	53,183	0.14%	2050	In law/policy document
Jamaica	7,442	0.02%	2050	Pledge
Lao PDR	6,783	0.02%	2050	Pledge
Maldives	913	<0.001%	2030[2]	Pledge
Mauritius	4,332	0.01%	2070	Pledge
Nepal	15,019	0.04%	2050	NDC
United Kingdom	364,906	0.96%	2050[3]	In law/policy document
The Vatican	N/A	N/A	2050	Pledge

Carbon-neutral targets

Country/region	2019 CO_2 emissions (kilotonnes)	2019 CO_2 emissions (% of world total)	Target year	Legal status
Argentina	199,414	0.52%	2050	NDC
Barbados	3,827	0.01%	2030	In law/policy document[4]
China	11,535,200	30.34%	2060	Pledge
Japan	1,153,717	3.03%	2050	Pledge
Kazakhstan	277,365	0.73%	2060[5]	Pledge
Korea, Republic of	651,870	1.71%	2050	NDC
Malawi	1,616	<0.001%	2050	Pledge
Nauru	N/A	N/A	2050	Pledge
Slovenia	15,365	0.04%	2050	National plan/strategy
South Africa	494,862	1.30%	2050[6]	National plan/strategy

Notes: Net zero emissions can refer to all greenhouse gas emissions or only carbon emissions, and involves emissions declining to zero. Carbon neutral refers to the balancing of carbon emissions caused by an entity with funding an equivalent amount of carbon savings elsewhere. Although carbon neutrality is sometimes considered to be a synonym for net zero carbon emissions, carbon neutrality can be achieved at the domestic level by using offsets from other jurisdictions, whereas net zero does not necessarily include this feature. Some of these countries – along with Colombia, Kenya and Peru – also adopted other targets less than carbon-neutral/net zero (see GSR 2021 Data Pack for full dataset).

1 Austria's target is for "climate neutrality".

2 Target to be reached with adequate international support and assistance.

3 Adopted in 2019.

4 Published in 2019.

5 Target could be advanced if the country raises USD 10 billion annually from other nations to help finance the transition.

6 South Africa's target is a net zero carbon emissions target.

N/A = data not available

Source: See GSR 2021 Data Pack.

New emission reduction commitments during 2020 covered around

47%

of total global emissions.

Carbon pricing and emission trading programmes have the potential to indirectly increase the deployment of renewables by increasing the relative cost of energy from fossil fuels. By the end of 2020, at least 64 national and state/provincial governments (up from 57 in 2019) had adopted or committed to carbon pricing policies through either direct taxation or a cap-and-trade programme.[11] During the year, Montenegro introduced a cap-and-trade system for major greenhouse gas emitters, and in Mexico a pilot emission trading programme began operating as part of a process to establish a more complete trading system.[12] New Zealand strengthened its emission trading programme by placing a finite cap on the total emission permits that will be issued under the programme.[13]

Bans and phase-outs of fossil fuels are other indirect climate change policies that can stimulate the uptake of renewables in different (or multiple) end-use sectors. In 2020, the most common type of fossil fuel ban enacted at the national and state/provincial levels was on coal. Since coal typically is used for electricity generation, **coal bans** can indirectly stimulate generation from renewables. (➔ ***See Reference Table R6*** *in GSR 2021 Data Pack.*) In Europe, both Austria and Sweden closed their last coal-fired power plants in 2020 as part of phase-out plans.[14] Although Germany's scheme to phase out hard coal was already under way, the government implemented the Coal Phase-Out Act during the year, which lays out a strategy to gradually reduce the use of coal-powered energy by 2038.[15]

In Asia, Japan committed to accelerating the closure of roughly two-thirds of its older, lower-efficiency coal-fired power plants by around 2030, and made pledges to further promote renewables.[16] The government of the Philippines announced a moratorium on all applications for new coal-fired power plants, and Pakistan announced an end to the construction of new coal plants (although plants under construction were expected to be completed).[17]

In the buildings sector, **bans or support for phasing out fossil fuels for heating** (such as heating oil and fossil natural gas) may indirectly stimulate the use of renewables for space and water heating. Many of these bans occur at the municipal level. (➔ ***See Reference Table R4 and Reference Table R9*** *in GSR 2021 Data Pack, and Renewables in Cities Global Status Report.*) At the national level, Germany's new Buildings Energy Act places limits on the installation of oil heating systems beginning in 2026.[18] The government of Finland included in its 2020 budget EUR 45 million (USD 55 million) in grants to phase out oil heating in both residential and municipal buildings.[19] The United Kingdom announced a ban on gas fuels for heating in all new homes, although no deadline was provided.[20] Slovenia's National Energy and Climate Plan included a commitment to ban the sale and installation of new heating oil boilers after 2022.[21]

In the transport sector, **bans on fossil fuels for road transport** can incentivise biofuels-based transport as well as electric vehicles, which could facilitate greater use of renewable electricity in the sector. **Bans on internal combustion engine vehicles** (or targets for 100% EVs) similarly incentivise EVs. (➔ ***See Reference Table R8*** *in GSR 2021 Data Pack.*) During 2020, as part of its new "green growth" strategy, the government of Japan announced that it would take actions to eliminate petrol vehicles in the next 15 years (although no target was set).[22] Scotland's updated Climate Change Plan includes a commitment to phase out sales of new petrol and diesel cars and vans by 2030.[23]

> # Bans and phase-outs
> of fossil fuels grew in popularity during 2020, particularly for coal.

At the state level, California (US) is requiring all new passenger vehicles (cars and trucks) sold in the state to be zero emission[i] by 2035, while all medium- and heavy-duty vehicles sold must be zero emission by 2045 – the first such policy in the world targeting trucks and vans.[24] Massachusetts (US) announced a ban on the sale of new petrol vehicles by 2035.[25] (→ *See Transport section in this chapter for more details.*)

Many cities also have adopted policies that either ban or heavily restrict the use of fossil fuels for road transport[ii], as well as policies that incentivise **non-motorised travel**. In addition to vehicle bans and EV targets, cities increasingly have used **low-emission zones** (LEZs) to restrict certain types of vehicles from entering city centres.[26] In 2020, governments placed a strong emphasis on walking and cycling infrastructure, as "pop-up" bike lanes were added during pandemic-related lockdowns and allocations were made for cycling infrastructure funding, subsidies and other incentives.[27] (→ *See Transport section in Global Overview chapter, and Renewables in Cities Global Status Report.*)

At least two countries **withdrew support for fossil fuel exploration** in 2020. Denmark announced that it will end all new domestic oil and gas exploration by 2050.[28] The United Kingdom announced an end to all public financing for international fossil fuel projects, including support for oil, most fossil-based natural gas[iii] and coal exploration and other operations starting in 2021.[29] However, this announcement does not include the UK's domestic oil and gas exploration.[30] Some countries also have begun engaging in so-called "subsidy swaps" that shift public funding away from fossil fuels to more sustainable alternatives.[31] (→ *See Sidebar 4.*)

i A zero-emission vehicle, or ZEV, is a vehicle that does not produce any direct tailpipe emissions. ZEVs may have a conventional internal combustion engine but also must be able to operate without using it. ZEVs include battery electric vehicles, hydrogen fuel cell vehicles and plug-in hybrid electric vehicles.

ii Cities include the Australian Capital Territory (Canberra) (ZEVs by 2021); London (100% zero-emission transport by 2050); Los Angeles (100% ZEVs by 2050); New York City (100% ZEVs by 2050); San Francisco (electrify all private forms of transport); and Toronto (all transport in the city to be low carbon).

iii Exceptions will be made for some natural gas-fired power plants.

SIDEBAR 4. "Subsidy Swaps" as a Means to Shift Financial Support Towards Renewables

Across the energy sector, technologies that enjoy access to grants, tax breaks and other forms of government support have a clear market advantage over those that do not. Direct subsidies to the oil, gas and coal industries amounted to more than USD 478 billion globally in 2019, and both direct and indirect[i] subsidies for fossil fuel production have continued to grow, increasing an estimated 38% or more that year. In the lead-up to the fifth anniversary of the Paris Agreement, in December 2020 a group of 10 governments[ii] spanning nearly all continents released a joint statement calling on world leaders to phase out fossil fuel subsidies.

Some fossil fuel subsidy schemes are designed to offset the falling margins and loss of competitiveness that fossil fuels have experienced in the face of ever-lower renewable energy costs. These subsidies have impeded the rapid transition to renewables that is necessary to achieve global climate and development goals. However, in recent years momentum has grown behind the idea of accelerating the transition through so-called subsidy swaps that shift public funding away from fossil fuels, which are increasingly seen as detrimental to both public health and the environment. (→ *See Feature chapter in GSR 2020.*)

Subsidy swaps generally involve elements of the following:

- reducing and removing fossil fuel subsidies and/or increasingly taxing fossil fuels;
- generating a greater share of tax revenues from environmental taxation (e.g., carbon pricing policies);
- reallocating a share of savings and tax revenues to renewable energy, energy efficiency and related infrastructure;
- mitigating negative social impacts through allocations targeted at specific population groups[iii]; and
- ensuring that all reallocations of funds are broadly supportive of an energy transition.

Many of these measures are reflected in the wider trends in power generation capacity in recent years. Since 2015, net installations of renewable capacity have outpaced those of both fossil fuel and nuclear power capacity combined. (→ *See Global Overview chapter.*)

Although most subsidies tend to be captured by the rich, efforts to reform fuel subsidies that support lower-income groups (such as subsidised heating oil) can sometimes be controversial. Rises in fuel prices could end up being regressive (having a greater impact on those with lower incomes) and risk reducing people's ability to meet basic energy needs. Through the design of adequate complementary measures, however, fossil fuel subsidies can be removed without limiting energy access. For example, a subsidy swap from kerosene to solar lighting can benefit poorer households while also lowering emissions, reducing reliance on fossil fuels and improving health through cleaner air.

India's subsidy policy has broadly followed the logic of a subsidy swap. One analysis found that the country's subsidies for all energy types fell from USD 35 billion in 2014 to USD 26 billion in 2019. Over this period, the energy subsidies that remained were increasingly allocated towards "clean energy" and transport. India has been able to lower subsidies for kerosene, a key fuel for poor households, in part by better targeting the beneficiaries of support for alternative fuels, in combination with expanding electrification and clean cooking. Although the Indian government has set a target for 450 GW of renewable energy capacity by 2030, fossil fuel subsidies in the country are still greater than financial support for renewables.

During 2020, some government responses to the COVID-19 crisis became a testing ground for the subsidy swap approach. Recovery packages have the potential to greatly shape future energy systems, as subsidies and bailouts could either derail or accelerate the energy transition. International organisations have called for using post-pandemic recovery packages as an opportunity to phase out fossil fuel subsidies, although so far very few governments have acted on this advice. Most new and amended energy policies introduced in 2020 sent a mixed signal: while there was a great deal of support for renewables in some recovery packages, many governments chose to further prop up fossil fuels. (→ *See Sidebar 3 in this chapter.*)

i Direct subsidies involve actual payment of funds to individuals and/or industries, while indirect subsidies do not involve actual cash outlays but encompass other financial benefits such as price reductions.

ii Costa Rica, Denmark, Ethiopia, Finland, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and Uruguay.

iii For example, targeted allocations could include "lifeline" tariffs for those identified as lacking basic energy access, grants for renewable energy systems for those not connected to the grid, or reducing income taxes for low-income earners funded by reforming fossil fuel subsidies. See International Institute for Sustainable Development, *Getting on Target: Accelerating Energy Access Through Fossil Fuel Subsidy Reform* (Winnipeg, Canada: 2018), https://www.iisd.org/system/files/publications/getting-target-accelerating-energy-access.pdf.

Source: IISD. See endnote 31 for this chapter.

CLIMATE PLANS THAT DIRECTLY SUPPORT RENEWABLES

While most climate change policies do not include renewable energy support directly, in some cases, climate change policies are designed to directly stimulate the deployment of renewables. During 2020, at least six governments at the regional, national and/or provincial or state levels adopted comprehensive, cross-sectoral climate policies that included direct support for renewables, in addition to elements of one or more of the indirect support policies mentioned previously.

For example, the **EU**'s 2020 commitment to reduce greenhouse gas emissions 55% by 2030 included earmarking EUR 1 trillion (USD 1.2 trillion) in funding for the European Green New Deal.[32] This strategy aims to transform Europe into a climate-neutral continent by 2050 by undertaking actions across all parts of the economy, including investing in renewable electricity generation, renewables in buildings and electrification of transport (which would facilitate increased renewable electricity in the sector)[i].[33]

At the country level, France and the United Kingdom also committed to various renewable energy policies as part of comprehensive climate change plans. France's new national energy plan (Programmation pluriannuelle de l'énergie) includes targets for renewable generation capacity for 2023 and 2028, a target for renewable hydrogen[ii] to comprise 10% of the industrial hydrogen mix by 2023 (and 20-40% by 2028), targets for energy efficiency in buildings, and targets of 660,000 EVs by 2023 (and 3 million by 2028) and 100,000 public EV charging stations by 2023.[34]

The United Kingdom's "10 point plan" for a green industrial revolution allocates around GBP 12 billion (USD 16 billion) in government investments to decarbonise the country.[35] It includes an offshore wind power target of 40 GW by 2030 (up from the 10 GW installed currently) in addition to providing GBP 1.3 billion (USD 1.8 billion) for EV charging infrastructure, grants for zero- or ultra-low-emission vehicles, funding for cutting emissions from aviation and maritime activities, funding for energy efficiency for homes and public buildings, and a new target to install 600,000 heat pumps in homes and public buildings.[36] In addition, the plan calls for phasing out sales of new petrol and diesel cars and vans by 2030 (moved up from the previous target year of 2035).[37]

During 2020,
only 6 governments
adopted comprehensive, cross-sectoral climate policies that included direct support for renewables.

In **Asia**, the Republic of Korea's Green New Deal outlines plans for the country to reach its 2050 target for carbon-neutrality.[38] They include introducing a carbon tax, expanding solar PV and wind power capacity to 42.7 GW by 2025 (up from 12.7 GW in 2019), installing solar PV on 225,000 public buildings, targeting 1.13 million EVs and 200,000 hydrogen-powered vehicles by 2025, providing funding for 45,000 EV recharging stations and 450 hydrogen refuelling units, and installing 4,000 public EV charging stations and 65 hydrogen charging stations by 2035.[39]

In **Africa**, Zimbabwe launched new renewable energy and biofuels policies to guide investments in renewables as a way to achieve the country's target of a 33% reduction in greenhouse gas emissions (compared to business as usual) by 2030.[40] The National Renewable Energy Policy includes a target of 1.1 GW of installed renewable electricity capacity by 2025 (or 16.5% of the country's total electricity supply) and 2.1 GW by 2030, along with tax breaks for renewable generation facilities and a requirement for all new buildings to host solar PV systems.[41] The Biofuels Policy commits to an ethanol blending mandate of up to 20% by 2030 and the introduction of biodiesel blending of up to 2% by 2030.[42]

In **North America**, Canada released a climate plan that includes a commitment to increase the carbon tax from CAD 50 (USD 39) per tonne in 2022 to CAD 170 (USD 133) per tonne by 2030, as well as CAD 15 billion (USD 11.7 billion) in funding for buildings, industry and transport.[43] The Canadian province of Quebec adopted a CAD 6.7 billion (USD 5.2 billion) climate change plan that includes a target to reduce emissions 37.5% below 1990 levels by 2030, a target of carbon neutrality by 2050, a ban on sales of new petrol passenger vehicles (cars, sport utility vehicles, vans and pick-up trucks for personal use) by 2035, targets for EVs and biofuels in transport, and funding for renewable heating and cooling in buildings.[44]

i EU Member States had to submit by 1 January 2020 their first long-term strategies covering specific sector plans, including electricity, industry, transport, heating/cooling and buildings, agriculture, waste and land use, and land-use change and forestry.

ii See Glossary.

HEATING AND COOLING IN BUILDINGS

The buildings sector – including both commercial and residential buildings – is a significant energy end use and contributor to global greenhouse gas emissions.[45] Energy is consumed in buildings for climate control (space heating and cooling), water heating, cooking, lighting, and the powering of appliances and electronics. A variety of policies exist at the national and provincial/state levels related to direct and indirect heating and cooling with renewables, including thermal renewable energy (geothermal, solar thermal), biomass-based energy and renewable electricity (which can be used to power heating and cooling appliances such as heat pumps) (→ *see Power section in this chapter*).

Heating and cooling demand in buildings accounts for around 25% of total final energy consumption, and although most of this consumption is currently met by fossil fuels, there is significant potential for greater use of renewables.[46] Bioenergy (including renewable gases[i]) is the largest renewable source of heating and cooling in buildings[ii] today, but other sources include geothermal and solar thermal energy, as well as renewable electricity[iii].[47] Despite the vast potential of renewables, policies designed to advance their use in heating and cooling remain less common than those in the power or transport sectors.

Policy makers can advance the production and use of renewable energy to heat and cool buildings through legislated targets, financial incentives, mandates (including building energy codes), policies that support the electrification of heating and cooling, and policies that support renewable district heating. Policies that indirectly encourage renewable heating and cooling include fossil fuel bans or phase-outs, fuel taxes and net zero emission standards for buildings. (→ *See Renewable Energy and Climate Change Policies section in this chapter.*)

In 2020, as in previous years, policy developments in heating and cooling for buildings remained scarcer than policies directed at electricity generation and transport. Although some developments occurred (including financial incentives, energy efficiency and electrification of heating and cooling), by year's end only 19 countries had committed to **renewable heating and/or cooling targets** for buildings (down from 49 countries in 2019, due to 2020 targets coming to term without being replaced by later targets), whereas 137 countries had renewable power targets.[48] Meanwhile, only 10 countries had renewable heat support policies covering all sectors (residential, industrial, commercial and public facilities) by the end of the year. (→ *See Figure 13, and **Reference Tables R4, R6 and R9** in GSR 2021 Data Pack.*) Interest in cooling has increased with the rising demand for cooling, particularly in developing countries, but this has not yet translated into more policies and targets for renewable cooling.[49] **Financial incentives for buildings** – including grants, rebates, tax incentives and loan programmes – were the most commonly used measures to encourage renewable heating and cooling in buildings during 2020. (→ ***See Reference Table R9** in GSR 2021 Data Pack.*) All of the new developments occurred in Europe. For example, Italy raised the tax-deductible "eco-bonus" benefit for building insulation and replacement of heating and cooling systems in apartment buildings and family homes (from 50% to 110%) and extended the benefit to the end of 2022.[50] Lithuania provided EUR 14 million (USD 17 million) to reimburse building owners who convert old, inefficient boilers to more energy-efficient installations that use renewable heat sources (including biofuel boilers and heat pumps).[51]

The Netherlands' subsidy programme scheme for renewables (Renewable Energy Production Incentive Scheme, SDE++), which compensates for the difference between the cost of the technologies and the market value of the product, was broadened to include renewable heat (such as geothermal, biomass and solar thermal systems).[52] Scotland provided GBP 1 million (USD 1.4 million) for projects using "low-carbon" heat and/or renewable electricity solutions for buildings, and the United Kingdom extended its Domestic Renewable Heat Incentive Scheme to 31 March 2022.[53] Portugal launched a new EUR 4.5 million (USD 5.5 million) energy efficiency programme that provides incentives for decarbonisation and energy efficiency in buildings, including to retrofit them with renewables.[54]

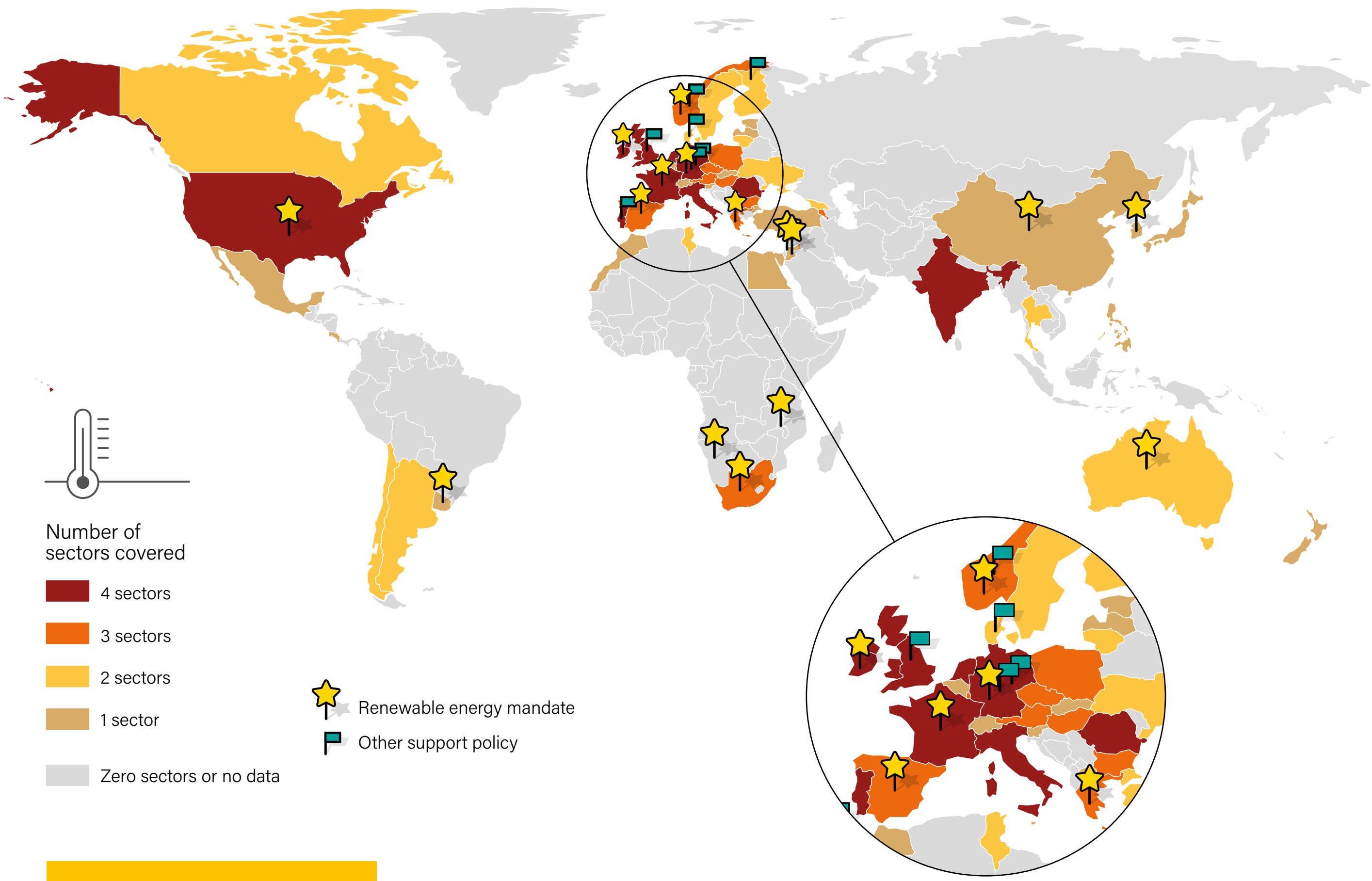
Mandatory **building energy codes** that require the deployment of renewable energy systems can play a key role in the uptake of renewable heating and cooling, particularly in new construction and retrofits.[55] Even when renewables are not explicitly required in building energy codes, these codes can have a positive effect on the energy demand of buildings because they typically require energy efficiency improvements.[56] By the end of 2020, 67 countries had in place mandatory or voluntary building energy codes (down from 73 in 2019).[57] At least 40 countries have mandatory codes for both residential and non-residential buildings.[58]

i Renewable gases include biogas, biomethane, renewable natural gas and renewable hydrogen produced from renewable electricity (electrolysis). Because renewable gases can replace fossil gas, they can leverage existing gas networks.

ii Mainly through the use of wood and pellet stoves and boilers and in district heating networks.

iii The electrification of heating is only renewable to the extent that the electricity used is generated from renewable sources.

FIGURE 13.
Sectoral Coverage of National Renewable Heating and Cooling Financial and Regulatory Policies, as of End-2020



Only
10 countries
had renewable heat support policies covering all sectors as of end-2020.

Note: Sectors include residential, industrial, commercial and public facilities. Policy types used for map shading include investment subsidies/grants, rebates, tax credits, tax deductions, loans and feed-in tariffs. Renewable energy mandates are the obligation to meet a certain renewable standard for heat, such as the use of a specified technology. Other support policies include fossil fuel bans, support for phasing out fossil fuels, CO_2 pricing for heat and support for R&D. Figure does not show policies at the local level; for local level data, see REN21 *Renewables in Cities Global Status Report*, www.ren21.net/cities.

Source: REN21 Policy Database. See Reference Table R9 in GSR 2021 Data Pack.

While not all of the codes included renewable energy requirements, at least 2 new renewable energy requirements were added to building energy codes in 2020 (in contrast to 2019 when no such requirements were added), only at the sub-national level. A requirement adopted in 2018 for all new homes in California to be equipped with solar panels came into effect in 2020, while the state of Washington announced additional energy credit options for builders incorporating solar power.[59] Conversely, some jurisdictions added restrictions for renewable energy in their building codes, such as Minnesota, which prohibits placing solar panels within 0.9 metres of a roof edge as a safety precaution – a measure that is estimated to shrink the available space for solar PV by at least 20%.[60]

Electrification of heating and cooling can increase the penetration of renewables in the buildings sector if the electricity used is generated from renewable sources. Globally, electrification of heating and cooling is increasing, with around 11% of global electricity generation used by electric heaters, boilers and heat pumps for buildings.[61] In 2020, policy makers gave greater attention to policies targeting the electrification of heating and cooling in buildings. Denmark provided tax incentives for the use of renewable electricity to heat buildings (while also raising taxes on fossil fuels for heating) and allocated DKK 2.3 billion (USD 0.38 billion) for the replacement of oil and natural gas boilers with renewable heat.[62]

At a sub-national level, British Columbia (Canada), which generated nearly 95% of its electricity from renewables in 2020, temporarily doubled rebates for residential heat pumps.[63] In the United States, California provided USD 45 million for electric heat pump water heaters, and New Mexico reinstated a USD 6,000 tax credit for households and businesses to install solar PV panels or solar thermal systems to heat water.[64] The Australian

Capital Territory committed AUD 500 million (USD 383 million) to build a hospital powered entirely with renewables, including a 100% renewable electric heating and cooling system.[65]

Renewable district heating can provide an entry point for renewables to reach end-users. In 2020, the European Commission approved a EUR 150 million (USD 184 million) programme to support the conversion of district heating systems in Romania from fossil fuels to renewables.[66] Poland launched a programme offering owners of district heating networks co-financing in the form of grants and loans to add renewable energy or waste heat to their systems.[67]

Policies targeting **energy efficiency** often are cost-effective options for decreasing the thermal demand of buildings.[68] In 2020, the EU launched a "renovation wave" that aims to reduce building emissions 60% by 2030 by doubling the yearly rate of energy-related building renovations.[69] The renovation wave includes an acknowledgement of the contribution of on-site renewables to achieve higher energy efficiency requirements.[70] Another European initiative, set to begin in 2022, is intended to facilitate collaboration between experts and entrepreneurs on buildings, including energy efficiency.[71] In the United Kingdom, England's new Green Homes Grant scheme provides homeowners the opportunity to receive a government subsidy for two-thirds of the cost of energy efficiency improvements[i].[72]

Israel's new national energy efficiency plan includes funding to make buildings more energy efficient over the next 10 years, including by ensuring that imported electrical products are more energy efficient, integrating energy ratings into new buildings and requiring contractors to publish energy efficiency ratings when they sell.[73] At a sub-national level, the US state of Washington implemented a Property Assessed Clean Energy (PACE)[ii] loan programme to finance energy efficiency and renewable energy retrofits for existing and new buildings.[74]

INDUSTRY

In addition to using electricity, some industrial processes utilise thermal energy (heat) to meet various needs. Like buildings, thermal energy demand (both direct thermal energy and electricity for heat) in industrial processes accounts for around 25% of global final energy consumption.[75] This demand can be met directly by thermal energy from renewables (including biomass, solar thermal and geothermal energy) or indirectly from renewable electricity, for example via heat pumps (provided that the electricity used is generated from renewable sources). Renewable hydrogen also can be used to meet certain energy demands in industry[iii].[76] (→ *See Sidebar 5 and Table 5.*) Currently, bioenergy accounts for nearly all of the renewable heat use in industry (almost 90% in 2019).[77]

Renewable energy solutions to provide low-temperature heat for industrial uses are widely available. However, for industries that require high-temperature heat, such as steel and cement, renewable technologies have not yet reached scale to be competitive with fossil fuels. Thus, government support through policy, targets, and research, development and demonstration (RD&D) remains important. Nevertheless, by the end of 2020, only 32 countries had some form of renewable heating and cooling policy for industry (unchanged from 2019). (➔ ***See Reference Table R9*** *in GSR 2021 Data Pack.*)

The most common form of policy support during 2020 was **financial incentives**. For example, the United Kingdom offered GBP 139 million (USD 189 million) to support industry efforts to cut greenhouse gas emissions, including switching from fossil-based gas to renewable hydrogen for fuel-heavy industry.[78] The Netherlands offered a subsidy for companies in the industrial sector to generate renewable electricity, heat and gas for their own use.[79] Denmark allocated DKK 2.5 billion (USD 413 million) in subsidies for 10 years for electrification and energy efficiency improvements in industry, as well as DKK 2.9 billion (USD 479 million) for biogas and other renewable gases for those parts of industry where renewable electricity cannot be utilised directly.[80] Although not specific to industry, Scotland announced interest-free loans of GBP 1,000 to GBP 100,000 (USD 1,358 to USD 135,772) for small and medium-sized enterprises to install renewables for heating (including biomass boilers, solar thermal technologies and electric heat pumps).[81]

In the agricultural sector, most policy during the year was aimed at improving irrigation systems. Jamaica committed to powering all irrigation systems operated by the National Irrigation Commission solely with solar PV within two years.[82] Egypt announced plans to invest EGP 184 million (USD 11.6 million) to modernise several irrigation systems, including equipping them with solar PV to improve electricity supply.[83] Canada, as part of its new climate plan, committed to investing CAD 166 million (USD 130 million) to support its agriculture sector to develop "clean technologies" (including renewables).[84]

i Up to a maximum of GBP 5,000 (USD 6,788) per household, or up to GBP 10,000 (USD 13,577) for low-income homeowners.

ii See Glossary.

iii In some cases, hydrogen also can be used as a feedstock for chemical processes.

SIDEBAR 5. Policy Support for Renewable Hydrogen

Renewable hydrogen is an energy carrier produced through renewables-driven electrolysis or gasification using renewable feedstocks. Hydrogen can either be combusted directly for use in heat or transport, or used to generate electricity via fuel cells. Apart from its potential to be stored and converted to electricity when needed, hydrogen provides an opportunity to increase the penetration of renewables beyond the power sector, mainly in industry and transport but also in buildings. (→ *See Systems Integration chapter.*) In 2020, nearly all hydrogen produced and used worldwide continued to be manufactured with natural gas for use as an industrial feedstock.

A number of governments made policy announcements during the year in support of hydrogen, although not all of these committed to pursuing renewable hydrogen[i]. However, several notable policy developments related to renewable hydrogen occurred, particularly in Europe and Australia (as in 2019) but also in Latin America.

In Europe, the EU introduced a new hydrogen strategy, including a goal of 6 GW of electrolyser capacity powered by renewable electricity by 2024 and 40 GW of renewable hydrogen electrolyser capacity by 2030[ii]. Germany launched its own hydrogen strategy, including plans to increase hydrogen production capacity to 5 GW by 2030 and 10 GW by 2040 using surplus electricity from renewable energy sources. Germany also committed to investing up to EUR 7 billion (USD 8.6 billion) to promote renewable hydrogen production and use.

The United Kingdom announced GBP 28 million (USD 38 million) in funding for five hydrogen production projects, one focused on using offshore wind power to generate renewable hydrogen. Norway allocated NOK 3.6 billion (USD 420 million) to support the move from "grey" hydrogen (produced from fossil fuels) to "blue" hydrogen (fossil fuels with carbon capture and storage) and finally to "green" hydrogen (renewable hydrogen). Spain unveiled a plan to boost renewable hydrogen production and set a target of 300-600 MW of capacity by 2024 and 4 GW by 2030. Scotland announced GBP 100 million (USD 136 million) for new electrolysers and set a target for 25 GW of renewable hydrogen by 2050.

In Australia, the government committed AUD 70 million (USD 54 million) to support the deployment of at least two new renewable hydrogen projects and established a new AUD 300 million (USD 230 million) fund to invest in the country's renewable hydrogen industry. At a state level, Tasmania announced a Renewable Hydrogen Action Plan and AUD 50 million (USD 38 million) for renewable hydrogen; the Northern Territory unveiled a strategy to become a hub for renewable hydrogen technology research, production and manufacturing; and Queensland announced AUD 10 million (USD 7.7 million) over four years (in addition to the original AUD 15 million (USD 12 million) Hydrogen Development Fund) to support the renewable hydrogen industry.

In Latin America, Chile unveiled a national green hydrogen strategy that aims to develop the country into a global producer and exporter by 2040. The strategy consists of a commitment to develop regulation for the use and production of renewable hydrogen, to analyse global best practices related to renewable hydrogen, and to convene government and the private sector to develop a roadmap and action plan by 2025 that will identify cofinancing opportunities with the private sector. Chile's strategy also updates the country's NDC by setting out a target for renewable hydrogen to reduce greenhouse gas emissions 18-27% by replacing fossil fuels.

i For example, Canada and France developed national hydrogen strategies but did not commit to the development of renewable hydrogen specifically.

ii By 2030, the EU wants 40 GW of electrolysers installed within its borders and another 40 GW in place in nearby countries that can export to the EU. The EU's strategy does not shut out "blue hydrogen" (fossil-based hydrogen with carbon capture and storage) as a means of phasing in hydrogen while the cost of renewable hydrogen decreases.

Source: See endnote 76 for this chapter.

TABLE 5.
Targets and Policies for Renewable Hydrogen, 2020

Note: This table includes details only on *renewable* hydrogen targets and policies. For additional details, see GSR 2021 Data Pack.

Jurisdiction	Target	Policy/Programme
European Union	6 GW electrolyser capacity and 1 million tonnes production by 2024; 40 GW and 10 million tonnes by 2030	**Hydrogen Strategy** provides framework to establish **European Clean Hydrogen Alliance**, including an investment agenda and support for scaling up value chain. The strategy targets production as well as end-use in industry.
Australia		**Renewable Hydrogen Deployment Funding Round** will provide AUD 70 million (USD 54 million) to support at least two projects. **Advancing Hydrogen Fund** of AUD 300 million (USD 230 million) supports new projects nationwide.
New South Wales		**Electricity Investment Bill** includes AUD 50 million (USD 38 million) over 10 years to develop renewable hydrogen sector. Parts of NSW will be designated renewable energy zones.
Northern Territory		**Renewable Hydrogen Strategy** outlines a plan for development of local industry, resource management infrastructure, fostering demand for exports and domestic applications, support for innovation and regulation to guide industry.
South Australia		AUD 17 million (USD 13 million) in grants and AUD 25 million (USD 19 million) in loans provided to four projects. **Hydrogen Action Plan** outlines plan to facilitate investments in infrastructure; establish regulatory framework; and support trade, supply capabilities, innovation, workforce development and energy system integration.
Tasmania	Production to start by 2022	**Renewable Hydrogen Industry Development Funding Program** allocates AUD 50 million (USD 38 million) to support industry development, including financial assistance for renewable electricity supply and concessional loans.
Victoria		**Hydrogen Investment Program** supports development of industry through market testing, policy development and targeted investment programme.
Western Australia	Up to 10% blend in gas pipelines and networks by 2030	**Renewable Hydrogen Strategy and Roadmap** include funding for grants to study production for export, use in mining operations, blending with natural gas and use as transport fuel.
Queensland		**Hydrogen Strategy** includes the AUD 15 million (USD 11 million) **Hydrogen Industry Development Fund**, providing funding for investors developing projects to increase supply of renewable hydrogen.
Canada		
Quebec		Hydro-Quebec's (public utility) **Strategic Plan 2020-24** supports R&D for production using hydroelectricity.
Chile	5 GW electrolyser capacity and 200 kilotonnes of production by 2025; 25 GW by 2030	Up to USD 50 million to help finance pilot projects that may not be initially competitive while operating at a small scale. A task force will help with provision of permits and development of pilot programmes.
France[1]	6.5 GW electrolyser capacity; 20-40% renewable by 2030; 10% renewable in industry by 2023	EUR 2 billion (USD 2.5 billion) from its coronavirus recovery plan by 2022 for pilot and regional projects, and EUR 7 billion (USD 8.6 billion) for development of industry by 2030.
Germany	5 GW electrolyser capacity and 14 TWh production per year by 2030; 10 GW and 28 TWh production per year by 2035-2040	**National Hydrogen Strategy** includes EUR 310 million (USD 380 million) by 2023 for research and innovation; EUR 9 billion (USD 11 billion) to stimulate use in transport, industry, heating and other applications; and EUR 7 billion (USD 8.6 billion) to increase capacity.
Netherlands	0.5 GW electrolyser capacity by 2025; 3 to 4 GW by 2030	**SDE++ (Stimulation of Sustainable Energy Transition)** subsidy scheme extended to include renewable hydrogen production.
Northern Netherlands	6 GW electrolyser capacity by 2024; 40 GW by 2030	
Norway		A portion of NOK 3.6 billion (USD 380 million) green restructuring package to support renewable hydrogen projects.
Portugal	10% to 15% in natural gas networks; 2 GW to 2.5 GW electrolyser capacity; 50 to 100 fuelling stations by 2030	EUR 7 billion (USD 8.6 billion) investment in renewable hydrogen by 2030.
Spain	4 GW electrolyser capacity and 25% in industry by 2030	EUR 1.5 billion (USD 1.8 billion) support for the period 2021-2023.
United Kingdom	5 GW electrolyser capacity by 2030	GBP 12 billion (USD 15 billion) plan to heat homes with renewable hydrogen. **Hydrogen Supply programme** allocates a portion of GBP 28 million (USD 36.5 million) for two projects.
United States		USD 64 million for 18 projects.

1 France's targets are for "decarbonised" hydrogen, which may include hydrogen produced by nuclear energy.

Source: See GSR 2021 Data Pack at www.ren21.net/gsr-2021.

TRANSPORT

Globally, the transport sector has the lowest share of renewable energy and accounts for around one-quarter of global energy-related greenhouse gas emissions.[85] Although renewable energy policies in the sector have been expanding, most policies continue to focus on road transport, with few directly supporting renewables in rail, aviation and shipping. As of the end of 2020, the share of renewables in the transport sector was 3.7%, unchanged from the year before. (→ *See Global Overview chapter.*) This section covers renewable energy transport policies enacted at the national and provincial/state levels. (→ ***See Reference Table R8*** *in GSR 2021 Data Pack.*)

ROAD TRANSPORT

Polices to incentivise renewables in road transport include policies directly supporting biofuels and the use of renewable electricity in electric vehicles, as well as some climate change policies, such as fossil fuel bans, carbon pricing and requirements for "zero-emission" vehicles. (→ *For climate policies that support renewables, see Renewable Energy and Climate Change Policy section in this chapter.*)

Biofuels in Road Transport

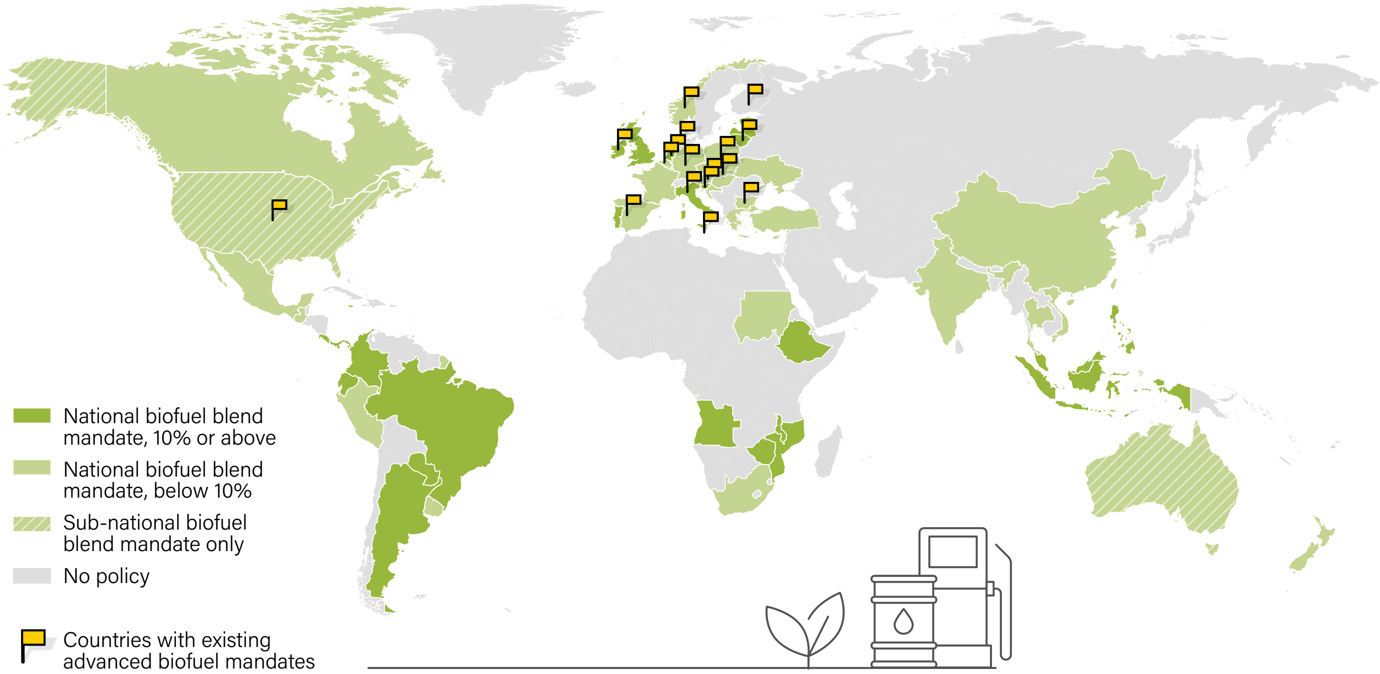
In 2020, biofuels continued to make the largest contribution of renewable energy to the road transport sector. Policies supporting the production or use of biofuels include biofuel blending targets, biofuel blending mandates, support for advanced biofuels, financial incentives, public procurement programmes, and support for biofuel production, fuelling and blending infrastructure.

At least three new **biofuel blending targets** were announced in 2020. The United States set a target for biofuels to make up 15% of US transport fuels by 2030 and 30% by 2050.[86] Zimbabwe launched a national biofuels policy, which includes targets for ethanol blending of up to 20% and for biodiesel blending of up to 2% by 2030.[87] Paraguay established a law requiring biodiesel blending of 4% in 2021 and 5% in 2022, up from 3% in 2020.[88]

Biofuel blending mandates remained the most widely used policies for ensuring renewable content in road transport. Overall, 65 countries had blending mandates as of the end of 2020 (unchanged since 2017). (→ *See Figure 14 and* ***Reference Table R8*** *in GSR 2021 Data Pack.*) While no new countries added biofuel blending mandates during 2020, some that already had a policy either added new mandates or targets or strengthened existing ones.

At least 28 countries revised their existing mandates during the year. Early in 2020, Brazil increased its minimum biodiesel blend from 11% to 12% (although, as a result of the COVID-19 crisis, the country later temporarily reduced it to 10%).[89] Belgium increased its biofuel blending mandate from 8.5% to 9.55%, while Cyprus raised its mandate from 5% to 7.3%.[90] Indonesia increased its biofuel blending mandate to 30%, up from 20%.[91] At the sub-national level, Ontario (Canada) raised its petrol blending mandate from 5% to 10%.[92]

FIGURE 14.
National and Sub-National Renewable Transport Mandates, End-2020



Note: Shading shows countries and states/provinces with mandates for either biodiesel, ethanol or both.
Source: REN21 Policy Database. See Reference Table R8 in GSR 2021 Data Pack.

By the end of 2020, 11 countries (and the EU) had targets in place for **advanced biofuels** (up from 10 countries in 2019), and 17 countries had mandates in place for advanced biofuels. (→ ***See Reference Table R8*** *in GSR 2021 Data Pack.*) Only one new country, Latvia, adopted an advanced biofuels target in 2020: the country's national energy and climate plan (NECP) included a target of 3.5% advanced biofuels and biogas in the transport sector's final energy consumption by 2030.[93]

Financial incentives supporting the production and use of biofuels are less common than blending mandates but were extended in some countries. Sweden extended its tax exemption for liquid biofuels to the end of 2021, and Iowa (US) extended a fuel tax incentive for diesel sold in the state containing at least 11% biodiesel.[94] Thailand announced plans to revoke the seven-year time frame for ending biofuel subsidies and to instead maintain the subsidies until sometime between 2022 and 2026.[95]

Some jurisdictions implemented **public procurement programmes** to support biofuels. At the national level, the Finnish postal service committed to using renewable diesel to fuel its light delivery fleet.[96] Additional public procurement initiatives related to transport took place at the local level, although more often for EVs than for biofuels. (→ *See Renewables in Cities 2021 Global Status Report.*)

Some jurisdictions promote biofuels for road transport by **supporting biofuel production and infrastructure**. In 2020, Paraguay's government granted "Free Zone"[i] treatment for an advanced biofuels plant to produce renewable diesel and renewable aviation kerosene.[97] Brazil's RenovaBio programme became fully operational in 2020, with decarbonisation credits being sold in the nation's stock exchange.[98]

The United Kingdom announced funding for four plants producing advanced biofuels.[99] The United States committed up to USD 75 million over five years for research on sustainable bioenergy crops, and up to USD 100 million for ethanol and biodiesel transport fuelling and biodiesel distribution facilities.[100] At a sub-national level, Iowa committed USD 3 million to its biofuel infrastructure programme for 2021.[101]

Electric Vehicles

Electric vehicle[ii] policies became increasingly popular in 2020. Although these are not renewable energy policies by themselves, EVs can increase the penetration of renewables in transport to the extent that the electricity used to charge them is generated from renewable sources. Policies to support EVs include targets, financial incentives, public procurement, funding for charging infrastructure, free parking and preferred access for EVs. Financial incentives and support for EV charging were the most common forms of EV policy implemented during 2020. (→ ***See Reference Table R8*** *in GSR 2021 Data Pack.*)

As in 2019, most of the EV policies implemented in 2020 lacked a **direct link to renewable electricity**, although the number of policies that do have a direct link increased from two countries to three[iii] by year's end. Japan announced plans to increase subsidies for EVs under the condition that the vehicles are charged with renewable electricity – a policy type that previously was found only in Austria.[102] Additional support linking EVs to renewable electricity occurred through state-owned and -operated transport companies. India's West Bengal Transport Corporation committed to using solar PV electricity to recharge its EVs.[103] In the United States, the Delaware Transit Corporation provided USD 3.1 million to install solar PV at its operations facility to help power electric buses.[104]

In jurisdictions with high shares of grid-connected renewable electricity, EV policies and targets can indirectly support renewable energy use in the transport sector even if not directly linked in the same policy, as long as the jurisdiction is simultaneously targeting increasing shares of renewable electricity.

By the end of 2020, at least 52 national or state/provincial jurisdictions had targets for EVs, up from 38 in 2019, although not always also targeting high renewable electricity shares.[105] (→ *See Figure 15, and* ***Reference Tables R8 and R6*** *in GSR 2021 Data Pack.*) At least 19 jurisdictions had targets for full bans on sales of internal combustion engine vehicles (or for 100% sales of EVs), including two adopted during 2020. (→ *See Renewable Energy and Climate Change Policy section in this chapter.*) At least 31 other jurisdictions had lower targets for EVs, including 6 adopted during 2020. Pakistan launched a plan to bring 500,000 electric motorcycles and rickshaws and more than 100,000 electric cars, buses and trucks into its transport system by 2025, with a target of 30% of all vehicles running on electricity by 2030.[106] Denmark committed to a target of at least 775,000 electric or hybrid cars by 2030.[107]

By the end of 2020, only 11 countries had targets in place for **advanced biofuels.**

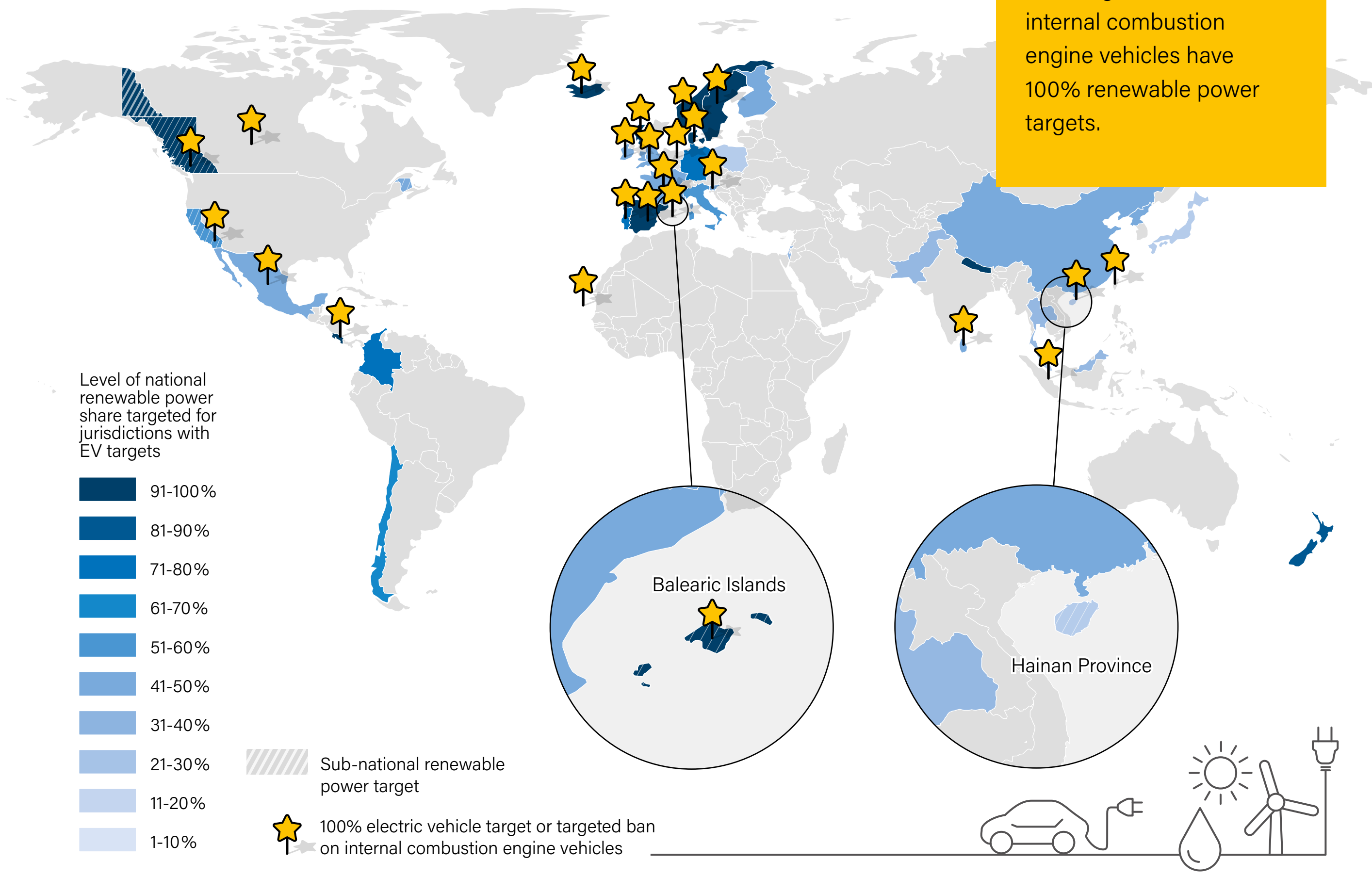
i The Free Zone guarantees the maintenance of the legal conditions of the project for 30 years and contributes to the competitiveness of the project.

ii In this section, EVs are defined as battery electric vehicles and plug-in hybrids.

iii Austria, Germany and Japan

Only
8 countries
with targeted bans on internal combustion engine vehicles have 100% renewable power targets.

FIGURE 15.
Targets for Renewable Power and Electric Vehicles, as of End-2020



Note: Renewable power targets include only targets for a specific share of electricity generation by a future year. Where a jurisdiction has multiple targets, the highest target is shown. Nepal and Quebec show actual renewable power shares; both jurisdictions along with Iceland and Norway have already achieved nearly 100% renewable power. Electric vehicle targets vary; for details, see Reference Tables R6 and R8 in GSR 2021 Data Pack.

Source: REN21 Policy Database. See Reference Tables R6 and R8 in GSR 2021 Data Pack.

In 2020, several countries introduced **financial incentives for EVs** as part of their COVID-19 recovery packages. (→ *See Sidebar 3.*) Among new financial incentives for EVs that were unrelated to COVID-19, Poland introduced purchase subsidies for electric cars, vans and taxis.[108]

Several governments announced plans for **public procurement of EVs**. In Australia, the state government of New South Wales tripled its public fleet procurement targets for hybrids and EVs to around 900 new hybrid or EVs annually, with around 300 of these vehicles being all-electric.[109] The US state of New York committed to providing USD 16.4 million for its public transport authorities to procure electric buses.[110]

In 2020, at least 7 governments implemented **policies to support EV charging**. In the United States, California provided USD 233 million to install public EV charging stations, and Hawaii passed a law to provide grants for adding and upgrading charging infrastructure.[111]

Some jurisdictions developed an **integrated set of policies to promote EV adoption**. As part of its 10-year climate plan, Greece pledged EUR 100 million (USD 123 million) for purchase subsidies for EVs (including electric taxis and motorbikes) and for the installation of public EV charging stations across the country, as well as tax deductions for EV charging.[112] El Salvador enacted a new law establishing preferential tax treatment for electric and hybrid vehicles and ensuring dedicated EV parking spaces in public (and some private) lots.[113] At the sub-national level, New Jersey (US) passed a law aimed at electrifying the state's transport sector, which included a target for 85% of vehicles sold to be electric by 2040, financial incentives of up to USD 5,000 for EV purchases and a commitment to install 1,400 public EV chargers.[114]

RAIL, AVIATION, SHIPPING AND PORTS

Although rail, aviation and shipping are the fastest growing transport sectors and account for a rising share of total final energy use in transport, they continue to receive much less policy attention than road transport. This is in part because road transport remains responsible for most transport energy use, and because renewable fuel options for these other sectors remain costlier than fossil fuels.[115] Additional challenges include the fragmented, international nature of rail, aviation and shipping, which makes co-ordinated actions more difficult, and the lack of commercially available renewable technologies that can be applied cost-effectively at scale.[116]

Most renewable energy initiatives in the **rail** sector are aimed at supporting renewable electricity. In 2020, just two countries enacted new policies and targets to advance the use of renewables in rail transport. India set a target to electrify 7,000 rail kilometres by 2020-2021 and to electrify all routes on its broad-gauge rail network by 2023, while also advancing plans to integrate rising amounts of renewable power capacity for its operations as well as efficiency and other sustainability improvements.[117] France's national railway company committed to meeting a portion of its electricity needs using renewable electricity and signed a renewable electricity power purchase agreement to provide around 2% of the electricity consumption of all national passenger trains.[118] In the private sector, UK-based Network Rail became the first railway organisation to set a science-based target in line with the Paris Agreement's goal to limit global temperature rise to 1.5 degrees Celsius above pre-industrial levels.[119]

During 2020, no jurisdictions adopted new targets to advance the use of renewables in **shipping**, and only one country added renewable energy policy support in the sector. The Netherlands announced plans obliging suppliers of heavy fuel oil and diesel for inland shipping to take part in its renewable fuel scheme.[120] A few jurisdictions advanced policy support for the use of renewables in **ports**. The Spanish Port Authority of Valencia committed to building 8.5 MW of solar PV at two of its ports on Spain's coast, and Portugal and the Netherlands signed a memorandum of understanding to connect Portugal's renewable hydrogen project with a seaport in the Netherlands.[121]

Only one country had a new biofuel blending policy for **aviation** by year's end, with Norway's blending mandate of 0.5% biofuels in all aviation fuel entering into force in 2020.[122] By year's end, only four countries had biofuel targets for the aviation sector[i]. However, other plans to support renewables in aviation advanced. For example, the EU held a public consultation for its draft plan (ReFuelEU) to cut emissions 55% (replacing a previous target of 40%) and to scale up the use of renewable biojet fuel (also called sustainable aviation fuel), including through a blending mandate, auctioning mechanism, funding and monitoring.[123]

At the national level, France was in the process of adopting legislation as part of its 2021 budget that would require planes that refuel in the country to use at least 1% sustainable aviation fuel from 2022, with the blend increasing to 2% by 2025, 5% by 2030 and 50% by 2050.[124] Germany published a draft law that would require airlines to increase sustainable aviation fuel of non-biogenic origin to 0.5% by 2025, 1% by 2028 and 2% by 2030.[125] Sweden planned to introduce an emission reduction requirement for aviation fuel sold in the country of 0.8% in 2021 and increasing to 27% by 2030.[126] Meanwhile, the United Kingdom's Jet Zero Council, a public-private partnership, began supporting sustainable aviation fuel through R&D.[127]

Alongside the somewhat slow public policy support for renewables in the rail, shipping and aviation sectors, several private sector players moved forward on their own to implement initiatives and programmes to support the uptake of renewables in transport. (→ *See Transport section in Global Overview chapter.*)

i Countries with existing biofuel targets in aviation include Brazil (10% by 2030), Finland (30% by 2030), Indonesia (5% by 2025) and Norway (0.5% by 2020 and 30% by 2030)

POWER

As in previous years, the power sector continued to receive the most renewable energy policy attention in 2020. Policies to support renewable electricity generation include targets, renewable portfolio standards (RPS), feed-in policies (tariffs and premiums), auctions and tenders, renewable energy certificates (RECs, or Guarantees of Origin – GOs), net metering, financial incentives (such as grants, rebates and tax credits) and policies to encourage self-consumption – as well as various enabling policies.

A global trend in the power sector is the increasing decentralisation of power generation. The uptake of renewable distributed generation[i] is accelerating, particularly for larger commercial and industrial consumers but also for residential consumers; however, it still accounts for only a small share of electricity generation worldwide.[128]

Targets continued to be a popular form of intervention to spur investments in both centralised and distributed renewables. By the end of 2020, 137 countries had some form of renewable electricity target (down from 166 countries in 2019). (→ ***See Reference Table R6*** *in GSR 2021 Data Pack.*) In addition, many electric utilities[ii] (both private and government-owned) have set targets for increasing shares of renewable power.[129] (→ *See Box 5.*)

Of the countries and states/provinces that set new renewable power targets in 2020, 2 set targets for 100% (or more) renewable electricity. Austria's new target for 100% renewable electricity by 2030 represents an almost 50% increase of renewable electricity from 2020 levels.[130] Nauru committed to 100% renewable energy by 2050, In line with its target for net zero greenhouse gas emissions by that year.[131] At the sub-national level, the governor of Rhode Island (US) signed an executive order for renewables to provide all of the state's electricity by 2030.[132] The Australian state of Tasmania announced a renewable power target of 200% by 2040, to be fulfilled in part by exporting excess renewable power to other parts of the country.[133]

BOX 5. Utility-Led Activity to Support Renewables

In some places, electric utilities are responsible for the infrastructure needed to deliver electricity to consumers, and they may own the generation systems as well. Utilities thus have an important role to play in enabling increased uptake and integration of renewables. In some jurisdictions, utilities' roles and responsibilities are changing in response to both the proliferation of distributed energy resources and rising electrification of transport and heating.

Utilities can play a key role in encouraging the integration and use of renewables by implementing their own renewable energy targets. For example, Ørsted in Denmark set a target for more than 99% renewable energy generation by 2025 and had already reached a 75% share as of 2018. In Uruguay, UTE set a target of 100% renewable electricity generation, 98% of which was achieved by 2017. Greece's biggest power utility (51% government owned) pledged to shut down most of its coal-fired plants by 2023 and committed EUR 3.4 billion (USD 4.2 billion) to expand its use of renewables and modernise the Greek distribution grid.

At a sub-national level, by the end of 2020 at least 19 US utilities had committed to targets of 50% or 100% renewable generation in the coming decades, including at least 6 that have set net zero emission targets. While some have committed to phasing out "coal-only" plants, many still plan to continue building natural gas plants and infrastructure and are relying largely on offsets to reach net zero goals.

Source: See endnote 129 for this chapter.

i Distributed generation, also called decentralised generation, refers to generation of electricity from sources at a relatively small scale and near the point of consumption, as opposed to centralised generation sources such as large power plants. Distributed generators can be renewable (e.g., rooftop solar PV) or fossil-based (e.g., distributed natural gas generation).

ii A utility is defined as an entity engaging in the generation and/or delivery of energy (including, but not limited to, electricity and natural gas) to consumers in a specific geographical area/jurisdiction. Because utilities can be generators, distributors and retailers of energy, they often own and operate network infrastructure. Utilities can be publicly or privately held, and in many cases governments or municipalities still hold a large (or majority) stake in a private utility. Utilities traditionally have been state-owned, vertically integrated monopolies. However, since the 1990s many jurisdictions have adopted reforms including unbundling of the energy sector and liberalisation of the energy market, generally giving consumers more choice in electricity and gas suppliers.

Many other countries set targets in 2020 for renewable electricity shares lower than 100%, demonstrating the scope of ambition among governments around the world. Zimbabwe set a target for 16.5% renewable installed power capacity by 2025 and 30% by 2030.[134] Saudi Arabia announced a target of 50% renewable electricity generation by 2030, and Israel set a target of 30% renewable electricity by 2030, with an intermediate target of 20% for 2025.[135] Papua New Guinea committed in its updated NDC to raising the share of grid-connected renewable power capacity from 30% in 2015 to 78% in 2030 (although down from its earlier target of 100% renewable electricity by 2030), conditional upon funding support from other nations.[136]

In Asia, the Republic of Korea's ninth long-term energy plan included targets for expanding the share of renewables in the electricity mix from 15.1% in 2020 to 40% by 2034.[137] Japan announced a target for 50% renewable electricity generation by 2050 as a means of achieving its carbon neutrality goal.[138] In Uzbekistan, a new strategy on electrical generation includes targeted shares of 8% solar power and 7% wind power in total electricity generation by 2030.[139]

Several targets were set or revised in Europe. The United Kingdom announced a new wind power capacity goal that boosts the previous target for 30 GW of offshore wind by 2030 to 40 GW.[140] Hungary's new climate change strategy sets a target for 90% fossil fuel-free electricity production by 2030 (to be achieved through nuclear as well as renewable power).[141] Regionally, the EU raised its offshore wind power capacity target to 60 GW by 2030 (up from the existing 2020 capacity of 25 GW) and 300 GW by 2050, and set targets for ocean power capacity of 1 GW by 2030 and 40 GW by 2050 (up from the existing 2020 capacity of around 11 MW).[142]

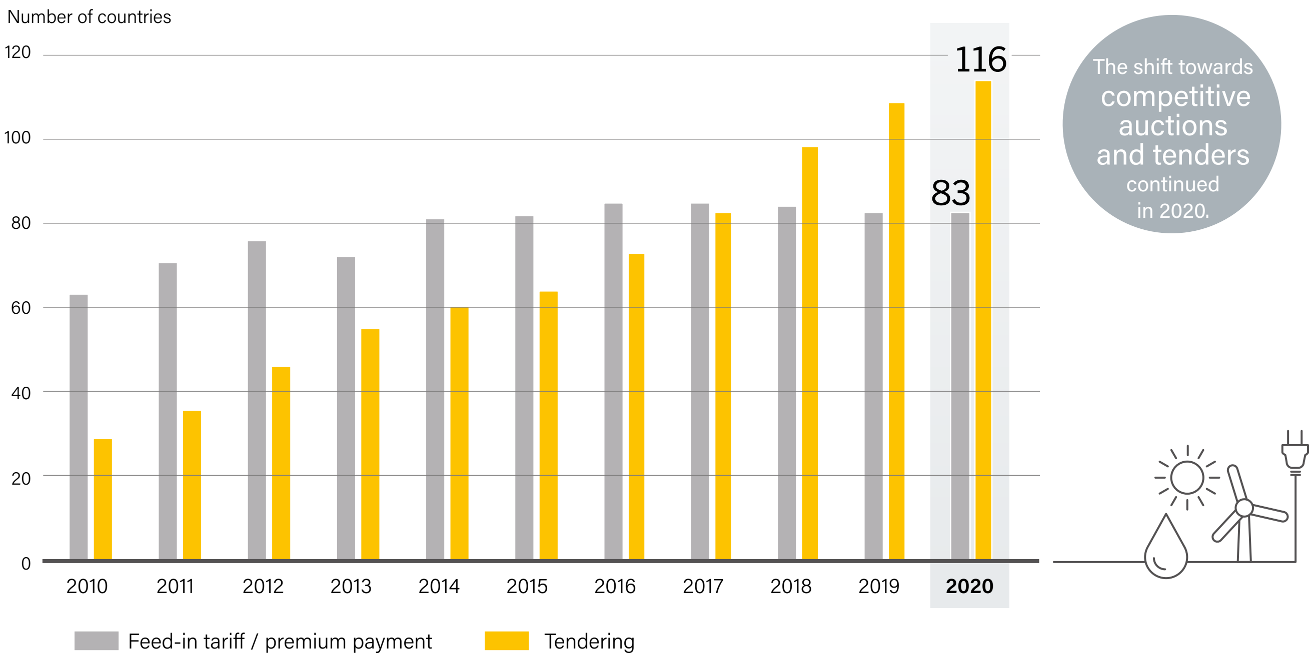
In the United States, the state of Arizona approved a plan for 100% "carbon-free" power by 2050 (including nuclear as well as renewables).[143] Virginia set a 100% carbon-free electricity target through its **renewable portfolio standard** (RPS), as well as targets for scaling up investment in energy efficiency, energy storage, and solar and wind power.[144] Virginia joined at least 8 other US jurisdictions[i] that had already made 100% carbon-free electricity RPS commitments (many of which include 100% renewable electricity), and at least 12 additional states were considering such commitments by mid-2020.[145]

Feed-in policies[ii], including feed-in tariffs (FITs) and feed-in premiums (FIPs), can be used to promote both large-scale (centralised) and small-scale (decentralised) renewable power generation. Although these remain among the most widely used policy mechanisms for supporting renewable power, the trend continued away from administratively set feed-in pricing policies to the use of competitive tenders or auctions for large-scale power generation.[146] (→ *See Figure 16.*) FITs nevertheless remained popular in 2020 and by year's end were in place in 83 jurisdictions at the national and state/provincial levels (unchanged from 2019). (→ ***See Reference Table R10*** *in GSR 2021 Data Pack.*)

i US states and jurisdictions with 100% renewable or "carbon-free" electricity targets include California, Hawaii, Maine, Nevada, New Mexico, New York, Virginia, Washington and the District of Columbia.

ii Feed-in policies may focus on a certain type or scale of renewable energy technology or may apply to many types and scales of technologies.

FIGURE 16.
Renewable Energy Feed-in Tariffs and Tenders, 2010-2020



Note: A country is considered to have a policy (and is counted a single time) when it has at least one national or state/provincial-level policy.
Source: REN21 Policy Database. See Reference Tables R10-R11 in GSR 2021 Data Pack.

During 2020, at least nine countries took new action on renewable energy feed-in policies. In at least four countries, these policy changes were to support or maintain existing programmes. Japan committed to transitioning its FIT to a FIP programme[i] starting in 2022, and Vietnam set new rates for its FIT programme, ensuring its continuation following a period of policy uncertainty[ii],[147] Turkey, which previously had planned to end its FITs in 2020, allocated TRY 3.9 billion (USD 570 million) to the programme and extended it until 30 June 2021.[148] Moldova approved 15-year FITs for renewable energy projects of 1 MW or less.[149]

In contrast, at least five countries, almost exclusively in Europe, cut back support for FITs by either reducing existing payments or cancelling their programmes in favour of auctions or tenders. The Czech government announced retroactive cuts for FITs granted to existing solar PV, wind and hydropower projects, and France retroactively cut FIT contracts signed between 2006 and 2010 for solar PV projects larger than 250 kilowatts (kW).[150]

Ukraine reduced its FIT payments for some wind and solar projects[iii] and announced that, starting in 2022, the FIT for ground-mounted solar projects of 1 MW-plus would be replaced by the country's auction regime (which came into force in January 2020).[151] Switzerland provided CHF 470 million (USD 532 million) to eliminate the waiting list for FIT contracts for small-scale solar PV systems, but also announced plans to replace FITs for large-scale solar PV with an auction mechanism.[152] Outside of Europe, China announced plans to phase out FITs for solar PV starting in 2021.[153]

Meanwhile, at least 33 countries held renewable energy **auctions or tenders** at the national or sub-national levels during 2020 (down from 41 countries in 2019). At least 3 of these auctions or tenders were technology-neutral. (→ ***See Reference Table R11*** *in GSR 2021 Data Pack.*) Many of the auctions and tenders took place in Africa, including in Angola, Chad, Djibouti and Nigeria, continuing the trend from previous years.[154]

At least 6 countries[iv] adopted renewable energy auctions or held auctions for the first time. For example, the Slovak Republic launched its first technology-neutral, large-scale renewable energy auction.[155] Bhutan launched its first tender for renewable power capacity to build the country's first solar PV plant, and the Philippines published a policy governing "green energy" auctions, the first of which was expected to be held in 2021.[156] Croatia introduced a tender scheme in which renewable energy and co-generation projects will be awarded a FIP above spot market prices.[157]

At least 4 countries strengthened support for
feed-in policies
in 2020, while 5 countries cut back support.

Some governments modified their auction design in 2020. Germany launched its first tender under a new technology-neutral innovation auction programme, which grants a fixed market premium on top of spot market prices (instead of the sliding FIP awarded via traditional renewable energy auctions).[158] The UK government decided to allow solar PV, onshore wind power, hydropower, landfill gas, sewage gas and energy from waste to participate in the country's 2021 power capacity auction, for the first time since 2015.[159]

Most **net metering policies** compensate the owners of renewable power systems for surplus electricity fed into the grid. These policies often do not distinguish between centralised/decentralised and large-/small-scale generation, although in some jurisdictions the focus is exclusively on small-scale or distributed renewable energy. Of the net metering policies that do not distinguish between size or type of generation, 7 new programmes were added in 2020, bringing the total number of countries, states and provinces with net metering policies to 72 by year's end (compared to 70 in 2019).

During 2020, Botswana launched a new net metering programme for both large and small rooftop solar PV systems.[160] Tunisia issued a decree allowing private companies that generate renewable power for their own use to sell any excess generation to the national utility under net metering rules.[161] Zimbabwe launched a net metering programme for rooftop solar PV, and Saudi Arabia established a new net billing programme for small-scale (1 kW to 2 MW) distributed solar PV.[162] At the sub-national level, Kerala (India) introduced a net metering programme for residential systems under 1 MW, and the US state of Virginia expanded its net metering cap from 1% to 6%.[163]

Despite the popularity of net metering in many places, some jurisdictions have begun to transition away from these programmes or have modified them to charge customers fees for participating[v]. Dubai (United Arab Emirates) announced that its net metering programme will no longer apply to large-scale, groundmounted projects and capped the maximum capacity for rooftop PV systems at 2,080 kW.[164] Egypt confirmed plans to impose a "merger fee" on net-metered solar PV systems in the country, although as of October 2020 the fee had not yet been determined.[165] The Belgian region of Wallonia also announced a fee for net-metered systems, which the government will reimburse at least partially until 2024.[166]

i Under Japan's FIT programme, the purchase price for the end-user of electricity is determined at a fixed rate regardless of the variation in market prices. Under the new FIP programme, renewable energy projects will receive a certain premium on top of the market price for the electricity that they generate starting in 2022.

ii Vietnam increased the FIT for biomass power projects and set new FIT rates for utility-scale, rooftop and floating solar PV installations.

iii Ukraine reduced FIT payments by: 7.5% for solar projects with installed capacity below 1 MW and wind projects commissioned during 2015-2019; 15% for solar projects with installed capacity exceeding 1 MW; and 2.5% for plants that begin operation up to the end of 2022.

iv The six countries that held auctions for the first time in 2020 were Bhutan, Croatia, Mozambique, Myanmar, Philippines and the Slovak Republic. See Reference Table R11 in GSR 2021 Data Pack.

v Typically, under a net metering arrangement, customers have lower electricity bills because they generate a portion of their own power. However, these customers may not be covering as much of the costs to maintain grid infrastructure as those who do not self-generate, and these costs are then shifted to these other customers. Some governments have chosen to counteract this by charging a fee to net-metered customers.

Some US states have pulled back from net metering, either implementing caps or adopting successor policies. For example, Kentucky committed to establishing new crediting structures based on dollar value rather than kilowatt-hour netting.[167] Virginia enacted a bill directing regulators to develop a net metering successor when a certain installed capacity threshold is reached, while Illinois hit its net metering cap and initiated a process to transition away from net metering.[168] Utah established a net metering successor that provides compensation at a rate between the retail cost and the avoided cost for exported energy.[169] New York approved an alternative to net metering for residential and small commercial customers that will include new monthly fees, but it delayed implementation to 2022 due to the COVID-19 crisis.[170] Arkansas regulators allowed utilities to propose net metering alternatives beginning in 2023.[171]

Financial incentives for renewable power were especially important in 2020 as a result of the COVID-19 pandemic. While many of these incentives were tied to economic recovery packages, not all were. For example, the EU, as part of its Green New Deal, released details of a new financing mechanism intended to bring together renewable energy investors and project developers through regular public tenders and to allow Member States to invest in renewables projects in other countries[i],[172]

Within Europe, Austria doubled the budget for its residential solar subsidy programme (capacities up to 5 kW), bringing the rebate for installed grid-connected capacity to EUR 250 (USD 307) per kW and for systems integrated into buildings to EUR 350 (USD 429) per kW.[173] Greece allocated EUR 850 million (USD 1,044 million) for homeowners to install solar PV systems and energy storage on residences.[174] The Netherlands doubled the funding available under its green energy subsidy programme to EUR 4 billion (USD 4.5 billion), and Spain provided EUR 181 million (USD 222 million) for renewable energy projects in seven regions.[175]

Switzerland provided CHF 470 million (USD 532 million) to expand renewable energy, with a focus on new solar PV systems, and allocated CHF 46 million (USD 52 million) to its residential and commercial rooftop rebate programme to stimulate demand.[176] The United Kingdom, meanwhile, set out plans to become the world leader in wind energy, including committing GBP 160 million (USD 217 million) to upgrade ports and infrastructure along coastlines to increase offshore wind power capacity.[177]

Elsewhere, Colombia made it easier to access tax incentives for renewables by halving the time required to secure tax deductions, customs exemptions and accelerated depreciation rates for renewable power technologies.[178] Turkey slashed the administrative fee charged to owners of rooftop solar PV systems (10-100 kW), reducing it from TRY 529 (USD 72) to TRY 278 (USD 38).[179] Jordan launched a programme offering 30% rebates for installing residential solar PV systems below 3.6 kW, and Israel committed ILS 80 billion (USD 25 billion) to additional solar PV deployment to support a target of 30% renewable power by 2030.[180]

i Renewable energy generated will count towards the targets for both the host and the contributing states, with the split based on the share of investment.

At a sub-national level, the Indian state of Uttar Pradesh announced subsidies for residential solar rooftop projects (between 1 kW and 10 kW), depending on the project size and location.[181] In Australia, New South Wales unveiled a AUD 32 billion (USD 25 billion) plan to deliver 12 GW of new renewable energy capacity and 2 GW of storage capacity by 2030, and Victoria adopted an interest-free loan programme for landlords that will provide subsidies of up to AUD 3,700 (USD 2,835) for installing a rooftop solar PV system.[182]

China, in contrast, reduced some financial incentives for renewables in 2020. It ended funding completely for new offshore wind farms and halved its budget for subsidising new solar power from CNY 3 billion (USD 460 million) to CNY 1.5 billion (USD 230 million).[183] Company efforts to meet deadlines in China for the phase-out of the onshore wind power feed-in tariff resulted in a spike in wind power investment during the year.[184] (→ *See Investment chapter.*) However, China also committed to increasing grants for solar and wind power starting in 2021.[185]

In addition to net metering, other policies to encourage **renewable self-consumption** have evolved as residential, commercial and industrial power consumers become more interested in generating their own power. In 2019, California became the first jurisdiction to make solar PV mandatory for newly constructed homes starting in 2020, although some loopholes exist.[186] The German state of Bremen passed similar legislation in 2020 to require solar PV on new homes and public buildings.[187]

Tradeable renewable energy certificates (RECs, also called Guarantees of Origin or GOs in Europe)[i] also can be used to support renewable electricity, although concerns have been raised about additionality[ii,188]

Several countries and regions across all major continents already permit the use of RECs, and in 2020 a few more countries allowed their use.[189] Bahrain announced the issuance of the country's first-ever REC, through an electronic platform.[190] In West Africa, companies were able at the start of the year to begin purchasing RECs documented by the International REC Standard.[191]

Support for renewables in
community energy
increased in at least 5 countries during 2020.

COMMUNITY ENERGY ARRANGEMENTS

Through small-scale **community energy arrangements**, residents, businesses and others located within a relatively small geographic area are able to develop, own, operate, invest in and/or benefit from a renewable energy project[iii]. Policy support plays a crucial role in these arrangements and includes measures supporting self-consumption, virtual net metering[iv] and various forms of shared ownership[v] of renewables, including community solar.[192]

In 2020, Chile introduced rules giving people who own small-scale solar PV systems for self-consumption the option of supplying power to multiple consumers, thereby creating "energy communities"[vi,193] France similarly updated its legislation to allow consumers and producers of renewables to create energy communities on low-voltage networks.[194] Italy launched a pilot programme that allows homes, businesses and public entities with rooftop solar PV systems of 200 kW or less to own, generate, sell, store and distribute renewable energy; to boost the development of these energy communities, the government provides a 20-year tariff of EUR 0.10 to EUR 0.11 (USD 0.12 to USD 0.14) per kWh of power shared among members.[195] Montenegro made it possible for individuals who generate renewable electricity to store and sell surplus power to others, either individually or through aggregation with other generation systems.[196] At a sub-national level, the US state of Virginia established a multi-family shared solar programme in 2020.[197]

i RECs are market-based instruments that represent the property rights to the environmental, social and other non-power attributes of renewable electricity generation. A REC certifies the ownership of 1 megawatt-hour of renewable electricity. Unbundled RECs may be bought and sold separately from the physical sale of electricity.

ii A unit (for example, a REC or a greenhouse gas emission reduction) is considered "additional" if it arises because of the incentives associated with the existence of a specific policy rather than as part of a business-as-usual practice.

iii Communities may vary in size and shape (for example, schools, neighbourhoods, city governments, etc.), and projects vary in technology, size, structure, governance, funding and motivation. See REN21's *Renewables in Cities Global Status Report*.

iv Virtual net metering utilises the same compensation mechanism and billing schemes as net metering without requiring that a customer's distributed general system (or share of a system) be located directly on site.

v Shared ownership refers to the collective ownership and management of renewable energy assets.

vi These energy communities will enable users to co-ordinate a shared solar PV array with a single grid connection to inject surplus power back into the electricity network, and also allow for distributed systems to be connected at different locations from their consumers.

SYSTEMS INTEGRATION OF VARIABLE RENEWABLE ELECTRICITY

As the penetration of variable renewable energy (VRE) sources such as solar and wind power increases, maintaining the reliability of power systems may become more challenging and costly.[198] Successful integration of VRE is critical to ensuring an efficient and effective power system.[199] (→ *See Systems Integration chapter.*) Increasingly, jurisdictions with relatively high shares of VRE (both large-scale/centralised and small-scale/decentralised generation) have implemented policies to ensure more successful VRE integration. This includes policies related to the design and operation of power markets, transmission and distribution system enhancements, and policies supporting energy storage.[200]

Changes to **power market rules** can increase system flexibility and control and make it easier for both centralised and distributed VRE, as well as energy storage systems, to participate in electricity markets. For example, in 2020 the US Federal Energy Regulatory Commission expanded its access rules to enable renewable distributed energy generators and energy storage to compete in regional wholesale electric markets, alongside large-scale generators.[201]

Policies to **improve electricity infrastructure**, including policies aimed at expanding or modernising transmission and distribution systems, also can facilitate VRE integration and boost resilience.[202] In 2020, India's government-owned transmission company approved seven new transmission projects to support renewable generation projects in the country.[203] South Africa's public utility Eskom announced plans for transmission expansion to strengthen the grid and to connect 30 GW of additional capacity, much of it expected to come from renewable energy projects.[204] In the United Kingdom, energy utility regulator Ofgem unveiled a five-year funding package that provides more than GBP 3 billion (USD 4.1 billion) for transmission grid upgrades to ensure that the network can manage rising levels of VRE.[205] In Australia, a number of states including New South Wales, Queensland and Victoria announced that they would strengthen transmission networks to support the deployment of planned Renewable Energy Zones.[206]

Policies that **promote energy storage deployment** also help with successful VRE integration, since storage can make it easier to balance the supply and demand of renewable generation and minimise the curtailment of electricity.[207] In 2020, Turkey's government introduced new rules for the grid connection of energy storage systems to encourage storage projects linked to rooftop solar PV.[208] New South Wales (Australia) announced funding for four large-scale battery projects to support renewables as the state transitions away from coal.[209]

Policies supporting **solar-plus-storage** explicitly link solar PV and energy storage. In 2020, both Austria and Italy provided financial support for solar-plus-storage installations. Austria launched a EUR 36 million (USD 44 million) rebate programme for small solar-plus-storage installations, and the regional government of Lombardy (Italy) allocated EUR 20 million (USD 25 million) in rebates to promote energy storage coupled with residential and commercial solar PV.[210]

TABLE 6.
Renewable Energy Targets and Policies, 2020

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
High Income Countries													
Andorra		●	●						●			●	
Antigua and Barbuda	E, P	●											
Australia	P, P*(N), T*	●	◖	●	◖	◖	●	●	●, ◖				●, ☆[6], ★*
Austria	E, P, HC(O), T	●	●		●	☆		●		★[6]	●		●[6], ◖
Bahamas, The	E, P	●											
Bahrain	E, P	●	●		●			★	●				●
Barbados[1]	E, P	●			●					●			●
Belgium	E, E*, P(O), P*(O), HC, T	●		◖	◖	☆		●	●	●[6]	●		◖
Brunei Darussalam	E	●											
Canada	P*	●	◖	◖	◖	●, ◖, ☆*		☆	◖	●[6], ☆	●[6]		●, ☆[6,7], ★*[7]
Chile	P	●	●	●	●			●	●, ○	●[6]	●[6]		●, ☆[6]
Croatia	E, P(O), HC(O), T	●	●[6]			☆			○			★	●[6]
Cyprus	E(N), P(O), HC(O), T(N)	●	●		●	☆			●				●
Czech Republic	E, P(O), HC(O), T	●	●			●		●		●[6]	●	☆	●[6]
Denmark	E, P(N), HC(O), T(O)	●	●[6]		●	☆	●[8, 9]	●	●, ○	●[6]	●		●[6], ★
Estonia	E, P, HC, T	●	●			☆			●, ○			●	●, ☆[6]
Finland	E, P(O), HC(O), T	●	●			☆		●	●	★[6], ●[7]		●	●[6], ★
France	E, P(N), HC, T	●	☆			☆	●	●	●, ○	●[6]	●[6]	☆	★[6]
Germany	E, P(N), HC(O), T	●	●			●	●[9]	●	●, ○	●	●		●[6], ★
Greece	E, HC(O), P, T	●	●	●	●	☆	●[8]	●	●	●[6]	●		●, ☆[6], ★
Hungary	E(N), P(N), HC(O), T(N)	●	●		●	☆			●, ○	●			●[6]
Iceland	E(O), T(O), HC(O), P(O)	●											
Ireland	E, P(N), HC(O), T(O)	●	●			☆	●[8]	●	●	★[6]			☆[6, 7]
Israel	E(N), P(N), T	●	●	●	●		●		●, ○	●[6]			●, ★
Italy	E, P, HC(O), T	●	●		●	☆			●, ○	●	●[6]		●[6, 7], ★*, ★
Japan	E, P	●	☆					●	●, ○	●		☆	●, ☆[6]
Korea, Republic of	E, P	●		●	●	●	●	●		★	●	●	●[6]
Kuwait	P	●							●				
Latvia	E(N), P(O), HC(O), T(N)	●	●		●	★			●	●			
Liechtenstein		●	●										
Lithuania	E, P, HC, T(O)	●	●[6]	●	●	☆	●[8]		●, ○	●[6]			●, ★[6]
Luxembourg	E, P(O), HC, T	●	●			☆			●, ○				●, ☆[6]
Malta	E, P(O), HC(O), T	●	●		●	☆			●	●			●[6]
Mauritius	P	●			●				●	●			●[6]
Monaco		●											
Nauru		●											
Netherlands	E, P(O), HC, T(O)	●	●[6]		●	☆	●[8]	●	●	★[6]	●[6]	●	●[6], ☆, ★
New Zealand	P	●			◖	●				☆			●
Norway	E(O), P(O), T(O), HC(O)	●		●		●[7]	●[9]	●	●	●			●[6]
Oman	P(N)	●							●				
Palau	E(O), P	●		●									
Panama	E	●	●		●	●			●	●	●	●	
Poland	E, P, HC(O), T	●	●	●		☆		●	●, ○	●			●[6], ★
Portugal[2]	E, P, HC(O), T(N)	●		●		☆	●	●	●, ○	●			●, ☆[6]
Qatar	P	●							●				
Romania	E(N), P(O), HC(N), T(N)	●		●	★	☆		●					●[6]
San Marino		●	●										
Saudi Arabia	P	●			●, ★				●				
Seychelles	E, P	●			●				●	●	●		●
Singapore	P(O)	●			●				●				●
Slovak Republic	E, P(O), HC(O), T	●	●			☆		●	○	●[7]			●[6]
Slovenia	E(N), P(O), HC(N), T(N)	●			●	☆		●	●	●	●		●[6]
Spain[3]	E(N), P(N), HC(O), T(N)	●			☆	☆	●		●, ○	★	●	●	●[6], ★
St. Kitts and Nevis		●											
Sweden	E(N), P, HC(O), T(O)	●		●		O		●		●	●		●
Switzerland	P	●	●					●		●		☆	●[6]
Taipei, China	P	n/a	●			●					☆		
Trinidad and Tobago	P	●								●	●		
United Arab Emirates	P, P*(O)	●		◖	☆*				●, ◐			◖	◖
United Kingdom	E(O), P(N), P*(O), T(N), HC(O)	●	◖	●		☆	●[8]	●	●, ◖	●		●	●[6], ☆[7], ★, ★*
United States	T(N), P*(N)	●	◖	☆*	☆*	◖, ☆	●, ◖[9]	◖	◖, ◐	●	●[7], ◖[7], ★, ★*		●[6], ☆[7], ★*
Uruguay		●			●	●	●		●	●		●	●[6]

Note: Please see key on last page of table.

TABLE 6.
Renewable Energy Targets and Policies, 2020 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Upper-Middle Income Countries													
Albania	E, T(O)	●	●	●	●	●		●	●, ○	●	●	●	●
Argentina	E, P	●	●	●	●	●			●	●[6]	●[6]	●	●, ☆[6]
Armenia	E, P	●	●		●				●				●[6]
Azerbaijan	P(N)	●											●
Belarus	P	●	●	●						●			●
Belize	P	●							●				
Bosnia and Herzegovina	E(O), HC(O), T(O), P	●	●						●				
Botswana	P	●			★				●, ○	●			●
Brazil	P, T	●			●	☆			●	●	●		●
Bulgaria	E, P(N), HC, T(N)	●	●			☆							●[6]
China	E(N), P(N), HC(O), T(O)	●	●	☆		☆	●		◖, ●[7]	●	●	●, ●	●, ★[6,7], ●
Colombia	E, P	●				●			●, ○	●	●		●
Costa Rica	P	●			●	●			●	●[6]			
Cuba	P	●											
Dominica		●											
Dominican Republic	E, P	●			●				●	●	●		●
Ecuador		●	●			●			●	●			●
Equatorial Guinea		●											
Fiji	E, P	●								●	●		
Gabon	E, P	●											
Georgia	E	●											●[6]
Grenada	P	●			●					●			
Guatemala	P	●			●	●			●	●	●		
Guyana	P	●								●			
Indonesia	E, P, T	●	●	●		●			●	●	●		●
Iran	P(O)	●	●							★	●	●	●
Iraq	P(O)	●							●				
Jamaica	P	●			●	●			●, ○	●	●		
Jordan	E, P, HC(O)	●	●		●		●		●	●			●, ☆[6]
Kazakhstan	P	●	●					●	●				●
Kosovo	E(O), P(O), HC(O)	n/a	●										
Lebanon	E, P(O), HC	●			●				●	●[6]			●[6]
Libya	E, P, HC(O)	✕								●			
Macedonia, North	E, P, HC(O), T(O)	●	●							●[6]			●[6]
Malaysia	P, HC(O), T(O)	●	●	●	☆	●			●	●			●
Maldives	E, P(O)	●	●						●				
Marshall Islands	E, P(O)	●								●			
Mexico	E(O), P(O), HC, T(O)	✕			●	☆			●	★	●		●, ☆[6], ★
Montenegro	E(O), P(O), HC(O), T(O)	●	●						●	★			
Namibia	P	●					●						
Paraguay	T(N)	●				●				●			
Peru		✕	●	●	●	●			●	●			●
Russian Federation	E(O), P	●	●						●				●
Samoa	E	●											
Serbia	E(O), P, HC(O), T(O)	✕	●										●
South Africa	P	●		●		●	●		●	●			●[6]
St. Lucia	P	●			●					●			
St. Vincent and the Grenadines[1]	P(O)	●			●								
Suriname	P	●			●				●				
Thailand	E, P, HC, T	●	●		●	●				●		●	☆, ●[6], ★[7]
Tonga	P	●							●				
Turkey	P, HC	●	☆		●	●	●[8]		●, ○			☆	●[6]
Turkmenistan		●											
Tuvalu	E, P(O)	●											
Venezuela		●											

Note: Please see key on last page of table.

TABLE 6.
Renewable Energy Targets and Policies, 2020 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Lower-Middle Income Countries													
Algeria	P	●	●						●			●	●
Angola	P	●	●			●							●
Bangladesh	E, P(N)	●							●	●			●, ★
Benin	E, P	●							●				
Bhutan	E, P, HC	●							○				
Bolivia	P	●	●	●	●				●	●		●	●
Cabo Verde	P	●			●				●	★	●	●	
Cambodia	E	●							●				
Cameroon	P	●								●			
Comoros	E, P	●											
Congo, Republic of	P	●											
Côte d'Ivoire	P	●							●	●			
Djibouti	E, P	●											
Egypt	E, P	●	●		●				●	●[6]			●
El Salvador		●							●	●	●	●	●
Eswatini	P	●							●				
Ghana	P	●	●	●	●	●		●	●	●			●
Honduras	E, P	●	●		●				●	●	●		
India	E, P, P*, HC, T	●	◖	●	◖, ★*	●		●	●, ○, ◖	●	●	●, ◖	●[6], ★[7]*
Kenya	E, P, HC	●	●		●				●	●		●	●
Kiribati	E, P	●											
Kyrgyzstan		X		●						●			●
Lao PDR	E	●											
Lesotho	P	●			●				●	★	●	●	●
Mauritania	E(O), P(O)	●											
Micronesia, Federated States of	E(O), P(O)	●			◖								
Moldova	E(O), P(O), HC(O), T(O)	●	●		●				●				●
Mongolia	E, P	●	●						●, ○	●			
Morocco	P, HC(O)	●			●				●				●[6]
Myanmar	P	●							○	●			
Nepal	E(O), P	●	●					●	●	●	●		●
Nicaragua	P	●	●							●	●		●
Nigeria	P(N)	●	●	●					●	●			●
Pakistan	E, P(N)	●	●		●			●		●			●
Palestine, State of[5]	E, P(O)	●	●		●				●	●			
Papua New Guinea	E, P	●											
Philippines	E, P	●	☆	●	●	●			○	●	●	●	●, ☆[6]
São Tomé and Príncipe	P	●											
Senegal	P	●	●	●	●				●	●			
Solomon Islands	E, P	●											
Sri Lanka	P(N), T(O)	●	●	●	●	●			●	●		●	●
Tanzania	E, P	●	●		●				●	●		●	●
Timor-Leste	E, P	●											
Tunisia	E, P	●			★				●, ○	●			●[6]
Ukraine	E, P(O), HC(O), T(O)	●	☆		●	●				●		☆	●[6]
Uzbekistan	E, P(N)	●							●, ○		★		
Vanuatu	E, P	●	●							●			
Vietnam	E(N), P(N), T	●	☆	●	●	●		●	●, ○	●	●	☆	●
Zambia		●	●						●	●			●
Zimbabwe	T(N), P	●			★	●			●, ○	●			●

Note: Please see key on last page of table.

TABLE 6.
Renewable Energy Targets and Policies, 2020 (continued)

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/ premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport obligation/mandate	Renewable heat obligation/mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Low Income Countries													
Afghanistan	E, P	●							●				
Burkina Faso	E, P	●							●	●	●	●	
Burundi	E, P	●											
Central African Republic	P	●											
Chad	P	●											
Congo, Democratic Republic of	E, P	●											
Eritrea	P	●											
Ethiopia	E, P	X				●			●				
Gambia	E, P	●							●	●			
Guinea	E, P	●								●			
Guinea-Bissau	E, P	●							●				
Haiti	E, P	●											●
Korea, Democratic People's Republic		●											
Liberia	E, P, T	●								●			
Madagascar	E, P	●							●	●			
Malawi	E, P, HC	●				●	●		●	●			●
Mali	E, P	●							●	★			●
Mozambique	P, HC, T	●				●			○	●			●
Niger	E, P(O)	●							●	●			
Rwanda	E	●	●						●	●	●		●
Sierra Leone	P, HC	●											
Somalia	P	●											
South Sudan	E, P	X											
Sudan	E, P	●				●							
Syria	P	●	●		●				●	●	●		
Tajikistan	P(O)	●	●							●			●
Togo	E, P(O)	●								●			
Uganda	P	●	●						●	☆			●
Yemen	E(O), P, T(O), HC(O)	●											

Targets
- **E** Energy (final or primary)
- **P** Power
- **HC** Heating or cooling
- **T** Transport
- * Indicates sub-national target
- **(R)** Revised
- **(N)** New
- **(O)** Removed or came to term
- X Renewable energy not included in NDC

Policies
- ★ New (one or more policies of this type)
- ★* New sub-national
- ☆ Revised (from previously existing)
- ☆* Revised sub-national
- ● (grey) Removed
- ● Existing national policy or tender framework (could include sub-national)
- ◖ Existing sub-national policy or tender framework (but no national)
- ○ National tender held in 2020
- ◐ Sub-national tender held in 2020

1 Certain Caribbean countries have adopted hybrid net metering and feed-in policies whereby residential consumers can offset power while commercial consumers are obligated to feed 100% of the power generated into the grid. These policies are defined as net metering for the purposes of the GSR.

2 FIT support removed for large-scale power plants.

3 Spain removed FIT support for new projects in 2012. Support remains for certain installations linked to this previous scheme.

4 State-level targets in the United States include RPS policies.

5 The area of the State of Palestine is included in the World Bank country classification as "West Bank and Gaza".

6 Includes renewable heating and/or cooling technologies.

7 Aviation, maritime or rail transport

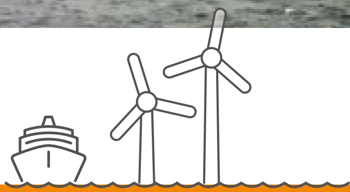
8 Heat FIT

9 Fossil fuel heating ban

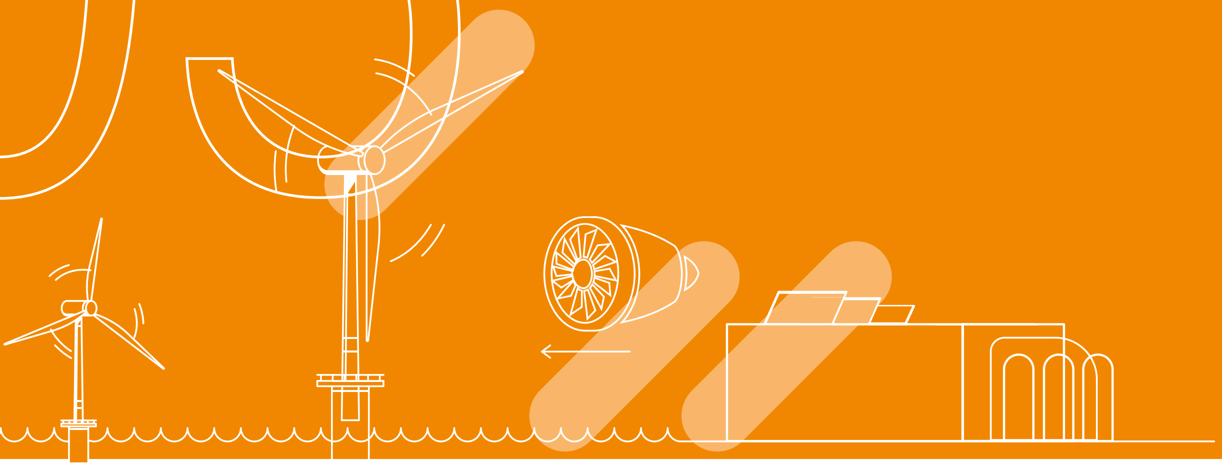
Note: Countries are organised according to annual gross national income (GNI) per capita levels as follows: "high" is USD 12,536 or more, "upper-middle" is USD 4,046 to USD 12,535, "lower-middle" is USD 1,036 to USD 4,045 and "low" is USD 1,035 or less. Per capita income levels and group classifications from World Bank, "Country and lending groups", http://data.worldbank.org/about/country-and-lending-groups, viewed May 2021. Only enacted policies are included in the table; however, for some policies shown, implementing regulations may not yet be developed or effective, leading to lack of implementation or impacts. Policies known to be discontinued have been omitted or marked as removed or expired. Many feed-in policies are limited in scope of technology.

Source: REN21 Policy Database. See GSR 2021 Data Pack at www.ren21.net/gsr-2021.

Ørsted's strategic suppliers are asked to disclose their own emissions, set science-based carbon reduction targets and use 100% renewable electricity in manufacturing, among other key requirements.



03



03 MARKET AND INDUSTRY TRENDS

KEY FACTS

- Modern bioenergy provided 5.1% of total global final energy demand in 2019, accounting for around **half of all renewable energy in final energy consumption**.
- Modern bioenergy for **industrial process heat** grew around 16% between 2009 and 2019, while **bio-heat demand in buildings** grew 7% over the same period.
- In 2020, **global biofuel production fell 5%**, with ethanol production down 8%, while biodiesel production rose slightly to meet increased demand in Indonesia, the United States and Brazil.
- **Bioelectricity production grew 6%** in 2020, with China the major producer.

BIOENERGY

Bioenergy involves the use of biological materials for energy purposes. A wide range of materials can be used, including residues from agriculture and forestry, solid and liquid organic wastes (including municipal solid waste (MSW)[i] and sewage), and crops grown especially for energy.[1] Many different processes can convert these feedstocks into heat, electricity and fuels for transport (biofuels). While some of these processes are fully established, others are in the earlier stages of development, demonstration and commercialisation.[2]

BIOENERGY MARKETS

Biomass provides energy for heating in industry and buildings, transport and electricity production. Overall, bioenergy accounted for an estimated 11.6%, or 44 exajoules (EJ), of total final energy consumption in 2019 (latest available data).[3] More than half of this total bioenergy came from the traditional use of biomass[ii], which provided around 24.6 EJ of energy for cooking and heating in developing and emerging economies, notably in Sub-Saharan Africa.[4]

i Municipal solid waste consists of waste materials generated by households and similar waste produced by commercial, industrial and institutional entities. The wastes are a mixture of renewable plant- and fossil-based materials; proportions vary depending on local circumstances. A default value is often applied based on the assumption that 50% of the material is "renewable".

ii The traditional use of biomass for heat involves burning woody biomass or charcoal, as well as dung and other agricultural residues, in simple and inefficient devices to provide energy for residential cooking and heating in developing and emerging economies.

The amount of **biomass used for heating** has grown 11% since 2009.

Other more modern and efficient uses of bioenergy[i] provided around half of all renewable energy in final energy consumption in 2019 – an estimated 19.5 EJ, or 5.1% of total global final energy demand.[5] (→ *See Figure 17.*) Modern bioenergy provided around 13.7 EJ for heating (7.3% of the global energy supply used for heating), 4.0 EJ for transport (3.3% of transport energy needs) and 1.7 EJ for global electricity supply (2.1% of the total).[6] Modern bioenergy use has increased most rapidly in the electricity sector – up 27% between 2010 and 2019 – compared to around 15% growth for transport use and less than 5% for bio-heat.[7]

BIO-HEAT MARKETS

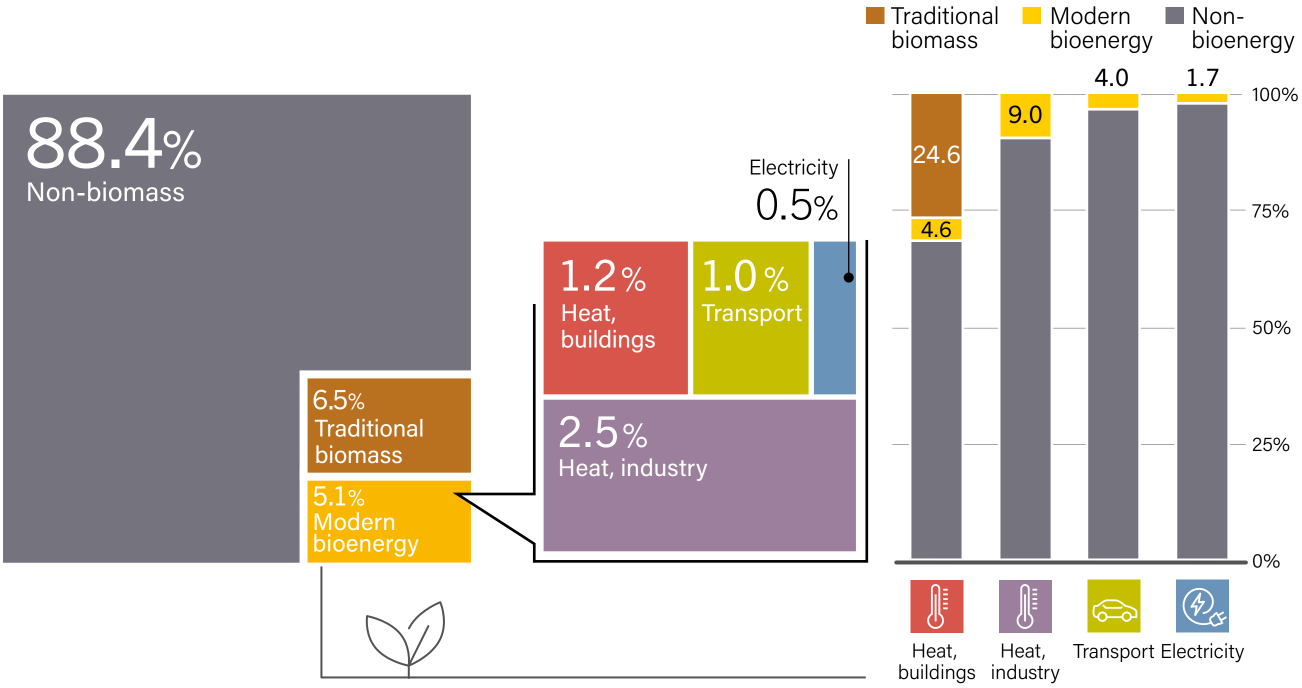
The use of biomass for heating has changed relatively little in recent years.[8] (→ *See Figure 18.*) The traditional use of biomass in developing and emerging economies is to supply energy for cooking and heating in traditional open fires or inefficient stoves.[9] (→ *See Distributed Renewables chapter.*) The amount of biomass used in these applications has decreased some 9% since 2009, from 27.0 EJ to an estimated 24.6 EJ in 2019.[10]

Because of the negative effects of the traditional use of biomass on local air quality and public health, as well as the unsustainable nature of much of the biomass supply, governments and international organisations are making significant global efforts to improve access to cleaner fuels for cooking and heating.[11] These fuels include fossil-based liquefied petroleum gas (LPG), electricity, and cleaner forms of biomass, such as ethanol fuels and wood briquettes and pellets.[12]

Modern bioenergy can provide heat efficiently and cleanly for industry and for residential, public and commercial buildings. The final user can consume biomass directly to produce bio-heat in a stove or boiler. Alternatively, bio-heat can be produced in a dedicated heat or district heating plant (including through the co-generation of electricity and heat using combined heat and power (CHP) systems) and distributed through the grid to final

i Modern bioenergy is any production and use of bioenergy that is not classified as "traditional use of biomass". See footnote ii on previous page.

FIGURE 17.
Estimated Shares of Bioenergy in Total Final Energy Consumption, Overall and by End-Use Sector, 2019



Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding. Buildings and industry categories include bioenergy supplied by district energy networks.

Source: Based on IEA. See endnote 5 for this section.

consumers. Most of the biomass used for heating is wood-based fuel, but liquid and gaseous biofuels also are used, including biomethane, which can be injected into natural gas distribution systems.[13]

In 2019 (latest data available), modern bioenergy applications provided an estimated 13 EJ of direct heat, an 11% increase from 2009.[14] In addition to the direct use of bio-heat in industry and buildings, bioenergy provided some 0.7 EJ to **district heating systems** in 2019; 51% of this was used in industry and agriculture and the remainder in buildings.[15] Bioenergy is the major source of renewable heat in district heating systems, accounting for 95% of all renewable heat supplied.[16] Its contribution grew 57% between 2010 and 2019.[17]

In 2019, 9.1 EJ of biomass was used to provide heat for industry and agriculture, meeting a combined 9.5% of these sectors' heat requirements.[18] Bio-heat demand in the two sectors has grown 16% since 2009.[19] Modern bioenergy provided 4.7 EJ to the buildings[i] sector in 2019, or around 5.0% of its heat demand.[20] The amount of bio-heat provided to buildings has increased 7% since 2009.[21]

Although final data for 2020 were not available at the time of publication, total energy use for heating was expected to decrease around 3.1% due to the economic effects of the COVID-19 pandemic.[22] The decline was expected to be highest in industry, down a projected 4.1%, due to the curtailment of industrial production in most regions (except China).[23] The use of bioenergy for industrial heat was expected to fall by the same percentage, but to hold its market share.[24] Heat use in buildings was projected to decrease 1.8%, with most of the decline occurring in commercial heating because of increased working and schooling from home.[25] Total bioenergy consumption in 2020 was expected to remain at 2019 levels.[26]

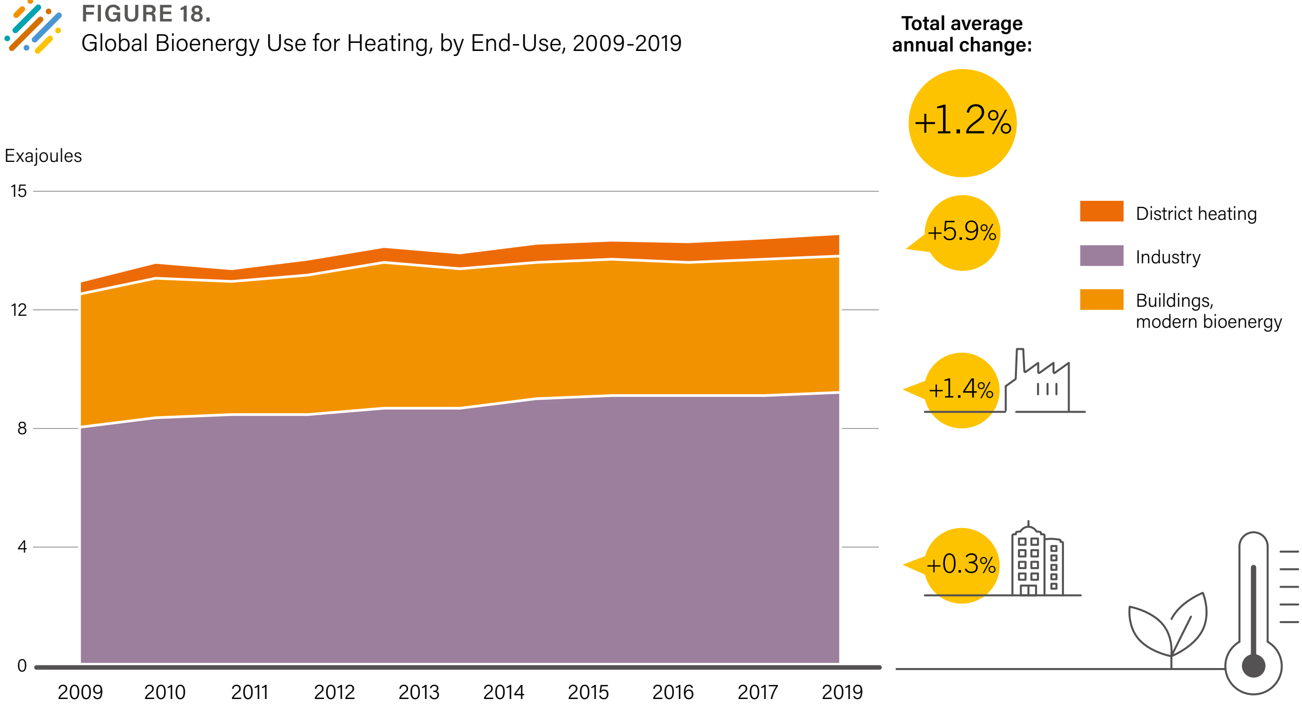
Industry use of biomass for heat production is primarily in bio-based industries, such as paper and board, sugar and other food products, and wood-based industries. These industries often use their wastes and residues for energy, including the "black liquor" produced in paper manufacture.[27]

Bioenergy is not yet widely used in other industries. However, biomass and waste fuels met around 6% of the cement industry's global energy needs in 2019.[28] In Europe, these fuels provided around 25% of the energy used in cement making in 2019.[29] The use of biomass and waste fuels for cement production in China is also growing.[30]

Bioenergy use for industrial heating is concentrated in countries with large bio-based industries, such as Brazil, China, India and the United States. Brazil uses large quantities of sugarcane

i Excluding the contribution to building heating from district heating; see discussion later in this section.

FIGURE 18.
Global Bioenergy Use for Heating, by End-Use, 2009-2019



Source: Based on IEA. See endnote 8 for this section.

residue (bagasse) from sugar and ethanol production to generate heat in CHP systems, producing an estimated 1.6 EJ in 2019.[31] India, also a major sugar producer, was the second largest user of bioenergy for industrial heat (1.4 EJ), followed by the United States (1.3 EJ), which has an important pulp and paper industry.[32]

Biomass can produce heat for space heating in buildings through the burning of wood logs, chips or pellets produced from wood or agricultural residues. The informal use of wood and other biomass to heat individual residences is prevalent in developed economies as well as in developing and emerging ones.[33] This can be a significant source of local air pollution if inefficient appliances and/or poor-quality fuels are used.[34] Stringent national regulations are being introduced to control emissions from small combustion facilities. Systems that can meet these requirements are commercially available, but at a higher cost.[35] Larger-scale systems, such as those used for district heating, can meet air quality requirements more easily and economically.

Modern use of bio-heat in buildings has been concentrated in the European Union (EU), which accounted for 47% of this total use in 2019, increasing 2% during the year to 3.8 EJ.[36] Policy measures that aim to promote renewable heat alternatives to meet the requirements of the EU Renewable Energy Directive (RED) – such as capital grants for biomass heating systems – have generated the growth in biomass use. Limiting the use of oil and natural gas for heating also plays an important role in stimulating alternative heat sources including biomass.[37] France, Germany, Italy and Sweden accounted for around half of the EU's bio-heat demand in 2019.[38]

Most of the biomass fuel used to heat buildings is in the form of logs and wood chips. However, the use of wood pellets for heating has been growing rapidly and was up 6% globally in 2019, to around 19.2 million tonnes (345 petajoules, PJ).[39] The bulk of the pellets (77%) were used in residences, with the rest consumed at commercial premises.[40] The EU remained the largest user (16.4 million tonnes or 294 PJ), with Italy still the world's largest market for pellet heating (3.4 million tonnes), followed by Denmark and Germany (2.3 million tonnes each), France (1.8 million tonnes) and Sweden (1.2 million tonnes).[41] Despite growth in the use of biogas for heating, and particularly in the production of biomethane and its introduction into gas grids, biogas provided only 4% of bio-heat in European buildings in 2019.[42]

North America was the second leading user of bioenergy in buildings in 2019. More than 1.8 million US households (1.4% of the total) relied on wood or wood pellets as their primary heating fuel, and an additional 8% used wood as a secondary heat source.[43] Use was concentrated in rural areas, with one in four rural US households combusting wood for primary or secondary space heating.[44] Total wood use in the US residential sector amounted to 0.55 EJ.[45] In Canada, the residential heating sector used some 0.13 EJ of bio-heat from wood fuels in 2019.[46] North America was the second largest regional market for pellets for building heating, up 4% in 2019 to 2.6 million tonnes (47 PJ).[47] Smaller-scale markets were found in non-EU Europe (0.9 million tonnes) and Asia (0.3 million tonnes), principally in the Republic of Korea (0.2 million tonnes) and Japan (0.1 million tonnes).[48]

Europe leads in the use of bioenergy in district heating. District heating (from all sources) supplied around 12% of the EU's heat demand in 2018.[49] The residential sector was the major user of district heat (45%), followed by the industrial (33%) and commercial and services (21%) sectors.[50] District heating meets at least 30% of heat demand in seven countries, including a 45% share in Denmark.[51]

This provides an important market opportunity for biomass, which supplied around 25% of all district heating in Europe in 2018 (620 PJ).[52]

Sweden was the largest user of bioenergy for district heating (130 PJ) in 2018, followed by Germany, Denmark and Finland (75 PJ each) and France (69 PJ), where the use of bioenergy grew 35% between 2015 and 2019, promoted by the Fonds Chaleur support system.[53] Lithuania has the highest share of district heat from biomass (65%, or 23 PJ); the country's use of bioenergy for this purpose has grown three-fold since 2010, driven mainly by the need to reduce dependency on imported oil to lower costs and improve energy security.[54] Bioenergy use has led to a 60% reduction in Lithuania's carbon dioxide (CO_2) emissions from heating.[55]

TRANSPORT BIOFUEL MARKETS

Global production[i] of liquid biofuels decreased 5% in 2020, dropping from 4.0 EJ (161 billion litres) in 2019 to 3.8 EJ (152 billion litres), as overall demand for transport fuels fell as a consequence of the COVID-19 pandemic.[56] While ethanol volumes declined sharply in 2020, biodiesel production and use held steady.[57] Lower transport demand for diesel fuel was offset by higher blending requirements and other factors, and the production and use of hydrotreated vegetable oil (HVO)[ii] increased significantly.

The United States remained the world's leading biofuel producer, with a 36% share in energy terms, despite a reduction in the country's ethanol production.[58] The next largest producers were Brazil (26%) followed by Indonesia (7.0%), Germany (3.4%) and China (3.0%).[59] In total, in 2020, ethanol accounted for around 61% of biofuel production (in energy terms), fatty acid methyl ester (FAME) biodiesel for 33%, and HVO for 6%.[60] (→ *See Figure 19.*) Other biofuels included biomethane[iii] and a range of advanced biofuels, but their production remained low, estimated at less than 1% of total biofuels production.[61]

Global production of ethanol decreased 8%, from 115 billion litres in 2019 to 105 billion litres in 2020.[62] Ethanol is produced primarily from corn[iv], sugar cane and other crops. The United States and Brazil, the two leading producers, accounted for 51% and 32%, respectively, of global production, followed by China, India, Thailand and Canada.[63]

Although ethanol production dropped sharply in 2020, **biodiesel production** remained steady.

US ethanol production fell 11% in 2020 to 53.2 billion litres, the lowest level since 2014, from 59.7 billion litres in 2019.[64] The country's ethanol consumption fell 12%, mirroring the 13% decline in petrol use in transport as blending opportunities were constrained and ethanol prices fell.[65] Many ethanol producers reduced output due to lower demand, negative operating margins and limited storage capacities.[66]

Ethanol production in Brazil decreased 6% to 34.0 billion litres, down from 36.0 litres in 2019.[67] Overall, petrol consumption in the country fell some 11% due to declining demand.[68] The drop in petrol use directly influences ethanol sales, as all petrol in Brazil contains 27% ethanol by volume.[69] Low oil prices also affect the competitiveness of 100% ethanol, which is widely available in the country.[70] Most Brazilian ethanol comes from sugar cane, with some 350 sugar ethanol mills operating nationwide.[71]

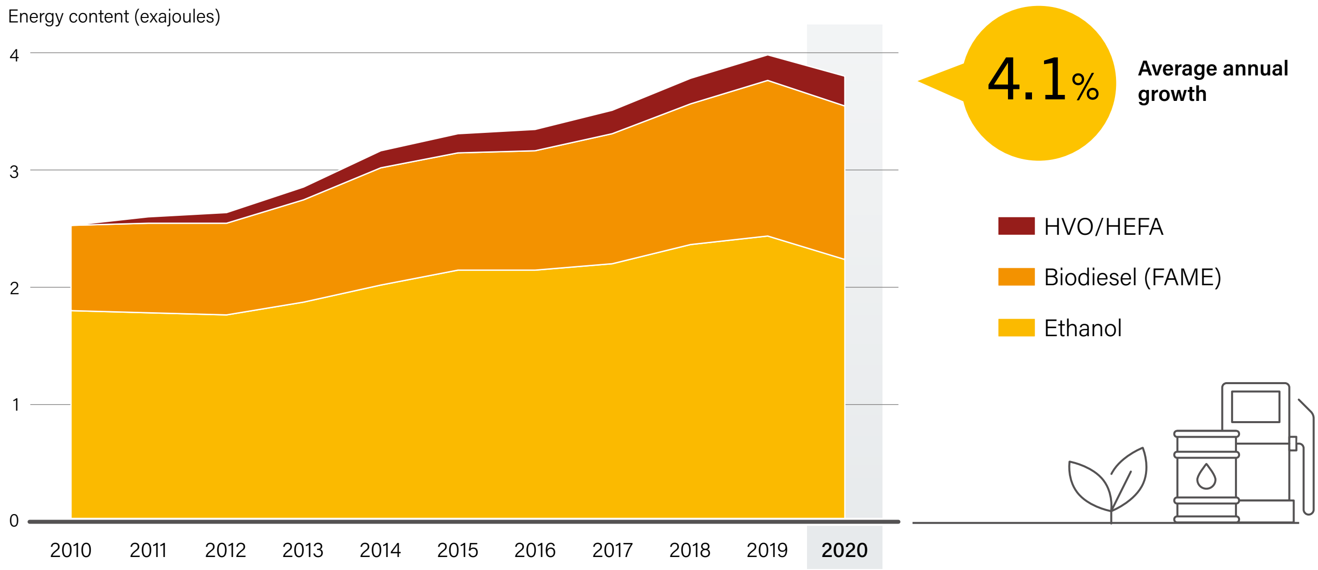
i This section concentrates on biofuel production, rather than use, because available production data are more consistent and up-to-date. Global production and use are very similar, and much of the world's biofuel is used in the countries where it is produced, although significant export/import flows do exist, particularly for biodiesel.

ii Hydrotreated vegetable oil is also referred to as hydroprocessed esters and fatty acids (HEFA). It is also called renewable diesel, especially in North America.

iii Often referred to as renewable natural gas (RNG), especially in North America. See Glossary.

iv The meaning of the word "corn" varies by geographical region. In Europe, it includes wheat, barley and other locally produced cereals, whereas in the United States and Canada, it generally refers to maize.

FIGURE 19.
Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2010-2020



Note: HVO = hydrotreated vegetable oil; HEFA = hydrotreated esters and fatty acids; FAME = fatty acid methyl esters

Source: See endnote 60 for this section.

However, a growing share of ethanol is produced from corn, and as of mid-2020 some 16 corn ethanol production plants were in operation and 7 more under construction.[72] Most of the plants can process both sugar cane and corn. Corn-based ethanol production in Brazil more than doubled in 2020, to 2.5 billion litres.[73]

China's ethanol production increased 3% to 4.0 billion litres in 2020 to meet growing domestic demand.[74] Petrol demand in the country fell some 7%, but growth in ethanol demand continued as 10% ethanol blends (E10) were extended to more provinces.[75] Production capacity doubled between 2017 and 2020, and several large new plants were in development.[76]

Ethanol production in India fell some 8% in 2020 to 1.8 billion litres, as petrol demand dropped 13% and as lower oil prices reduced the affordability of ethanol relative to unblended gasoline.[77] Canadian ethanol production remained stable in 2020, at 1.8 billion litres, while in Thailand, production fell 9% to 1.5 billion litres.[78]

Global production of biodiesel increased slightly (less than 1%) to 46.8 billion litres in 2020, up from 46.5 billion litres in 2019.[79] Its production is more widely distributed than that of ethanol; 11 countries account for 80% of global biodiesel production, compared to just 2 countries for ethanol.[80] This is due to the wider range of biodiesel feedstocks that can be processed, including vegetable oils from palm, soy, and canola, and a range of wastes and residues, including used cooking oil. In 2020, Indonesia was again the lead biodiesel producer (17% of the global total), followed by the United States (14.4%) and Brazil (13.7%).[81] The next largest producers were Germany (7.4%), France (5.0%) and the Netherlands (4.6%).[82]

Despite an estimated 12% reduction in demand for diesel for transport, Indonesia's biodiesel production grew 11% in 2020, to 8.0 billion litres.[83] In the face of growing dependency on imported oil, the blending level in the country is being increased gradually to prioritise domestically produced biodiesel, primarily from palm oil. The diesel blending level was increased from 20% to 30% in January 2020 and was expected to rise to 40%.[84]

While total US diesel demand fell 5% in 2020 due to the impacts of the COVID-19 pandemic, biodiesel production in the country rose more than 3% to 6.8 billion litres, boosted by the federal Renewable Fuel Standard (RFS2) and by California's Low Carbon Fuel Standard (LCFS).[85] In addition, the federal Biodiesel Blender's Tax Credit was reintroduced.[86] Increased duties on biodiesel imports from Indonesia and Argentina also favoured US domestic biodiesel production.[87]

In Brazil, biodiesel production rose 9% to a record 6.4 billion litres to meet increased domestic demand.[88] The country's biodiesel blending requirement increased from 11% to 12% and was scheduled to rise to 15% by 2023.[89]

In Germany, reduced diesel fuel use limited biodiesel demand, and production fell an estimated 9% to 3.5 billion litres in 2020, down from 3.8 billion litres in 2019.[90] Production in France also declined slightly to 2.4 billion litres, while production in the Netherlands stayed stable at 2.1 billion litres.[91]

Argentina dropped from fifth to ninth place among producers as biodiesel production decreased some 35% to 1.6 billion litres, with US duties on biodiesel imports discouraging trade.[92]

HVO production, a process of hydrogenating bio-based oils fats and greases, continued to grow sharply in 2020, rising 12% to an estimated 7.5 billion litres, up from 6.5 billion litres in 2019.[93] While early production capacity was concentrated in Finland, the Netherlands and Singapore, HVO capacity in the United States has increased rapidly in recent years, in line with the surging US market for these fuels.[94] HVO use in the country is heavily incentivised by the RFS2, by California's LCFS and by the availability of an investment tax credit.[95] US use of HVO under the RFS2 grew some 48% in 2020, to 3.5 billion litres (114 PJ).[96]

Biomethane is used as a transport fuel mainly in Europe and the United States (the largest producer and user of biomethane for transport).[97] US production and use of biomethane is also stimulated by the RFS2 (which includes biomethane in the advanced cellulosic biofuels category) and by California's LCFS, thereby qualifying for a premium.[98] US biomethane use under the RFS2 increased 24% in 2019 to around 41 PJ.[99]

In Europe, the use of biomethane for transport increased 74% in 2019 to 14 PJ (latest data available).[100] Sweden remained the region's largest biomethane consumer, using nearly one-third of the total, followed by the United Kingdom (where biomethane use increased five-fold in 2019), Germany and Italy (where use rose from nearly zero to 1.7 PJ in 2019).[101]

Although efforts to develop other "advanced biofuels" continued, and some new production capacity was installed (→ *see Industry section in this chapter*), these fuels have been produced and used only in small quantities to date. For example, the contribution of cellulosic ethanol under the US RFS2 scheme declined by a factor of five in 2020 to below 0.2 PJ.[102]

The United States and Brazil, the two leading producers of biofuels, account for around 80% of global production.

BIO-POWER MARKETS

Global bio-power capacity increased an estimated 5.8% in 2020 to around 145 gigawatts (GW), up from 137 GW in 2019.[103] China had the largest capacity in operation by the end of 2020, followed by the United States, Brazil, India, Germany, the United Kingdom, Sweden and Japan.[104]

Total bioelectricity generation rose some 6.4% to around 602 terawatt-hours (TWh) in 2020, from 566 TWh in 2019.[105] (→ *See Figure 20.*) China remained the leading producer of bio-power, followed by the United States and then Germany, Brazil, India, the United Kingdom and Japan.[106]

In line with the provisions of the country's 13th Five-Year Plan (2016-2020), China's bio-power capacity rose 26% to 22.5 GW in 2020, up from 17.8 GW in 2019.[107] Generation increased 23% to more than 111 TWh.[108] In 2020, 77 additional projects, with a combined capacity of 1.7 GW, were approved for financial support in 20 provinces.[109] They included projects using municipal waste (1.2 GW), agroforestry raw materials (0.5 GW) and biogas power generation (21 megawatts, MW).[110]

The United States had the second highest national bio-power capacity and generation in 2020.[111] The country's 16 GW capacity did not change significantly.[112] Generation fell 2.5% to 62 TWh, continuing the trend of recent years.[113]

Brazil was the third largest producer of bioelectricity globally, with most of the country's generation based on sugarcane bagasse.[114] Brazil's generation fell an estimated 10% to 50 TWh in 2020, as sugar production and the related electricity generation was reduced.[115]

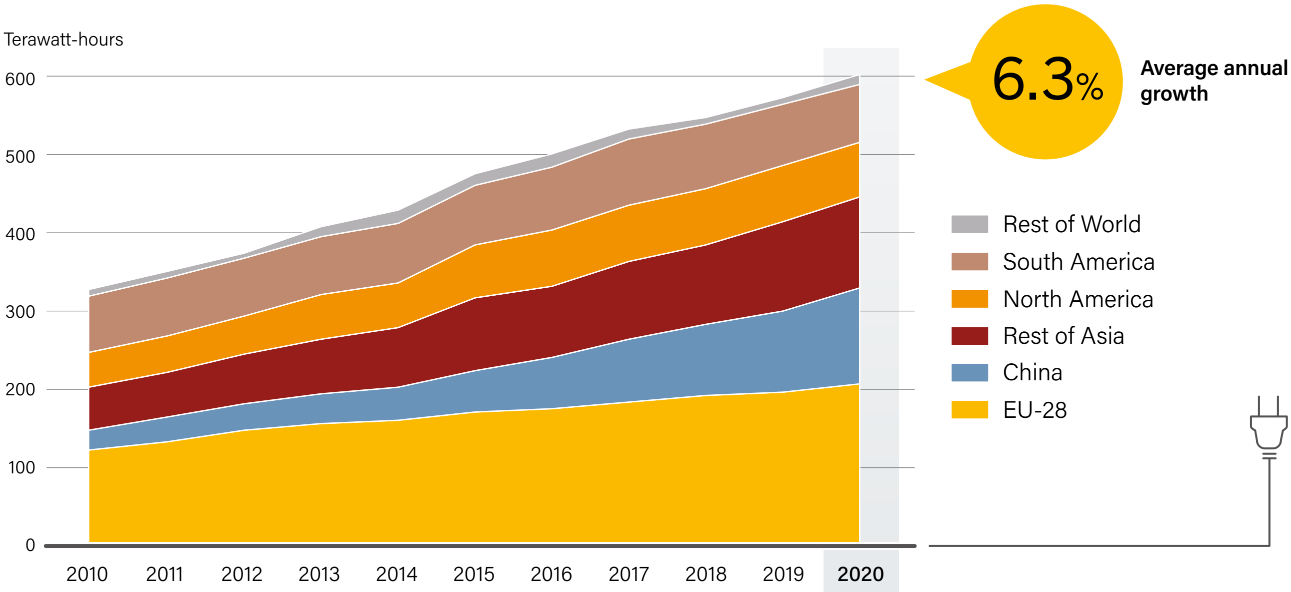
In the EU, bio-power capacity grew around 4% in 2020 to 48 GW, and generation increased 4% to 205 TWh, providing 6% of all generation.[116] This increase occurred as countries pushed to meet the region's mandatory national targets for 2020 under the RED.[117] Germany remained the region's largest bioelectricity producer, mainly from biogas: capacity increased 400 MW in 2020 to 10.4 MW, and generation rose 0.8% to 51 TWh.[118] Generation surged in the Netherlands (up 90%) to 11 TWh as the volume of wood pellets co-fired in large power stations increased significantly, supported by the SDE feed-in premium scheme and to help the country meet its obligations under the EU RED.[119]

In the United Kingdom, bio-power capacity grew 135 MW to 8.0 GW.[120] Generation rose 5.5% to 39.4 TWh, with increases in large-scale pellet-fired generation, biogas and MSW plants.[121]

In Asia, Japan's growth in bio-power capacity and generation grew slowly during 2020, with capacity rising 9% to 5.0 GW, and generation increasing to 25 TWh.[122] In the Republic of Korea, bio-power capacity rose 3% to 2.7 GW, with generation up 30% to 12.3 TWh, supported by the Renewable Energy Certificate Scheme and feed-in tariffs.[123] In India, bio-power capacity increased marginally to 10.5 GW, and generation remained stable at 45 TWh.[124]

The use of internationally traded pellets produced from wood and agricultural by-products for power generation continued to grow. In 2019, 18 million tonnes of pellets were used for power generation, up 7% from the previous year.[125] Nearly three-quarters of the pellets were used in the EU, particularly in the United Kingdom (8.5 million tonnes), Denmark (2.0 million tonnes) and the Netherlands, where use more than doubled to 0.8 million tonnes.[126] The rest were used in Japan (1.5 million tonnes) and the Republic of Korea (0.9 million tonnes).[127]

FIGURE 20.
Global Bioelectricity Generation, by Region, 2010-2020



Source: See endnote 105 for this section.

BIOENERGY INDUSTRY

Solid Biomass Industry

The companies that make up the solid biomass industry range from small, locally based entities that manufacture and supply smaller-scale heating appliances and their fuels, to major regional and global players involved in the supply and operations of large-scale district heating and power generation technology.

Most solid biomass projects rely on local feedstocks, such as wood residues and sugarcane bagasse, which can be used where they are produced. The growth in biomass pellet production to serve international markets for heat and electricity production is an important development in the sector, enabling countries to scale up the use of bioenergy even when they have limited national biomass resources.

In 2019, global production of biomass pellets reached an estimated 59 million tonnes.[128] Production data for China are uncertain but reached an estimated 20 million tonnes in 2018.[129] Production in the rest of the world grew 9% to 39.4 million tonnes in 2019.[130] The EU remained the largest regional producer (17 million tonnes), with production rising 5% that year.[131] Production from other European countries rose 17% to over 4 million tonnes, with production in the Russian Federation up 21%.[132] North American production increased 12% to 12.4 million tonnes.[133]

Excluding China, 19 million tonnes (5,326 PJ) of biomass pellets were used worldwide to provide heat in the residential and commercial sectors.[134] Pellets also provided an estimated 7.5% of the biomass used to heat buildings.[135] Worldwide, 18 million tonnes (31 PJ) were used for power generation, CHP production and other industrial purposes in 2019.[136]

The United States was the world's largest exporter of wood pellets in 2020.[137] While US pellet production decreased 2% to 9.3 million tonnes, exports rose 1% to 6.8 million tonnes.[138]

The wood pellet market for power generation continued to grow in the EU, where power producers can co-fire pellets with coal or convert coal plants, or build new plants that operate entirely on pellets.[139] The market also expanded in Japan and the Republic of Korea, stimulated by favourable support schemes.[140] By the end of 2020, Japan's Ministry of Economy, Trade and Industry had approved 70 projects with a capacity of nearly 8 GW under the feed-in tariff.[141]

Debate continues regarding the carbon savings and other environmental impacts related to pellet production from forestry materials and their use in power generation.[142] Starting in 2020, the sustainability provisions in the EU's RED included solid biomass, setting tighter sustainability criteria; as of 2021, minimum greenhouse gas reduction thresholds also were set for new projects seeking national support.[143] Sustainability criteria are being put in place in Japan as well, which is expected to reduce the use of palm-based products but increase the use of certified wood pellets.[144]

Liquid Biofuels Industry

The liquid biofuels industry produces ethanol, FAME biodiesel and increasingly HVO. Together, these comprise nearly all current global biofuels production and use. In addition, the industry is developing and commercialising new types of biofuels designed to serve new markets, notably for the aviation and marine sectors. These offer improved results in terms of greenhouse gas footprints and other sustainability criteria. There is a growing interest in the production of bio-materials and chemicals as part of the shift to a broader bioeconomy.[145] (→ *See Box 6.*)

In 2020, the industry was negatively affected by the lower demand for transport fuels during the COVID-19 pandemic, which constrained production and reduced profitability. At the height of the 2020 crisis, more than half of US ethanol industry production capacity was idled.[146] For example, ADM announced that it would idle four of its plants for at least four months in mid-2020.[147] Global ethanol prices fell 28% between January 2020 and April 2020, before recovering to within 5% of the January value by year's end.[148] In Brazil, ethanol demand was constrained and prices fell as much as 19% in 2020, with more sugar cane used for sugar than for ethanol production.[149]

By contrast, markets for FAME biodiesel were less affected by the pandemic. Although fossil diesel demand also fell, biodiesel

BOX 6. Bioenergy and the Bioeconomy

While bioenergy can directly replace fossil fuel use for heating, transport and electricity generation, biomass-based materials also could play an expanded role in the move to a sustainable bioeconomy. This would lower greenhouse gas emissions by reducing the use of fossil-based feedstocks for materials such as plastics and by replacing energy-intensive materials such as concrete and steel with wood- and agricultural-based materials.

Policy emphasis on recycling bio-based materials (within a circular economy) has increased, as has industry interest in developing a wider range of high-value-added products based on sustainably produced biomass feedstocks. Policy measures are being developed to promote the bioeconomy concept. The EU has drafted an integrated bioeconomy strategy, which it views as contributing to the European Green Deal, and the US Renewable Chemicals Act, introduced in 2020, provides tax credits for bio-based chemical production.

The growth of bioplastics is also a relevant trend. In 2020, these represented around 1% of the more than 368 million tonnes of plastic produced annually worldwide. Bioplastics that are also biodegradable, such as polylactic acid (PLA), polyhydroxyalkanoates (PHA) and starch-based plastics, account for 60% of global bioplastics production.

Industrial investment and engagement in bioplastics production grew in 2020. Braskem (Brazil), the world's largest bioplastics producer, produced 200,000 tonnes of polyethylene from ethanol that year. UPM (Finland) also announced a EUR 550 million (USD 644 million) investment in a German plant that will convert wood to bio-monoethylene glycol (BioMEG) and monopropylene glycol (BioMPG), intermediates used to produce plastics utilised as fibre and packaging material.

Source: See endnote 145 for this section.

levels were maintained due to higher incentives or increased blending mandates in key producing countries, such as the United States, Brazil and Indonesia.[150] Biodiesel production in Argentina was affected by import duties in the United States.[151]

HVO production capacity rose sharply in 2020, driven by attractive market incentives, particularly those provided by the US RFS2 and California's LCFS and under the EU's RED.[152] Many plans for new capacity were announced.[153] Total HVO production capacity reached an estimated 9.2 billion litres (0.3 EJ) in 2020.[154] When taking into account both the expansion of existing facilities and new production sites, the additional capacity under construction or being planned was estimated to reach more than 41 billion litres (equivalent to 1.1 EJ per year) at the end of 2020.[155] With these new projects, total existing and planned HVO capacity is expected to exceed that of FAME biodiesel and to equate to around 60% of 2020 ethanol production, underscoring a significant evolution of biofuels in transport.[156]

Most of the existing and planned capacity is based on treating vegetable oils, animal fats and other by-products with hydrogen to produce HVO/HEFA, which then can be refined to produce fuels with the same properties as fossil-based diesel, jet fuel and other hydrocarbon products, including biopropane. When these feedstocks are wastes or by-products (such as used cooking oil, animal fats or tall oil), the greenhouse gas savings associated with their use are much higher than for virgin vegetable oils, such as palm or canola oil.[157] The fuels then qualify for higher credits under biofuels support schemes. For example, under the California LCFS, HVO from used cooking oil qualifies for a credit up to twice that for HVO produced from soy oil.[158] Under the EU RED, waste- and residue-based fuels are counted twice towards national targets and can earn double credits under national support schemes in member countries.[159]

Production of
HVO biodiesel
rose sharply in 2020, driven by attractive market incentives in the United States and Europe.

In 2020, several companies that produce HVO fuels announced that new capacity was available or planned. For example, Phillips 66 (US) announced plans to extend production capacity at its UK Humberside plant from 57 million litres to 460 million litres per year and to convert the Rodeo facility at its San Francisco oil refinery to produce HVO and jet fuel.[160] The Rodeo facility would be one of the world's largest such plants, producing 4 billion litres of the fuels from used cooking oils, fats, greases and soy oils starting in 2024.[161]

Other oil majors are undertaking similar refinery conversions. Total (France) announced plans in 2020 to convert its Grandpuits refinery in the Seine-et-Marne department of France to produce biojet fuel, with an investment of EUR 500,000 (USD 0.6 million).[162] This complements Total's La Mède plant, which was converted in 2019 to produce 570 million litres of HVO and biojet from palm oil and waste fats and oils.[163] ENI (Italy) converted its refineries in Venice and Sicily to make HVO and is more than doubling its capacity in Venice to more than 1.6 billion litres.[164] Marathon Oil (US) planned to convert its North Dakota plant to HVO by the end of 2020, with an annual production capacity of 700 billion litres, along with its Martinez refinery (California), which is expected to reach an HVO capacity of some 3 billion litres by 2022.[165] While most HVO projects are in the United States and Europe, Pertamina (Indonesia) is developing two projects in Indonesia, which will produce a combined 1.5 billion litres of HVO from palm oil under the country's strategy to increase the share of biofuels in diesel to 40%.[166]

In addition to these projects, which hydrogenate oils and fats, several other technological approaches that use a wider range of feedstocks are being demonstrated and commercialised. Projects designed to produce HVO and jet fuels by gasifying MSW or forestry residue feedstocks and synthesising the resulting gas via the Fischer-Tropsch process are under development. Their aggregate capacity is over 1 billion litres of fuel and includes the use of feedstocks such as forestry and timber residues and processed MSW, which is less expensive and thus produces cheaper fuel.[167]

The Red Rock Biofuels (US) project in Lakeview, Oregon (US) will convert 166,000 dry tonnes of waste woody biomass into 60 million litres of drop-in jet, diesel and petrol fuels to be supplied under eight-year off-take agreements with FedEx and Southwest Airlines.[168] The project is based on gasification and Fischer-Tropsch technology provided by Velocys (UK). Velocys has launched a project at Immingham (UK) in collaboration with British Airways PLC and Shell (Netherlands) to produce jet fuels from MSW and is developing another in the US state of Mississippi that will use paper and timber residues from local industries.[169] In 2020, Fulcrum Energy (US), which is developing two MSW projects in the United States, began work to produce jet fuel from MSW in Japan, in collaboration with Japan Airlines Marubeni, JXTX Nippon OIL and JGC Japan.[170]

Three projects involving pyrolysis of wastes and other feedstocks were under way in Canada and in the Netherlands at year-end 2020.[171] The Lieksa plant of Green Fuel Nordic Oy (Finland), with a capacity of 24 million litres per year, also began supplying fuel oil (for heat) produced by the pyrolysis of wood residues.[172]

Other approaches include the conversion of ethanol to fuels such as biojet. In 2020, the FLITE consortium, led by SkyNRG (Netherlands) and Lanzatech (US), initiated a project in the Netherlands to build an ethanol-to-biojet facility to convert waste-based ethanol to sustainable aviation fuel, producing more than 30,000 tonnes per year.[173] The project received EUR 20 million (USD 23 million) in grants from the EU's Horizon 2020 programme.[174]

Only a small number of facilities producing ethanol from cellulosic materials were operating successfully worldwide by the end of 2020.[175] During the year, construction was under way at Clariant's (Switzerland) planned plant in Romania, and the company also has licensed its technology for projects in Bulgaria and China.[176]

Despite the sharp drop in air travel and related fuel use in 2020, the market for sustainable aviation fuels (SAF) – biofuels tailored for use in aircraft engines – continued to expand, with seven fuel pathways approved for use by year's end.[177] As of 2020, 45 airlines had used SAF, and 7 airlines were actively investing in SAF production capacity.[178] Some 100 million litres of SAF was expected to be available for use in 2021.[179] The availability of these fuels has increased at airports, with continuous supply established in 2020 at San Francisco International Airport and at London Luton Airport.[180]

Biomethane production is rising, and accounts for around 1% of total global fossil gas demand.

GASEOUS BIOMASS INDUSTRY

The gaseous biomass industry is involved mainly in producing and using gas produced by the anaerobic digestion of biomass feedstocks, which produces biogas, a mixture of methane, CO_2 and other gases.[181] The same process occurs in waste landfills, and the resulting landfill gas can be collected and used – providing energy while also reducing emissions from the landfill site. The gases can be used directly for heating or power generation. Alternatively, the methane component can be separated and compressed and used to replace fossil gas by injecting it into gas pipelines or for transport purposes. Biomethane production totalled an estimated 1.4 EJ in 2018, or just over 1% of total global fossil gas demand.[182]

Biogas can be used at a small scale in developing economies as a sustainable fuel source for cooking, heating and electricity production and to improve energy access. (→ *See Distributed Renewables chapter.*) In developed economies, most biogas is used for power generation or in CHP systems, often stimulated by favourable feed-in tariffs and other support mechanisms.[183] The energy content of biogas upgraded to biomethane and used for transport or injection into gas grids, primarily in the United States and Europe, rose to around 170 PJ in 2020.[184] Stimulating this development are incentives that favour biomethane production over power production, notably under the US RFS2 and the California LCFS, which offer larger incentives than those for power or heat generation.[185]

US biomethane production capacity rose sharply in 2020, with many new projects based on landfill gas, cattle waste, and other wastes and residues. In total, 157 production facilities were in operation during the year (up 78% from 2019), with another 76 projects under construction and 79 projects in the planning phase.[186] The total operating production capacity in 2020 was more than 60 PJ.[187]

Recent projects illustrate that both specialist companies and energy majors are involved in the rapidly growing US biomethane sector.[188] In August 2020, Republic Services and Aria Energy (both US) announced a start-up project to process and purify landfill gas from the South Shelby (Tennessee) landfill site; BP will then inject the gas into the interstate natural gas pipeline grid and market it to renewable energy customers.[189] In September 2020, Fortistar and Rumpke Waste and Recycling (both US) started building a landfill gas project in Shiloh, Ohio that will extract and capture waste methane and transform it into biomethane for distribution to natural gas vehicle fuelling stations.[190]

In 2020, Aemetis (US) completed construction of two dairy digesters and a pipeline to supply biomethane to provide fuel for biomethane trucks and buses.[191] Verbio (Germany) announced the installation of an anaerobic digester at the former DuPont cellulosic ethanol plant in Nevada, which will now use 100,000 tonnes of corn stover annually to produce biomethane with the energy equivalent of 80 million litres of petrol.[192]

Biogas and biomethane installations also have grown rapidly in Europe, which in 2020 was home to at least 18,855 biogas plants producing 176 TWh, as well as 726 biomethane plants with a total capacity of 64 PJ (an increase of 66 biomethane plants and 4 PJ compared to 2019).[193] Recent projects include Gasum's (Finland) construction of two new biogas plants in Sweden: a 120 gigawatt-hour (GWh) plant that will produce liquefied biogas from manure and food waste slurry from a local pretreatment plant, and a 70 GWh plant established alongside a local farmer co-operative that will use manure and other agricultural waste products.[194] Weltec Biopower (Germany), working with Agripower France, a local agroindustrial firm, commissioned a EUR 11 million (USD 13 million) biomethane plant in Normandy, France that processes around 70,000 tonnes of substrates to produce biogas, which is then refined into biomethane.[195] The plant's raw material mix, comprising inexpensive waste and other byproducts from the agriculture and food industry, is gathered from within a seven-kilometre radius.[196]

The market continued to expand in China, where the national energy plan prioritises the growth of biogas and biomethane. Construction was under way on two EnviTec Biogas projects: one in Henan province, where the state-run PowerChina Group is the prime contractor, and the other operated by Shanxi Energy & Traffic Investment in Qinxian province.[197] Once completed, the Qinxian plant's four digesters are expected to convert agricultural waste such as corn stover into around 0.5 PJ of biogas per year, which then will be upgraded into biomethane.[198]

Growing demand from delivery companies for clean fuels is boosting the biomethane market. The UK supermarket company ASDA ordered 202 biomethane-fuelled Volvo FH tractors in 2020 and aims to convert all of its trucks from diesel to biomethane by 2024, after in-house trials showed that biomethane reduced CO_2 emissions more than 80%.[199] Air Liquide (France) also will provide biomethane at six of its sites.[200]

BIOENERGY WITH CARBON CAPTURE AND STORAGE OR USE

The capture and storage of carbon dioxide emitted when bioenergy is used is a key feature of many low-carbon scenarios.[201] Removing from the atmosphere the CO_2 that is produced during bioenergy production, which is considered part of the carbon cycle, offers a dual benefit resulting in net negative emissions.[202] Although policy makers have shown increasing interest in such options, strong policy drivers that might make such efforts economically attractive are lacking. Thus, very few projects demonstrating these technologies have operated at scale to date.[203]

Additional pilot-scale carbon capture projects were conducted during 2020. Drax Power (UK) successfully demonstrated carbon capture using a novel technology at its large-scale bio-power plant in the United Kingdom and has begun planning for large-scale application.[204] In the United States, Power Tap is producing hydrogen for use as a transport fuel by reforming biomethane and capturing the CO_2 that is released.[205]

KEY FACTS

- **An estimated 0.1 GW of new geothermal power generating capacity came online in 2020** – significantly less than in recent years – with just one country (Turkey) representing the bulk of new installations.
- **Direct use of geothermal energy for thermal applications continues to grow around 8% annually**, but the market remains geographically concentrated, with only four countries (China, Turkey, Iceland and Japan) representing three-quarters of all direct geothermal use.
- The main focus continued to be on technological innovation, such as new resource recovery techniques and seismic risk mitigation, with the aim of **improving the economics, lowering the development risk and strengthening prospects** for expanded geothermal resource development.

GEOTHERMAL POWER AND HEAT

GEOTHERMAL MARKETS

Geothermal resources are harnessed for energy applications through two primary pathways (similar to solar- and bioenergy), either through the generation of electricity or through various "direct-use" thermal applications (without conversion to electricity), such as space heating and industrial heat input[i]. Geothermal electricity generation was around 97 TWh in 2020, while direct useful thermal output was about 128 TWh (462 PJ)[ii].[1] In some instances, geothermal plants produce both electricity and heat for thermal applications (co-generation), but this option depends on location-specific thermal demand coinciding with the geothermal resource.

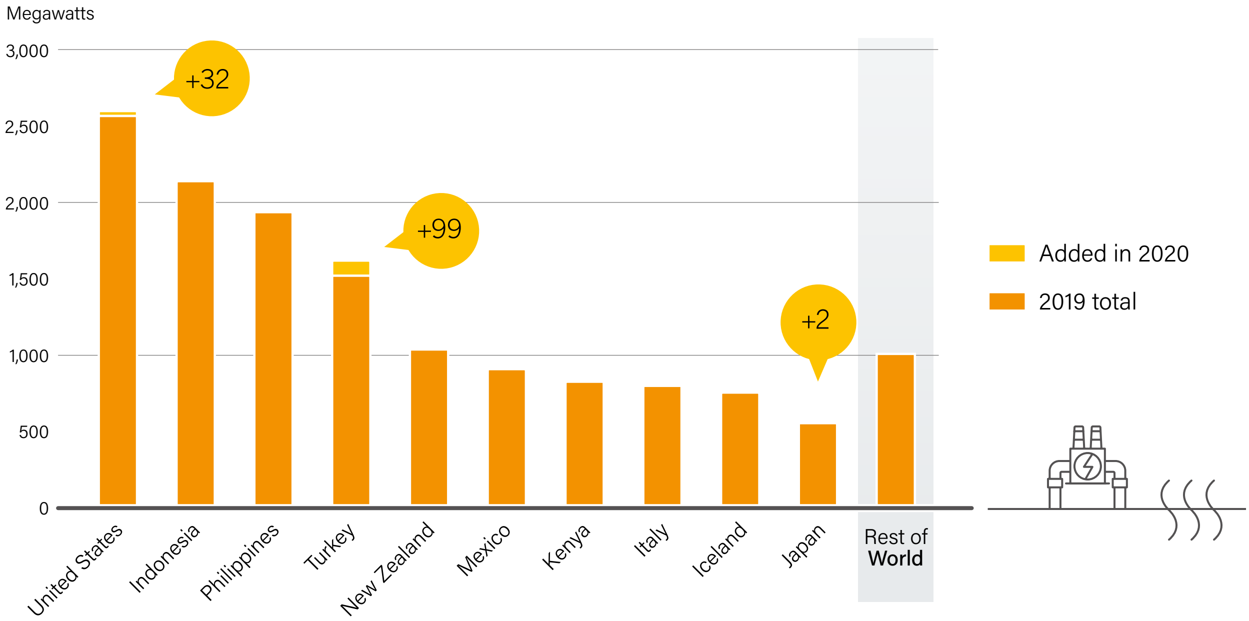
An estimated 0.1 GW[iii] of new **geothermal power** generating capacity came online in 2020, bringing the global total to around 14.1 GW.[2] The distinct feature of 2020 was the disproportionately small growth in capacity relative to recent years (attributable in part to pandemic-related disruption), with almost all new facilities located in Turkey. Other countries that added minor amounts of geothermal power capacity in 2020 were the United States and Japan.[3] (→ *See Figure 21.*)

i The two pathways cross downstream when geothermal resources are used for electricity generation, because a portion of the electricity is used for "in-direct" thermal applications, such as cooling (air conditioning) and heating (via heat pumps or through electric resistance).

ii This does not include the renewable final energy output of ground-source heat pumps. (→ *See Systems Integration chapter.*)

iii Net additions were somewhat lower due to decommissioning or derating of existing capacity.

FIGURE 21.
Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2020



Note: Figure shows known new capacity and capacity increases at existing facilities but does not indicate known capacity decommissioning or derating of existing facilities, although those may be reflected (at least partially) in total capacity values.

Source: See endnote 3 for this section.

The 10 countries with the largest stock of geothermal power capacity at the end of 2020 were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland and Japan.[4] In some instances, effective generating capacity (running capacity) may be lower than indicated values, due to gradual degradation of the steam-generating capability of geothermal fields or to insufficient drilling of make-up[i] wells to replenish steam flow over time. For example, the effective net[ii] generation capacity in the United States was 2.6 GW at the end of 2020, whereas the gross nameplate generator capacity was 3.7 GW.[5]

Turkey's geothermal capacity expansion in 2020 (net of any deratings) was reported to be 99 MW, which was the country's smallest annual increment since 2014 and less than half the mean annual additions for the preceding five years.[6] However, new capacity installations reported during the year amounted to around 128 MW, all in the last quarter.[7] Five binary-cycle[iii] power plant commissions were announced for the month of October, ranging from 3.5 MW to 26 MW.[8]

Each of these plants, including the 20 MW Nezihe Beren facility, qualified for Turkey's highest national feed-in tariff for geothermal installations due to local content manufacturing.[9] Following an identical addition in 2019, the Pamukören complex added another 32 MW unit in December.[10] Also, the Efeler complex was expanded at least 25 MW by the end of the year.[11] All of Turkey's new geothermal power plants are located in Western Anatolia (along with all existing capacity), with most concentrated in an area extending less than 100 kilometres.[12] In 2020, Turkey still ranked fourth globally for total geothermal power capacity, with 1.6 GW.[13] Geothermal power supplies around 3% of the country's electricity.[14]

The technology-specific feed-in tariff (FIT) in place since 2011 has been instrumental in Turkey's geothermal energy development.[15] Revisions to the FIT were anticipated throughout 2020, possibly causing some projects to be rushed to completion before the scheduled expiration of the FIT at year's end (but this was extended to mid-2021 on account of the pandemic).[16] A new FIT introduced in early 2021, around one-third lower than the existing tariff, abandoned the USD-based structure for the local currency, for both the basic tariff and the local content increment.[17]

The United States holds an enduring global lead in installed geothermal power capacity despite being a relatively stagnant market in recent years. Minor changes in 2020 raised the country's net geothermal capacity by around 32 MW, bringing total net operating capacity to 2.6 GW.[18] After more than 30 years of operation, the Steamboat Hills power plant in Nevada saw its capacity rise by around 19 MW (to 84 MW) following refurbishment that included the replacement of all generating equipment as well as resource modifications.[19] The upgrades are expected to increase the plant's productivity and efficiency while reducing maintenance costs per unit of output.[20] In November, the Puna geothermal power plant in Hawaii, which had been disabled by a volcanic eruption in 2018, resumed partial operation.[21] Geothermal power in the United States generated as much as 16.9 TWh[iv] in 2020, a notable increase of 9.4% over 2019, representing around 0.4% of US net electricity generation.[22]

In Japan, following the completion of two plants in 2019, some small additions saw light in 2020. The renovation of the Otake geothermal plant in Oita Prefecture improved efficiency and raised its capacity by 2 MW to 14.5 MW.[23] The upgrade improved stability and efficiency of operation by incorporating bi-level steam pressure to feed a single turbine.[24] Elsewhere, two 150 kW low-temperature binary modules were installed: a bottoming-cycle unit at an existing high-temperature geothermal plant to more fully use the available thermal energy, and a unit at a traditional Japanese spa.[25]

Indonesia, which ranks second to the United States for installed geothermal capacity, did not manage to complete any facilities in 2020 due to pandemic-related delays to three projects that previously were planned to come online that year.[26] The delayed projects, now expected online in 2021, are the 45 MW Sorik Marapi Unit 2 in North Sumatra (Unit 1 completed in 2019), the 90 MW Rantau Dadap and the 5 MW Sokoria Unit 1.[27] In all, Indonesia aimed to complete nearly 200 MW of geothermal power capacity in 2021.[28] A potential danger associated with geothermal energy exploration and extraction is the uncontrolled or excessive release of noxious gases. During preparations for commissioning of the Sorik Marapi Unit 2 in early 2021, procedural failures led to the release of hydrogen sulphide gas in concentrations that caused multiple injuries and five deaths among nearby residents.[29]

i If a geothermal power plant extracts heat and steam from the reservoir at a rate that exceeds the rate of replenishment across all its boreholes, additional wells may be drilled over time to tap additional steam flow, provided that the geothermal field overall is capable of supporting additional steam flow.

ii In general, a power plant's net capacity equals gross capacity less the plant's own power requirements and any seasonal derating. In the case of geothermal plants, net capacity also would reflect the effective power capability of the plant as determined by the current steam production of the geothermal field. See endnote 5 for this section.

iii In a binary-cycle plant, the geothermal fluid heats and vaporises a separate working fluid (with a lower boiling point than water) that drives a turbine to generate electricity. Each fluid cycle is closed, and the geothermal fluid is re-injected into the heat reservoir. The binary cycle allows an effective and efficient extraction of heat for power generation from relatively low-temperature geothermal fluids. Organic Rankine Cycle (ORC) binary geothermal plants use an organic working fluid, and the Kalina Cycle uses a non-organic working fluid. In conventional geothermal power plants, geothermal steam is used directly to drive the turbine.

iv Based on net generation of 15.5 TWh in 2019, revised from 16 TWh as reported in early 2020. Likewise, generation for 2018 was first reported as 16.7 TWh but later revised to 16 TWh. The implied growth of 9.4% may be found to be smaller, if 2020 generation figures are later revised downward, as was the case for the preceding two years. See endnote 22 for this section.

Along with Turkey, Indonesia has been a relatively strong and consistent market with around 700 MW added since 2015 and a total installed capacity of 2.1 GW.[30] Geothermal power supplied 14.1 TWh of electricity to Indonesia in 2019, or 4.8% of the country's total generation that year.[31]

As part of an effort to more than double the renewable share of Indonesia's electricity supply to 23% by 2025, the government committed to absorbing some of the early exploration risk by taking over exploratory drilling from private developers going forward.[32] The objective is to accelerate progress towards long-term geothermal energy targets by improving geothermal data before again auctioning off development areas to developers, starting in 2023.[33] Combined with new reimbursements for exploration activities, the government expects these changes to reduce the risk premium on new projects, leading to lower electricity rates for consumers.[34] Exploratory drilling was planned for three areas in 2021 but later reduced to two due to budget constraints.[35] Indonesia's geothermal resources are located mainly in mountainous conservation areas and far from load centres, further complicating development.[36]

With no capacity added since 2018, the Philippines still ranks third for total installed capacity, at 1.9 GW, although dependable capacity is reported to be somewhat less (1.8 GW).[37] To spur investment in geothermal power, the government moved in 2020 to allow full foreign ownership in renewable energy projects.[38] Nonetheless, with five prospective geothermal areas up for auction until early 2021, no foreign firms had placed bids by the end of 2020.[39] The local geothermal industry awaits the implementation of a risk mitigation fund by the government to ameliorate the risk of pursuing the mostly low-enthalpy resources that are up for exploration.[40] New discoveries of high-enthalpy resources in the country are considered unlikely, and for existing known resources, mountainous terrain adds to project costs, while permitting is complicated by laws protecting ecologically sensitive areas and rural populations.[41]

New Zealand's geothermal electricity sector has been relatively inactive over the last five years, following a period of rapid growth in the use of geothermal energy in the prior decade.[42] While the country has not added any capacity since 2018, geothermal power has remained at nearly 18% of the generation mix since 2015, in large part because the country has seen no growth in electricity demand during the last decade.[43]

Demand growth was expected to be dampened further in 2021 by the proposed closing of an aluminium smelter.[44] However, the successful appraisal of a new geothermal field confirmed the viability of the proposed 152 MW Tauhara plant, to be built by 2023 near Taupō on the North Island.[45] The developer considers the field to be especially attractive because its associated CO_2 emissions are just one-eighteenth those of a coal-fired unit.[46] By early 2021, New Zealand's 32 MW Ngawha plant was commissioned after three years of construction.[47]

Worldwide, the capacity for **geothermal direct use**[i] – direct extraction of geothermal energy for thermal applications – increased by an estimated 2.4 gigawatts-thermal (GW_{th}) (around 8%) in 2020, to an estimated 32 GW_{th}.[48] Geothermal energy use for thermal applications grew an estimated 11.3 TWh during the year to an estimated 128 TWh (462 PJ).[49]

Geothermal heat has varied direct applications. Bathing and swimming remains the largest category, comprising around 44% of total use in 2019 (latest available consolidated data), and it is growing around 9% annually on average.[50] Second, but with the fastest growth, was space heating (around 39% of direct use), expanding around 13% annually on average.[51] The remaining 17% of direct use was allocated to greenhouse heating (8.5%), industrial applications (3.9%), aquaculture (3.2%), agricultural drying (0.8%), snow melting (0.6%) and other uses (0.5%).[52]

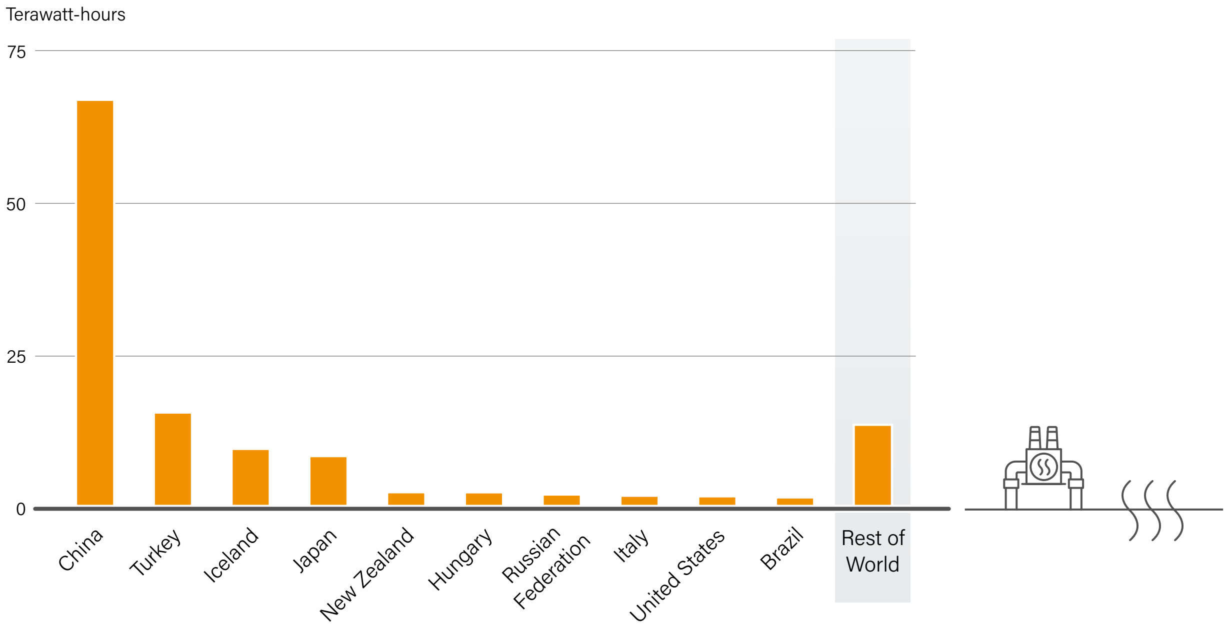
The top countries for geothermal direct use (in descending order) in 2020 were China, Turkey, Iceland and Japan, which together represented roughly 75% of the global total.[53] (→ *See Figure 22.*)

Geothermal direct use capacity

increased by around 8% in 2020, to an estimated 32 GW_{th}.

i Direct use refers here to deep geothermal resources, irrespective of scale, that use geothermal fluid directly (i.e., direct use) or by direct transfer via heat exchangers. It does not include the use of shallow geothermal resources, specifically ground-source heat pumps. (→ *See Heat Pumps section in Systems Integration chapter.*)

FIGURE 22.
Geothermal Direct Use, Estimates for Top 10 Countries and Rest of World, 2020



Source: See endnote 53 for this section.

China is both the largest user of geothermal heat (47% of the total) and the fastest growing market, with its installed capacity growing more than 18% annually on average during 2015 through 2019, and consumption growing more than 21% annually on average.[54] That period of growth coincides with the government's first geothermal industry plan, issued in 2017, for rapid expansion of geothermal energy use, especially for heat applications.[55] As of 2019, China had an estimated 14.2 TW_{th} of installed geothermal capacity for direct use (excluding heat pumps), with 7 TW_{th} allocated to district heating, 5.7 TW_{th} serving bathing and swimming applications, and the rest used for food production and other industry.[56] Most of China's hydrothermal resources are relatively low enthalpy; of the 546 production wells drilled during the period 2015 through 2019, 94% had a wellhead temperature below 100°C.[57]

Other top countries (Turkey, Iceland and Japan) have experienced more moderate capacity growth of around 3-4% annually (consumption growth of 3-5%).[58] In Turkey, geothermal development is devoted mainly to electricity generation, while investment in direct use has contracted somewhat over the last decade.[59] Iceland has significant thermal demand served by district heat networks and continues limited drilling of reinjection and make-up wells for those systems as well as for existing power plants.[60] In Japan, more than 80% of direct use is believed to be associated with bathing facilities located near geothermal springs, but due to limited data gathering, information is lacking on immediate prospects for further development.[61] The remaining countries that rely on geothermal heat, each representing less than 3% of direct use, include (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.[62]

Some of the most active markets for direct use do not have access to high-enthalpy resources and often endure higher costs and greater technical challenges to access geothermal heat. Several examples are found in continental Europe where low-to-medium enthalpy resources are used mainly for district heating and greenhouse cultivation. This market remained active in 2020 with notable new development in France, Germany and the Netherlands.

In Germany, Munich completed drilling in 2020 for what will be the country's largest geothermal plant, exceeding 50 megawatts-thermal (MW_{th}) and expected to provide heat for more than 80,000 city residents.[63] By use of absorption chillers, the plant also will contribute to the city centre's district cooling network, which was undergoing expansion during the year.[64] In addition, plans were under way for what would be the seventh geothermal facility serving the municipality since the first plant came online in 2004.[65]

France continues to see growing use of localised geothermal resources, mostly for district heating. In the greater Paris region, several geothermal district heating systems have been developed in recent years, with new projects started or announced in 2020. In August, drilling commenced in Vélizy-Villacoublay, southwest of central Paris, on a system that is expected to meet 66% of the energy demand of the local district heat network, serving the equivalent of 12,000 dwellings; the project was aiming for completion in 2021.[66]

In the eastern suburbs of Paris, the communities of Champs-sur-Marne and Noisiel advanced work on the construction of a joint heating network following a drilling phase. Expected for completion in late 2021, the geothermal district heating project will supply heat to the equivalent of 10,000 homes across the two municipalities; the renewable energy component of the supply is expected to be 82%.[67] For another project in the nearby communities of Drancy and Bobigny, four wells were drilled in 2020 and distribution of geothermal heat began in early 2021.[68] The project is expected to supply the equivalent of 20,000 homes when completed, displacing 60% of the fossil fuels currently used on the network.[69]

Technology innovations promise expanding project viability and are attracting investment from the oil and gas majors.

A once-promising geothermal project in the Alsace region of France came to an apparent end in late 2020, and its fate could have repercussions for geothermal development in the area going forward.[70] After a series of earthquakes over the course of a year, attributed to geothermal drilling and associated well stimulation on the northern outskirts of Strasbourg, local authorities ordered the final shutdown of the Vendenheim facility in December, along with three other permitted projects in the area.[71] Local authorities claimed that the operator had exceeded permitted well pressures for stimulation as well as the authorised well-drilling depth, reaching beyond the sandstone strata into the deeper bedrock, which increased the risk of seismic activity.[72]

Problems associated with induced seismic activity also affected projects in the Netherlands. A Dutch geothermal greenhouse operation was declared bankrupt in 2020 after two years of inactivity following seismic disturbances in 2018.[73] Although the operator claimed that the earthquakes near the project were unrelated, Dutch regulators declared continued operations too risky.[74] The operator observed that unlike other Dutch geothermal projects that tap only the porous sandstone layer, the drilling in this case penetrated deep bedrock in the search for greater hydrothermal flow.[75]

In the Netherlands, geothermal energy output grew 10% in 2020 (following 51% growth in 2019), to 6.2 PJ, driven mostly by drilling activity in the preceding year.[76] The country's use of geothermal energy is generally limited to greenhouse horticulture, but expansion into district heating and industrial applications is anticipated, pending the construction of heat networks but also the need to overcome political, financial and social barriers to uses beyond horticulture.[77] Multiple drilling operations were under way or completed in 2020.[78]

As Dutch mining laws and regulations pertaining to geothermal exploration and development were being reviewed in 2020, the country's geothermal industry raised concerns about regulatory uncertainty and any associated project delays.[79]

GEOTHERMAL INDUSTRY

In a year of project delays as well as both meagre and highly concentrated market growth, the geothermal industry found promise in the pursuit of new technology. Technological innovation, such as new resource recovery techniques and seismic risk mitigation, continued to be the industry's main focus towards achieving improved economics, lower development risk and overall better prospects for expanded geothermal resource development around the world. However, industry hopes to expand development beyond the relatively few and concentrated centres of existing activity remained largely unfulfilled, as in years past. While high costs and project risks continue to create a drag on investment in most places, especially in the absence of government support (i.e., feed-in tariffs and risk mitigation funds), certain pockets of industry innovation attracted new investment from established entities in the energy industry.

In some markets, the real or perceived risk of induced seismic activity related to geothermal development appears to present a specific risk to individual geothermal developers, if not a systemic risk to the industry (as evidenced by recent events in France and the Netherlands). Beyond the projects directly affected, collateral damage has emerged in the form of cancellations of other nearby projects (i.e., Alsace) and of shaken public confidence.[80] The prevalence of such events has grown with the increased application of hydraulic fracturing (well stimulation), as was used in the Vendenheim project in Strasbourg. Before that, earthquakes associated with such enhanced geothermal systems (EGS)[i] in Switzerland (Basel in 2006 and St. Gallen in 2013) caused severe setbacks for Swiss geothermal prospects.[81] Yet a solution is needed if geothermal energy use is to expand significantly beyond the relatively few locations in the world that enjoy the most valuable, medium-to-high enthalpy geothermal resources.[82]

Driven by the early setbacks and the need to rekindle local geothermal development, Swiss researchers continue to pursue technological and procedural solutions to the problem of induced seismic activity. In late 2020, Geo-Energie Suisse AG (GES) proved the concept of forming a sufficiently permeable "heat exchanger" reservoir at a depth of 4-5 kilometres through a process of multi-stage (incremental steps) stimulation that minimises the probability of induced seismic events.[83] Further validation of the technology will be conducted at the US test site FORGE[ii] in Utah. GES anticipates that these findings will improve government confidence in a currently suspended geothermal pilot project for the technology in the canton of Jura.[84]

Across Germany, the Netherlands and Italy, industry actors and research institutions worked to draw attention to the potential of geothermal energy to aid in the renewable energy transition (particularly to meet thermal energy demand) and to highlight the need for additional support policies. In Germany, geothermal industry and research institutions came together under the banner of "Heat transition through geothermal energy" (Wärmewende durch Geothermie).[85] The Dutch geothermal

i EGS encompasses the use of hydraulic fracturing of hot rock to create the conditions for a geothermal reservoir. Specifically, the objective is to attain a combination of heat, permeability and flow of geothermal fluid that is sufficient to make extraction economical for heat and/or electricity generation.

ii Frontier Observatory for Research in Geothermal Energy.

industry also indicated that the sector will be critical to the pending heat transition in the Netherlands, while drawing attention to the alleged lack of financial incentives and to the perceived un-level playing field, relative to other technologies.[86] The Italian Geothermal Union similarly claimed that ineffective incentives and national legislation had severely slowed Italy's geothermal development and jeopardised industrial know-how.[87]

The persistent but variable emissions of CO_2 and hydrogen sulphide from open-loop geothermal facilities remain a concern. In most instances, CO_2 emissions are far below those from fossil fuel facilities, but they are non-negligible nonetheless, and sometimes geothermal plant emissions can rival those of coal-fired power plants.[88] Significant progress has been made in recent years to advance the process of sequestering CO_2. The Icelandic company Carbfix, with its international partners, has developed a process to permanently capture and store CO_2 by imitating and accelerating the natural process through which dissolved CO_2 reacts with sub-surface rock formations to form stable carbonate minerals.[89] In 2020, an agreement was reached to build a CO_2 sequestration plant in Iceland capable of removing 4,000 tonnes of atmospheric CO_2 per year, combining the Carbfix method with the direct air capture technology for CO_2 removal provided by Climeworks of Switzerland.[90]

When resource exploration disappoints and precludes conventional hydrothermal projects, new technologies may help. For example, in Gertetsried, Germany, a developer drilled two wells, starting in 2013 (the first being the deepest geothermal well in Europe to date, at over 6,000 metres), that proved unable to produce enough hydrothermal flow to make a conventional geothermal power project viable.[91] Eavor Technologies (Canada) joined the project in 2020 to deploy its new modular closed-loop technology, which is well suited for the local geothermal conditions and thus to improve viability of the site.[92] Eavor's technology, first demonstrated in Alberta (Canada) in early 2020, uses directional drilling techniques developed in the oil and gas industry to create a closed-loop system that circulates a working fluid to extract heat from bedrock without bringing geothermal fluid (brine) to the surface. In addition to eliminating surface emissions of CO_2 and hydrogen sulphide, the thermosiphon effect (bringing hot fluid up on one side as cold fluid descends on the other) of the closed-loop design reportedly mitigates the energy demand from pumping that is associated with other geothermal techniques.[93]

Such innovations have gained the attention of the oil and gas majors. In early 2021, Eavor Technologies completed a USD 40 million funding round including investments from BP Ventures and Chevron Technology Ventures, among others.[94] Chevron also announced investment in Baseload Capital A.B. (Sweden), whose projects include the deployment of modular "heat power" units by Climeon (Sweden) for low-temperature electricity generation from geothermal or other sources of excess heat (including both of the units installed in Japan in 2020).[95]

The industrial entities that provide the technology for geothermal energy capture and conversion (excluding drilling) comprise a relatively small group. The power unit (turbine) manufacturers include Atlas Copco (Sweden), Exergy (Italy, subsidiary of Tica Group of China since 2019), Fuji Electric (Japan), Mitsubishi and its subsidiary Turboden (Japan/Italy), Ormat (US) and Toshiba (Japan).[96] In some key markets, such as Turkey, the suppliers of binary-cycle technology are prominent (for example, Atlas Copco, Exergy and Ormat), while other suppliers specialise in more conventional flash turbines (for example, Toshiba and Fuji).[97] Ormat Technologies and Exergy supplied most of the binary-cycle plants that were completed during the year.[98]

KEY FACTS

- The **global hydropower market expanded in 2020** but did not recover from several years of deceleration.
- **China added 12.6 GW of hydropower capacity in 2020**, its largest addition of the previous five years, and regained the lead from Brazil in commissioning new hydropower capacity.
- **Hydropower faced challenges** including operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure.

HYDROPOWER

HYDROPOWER MARKETS

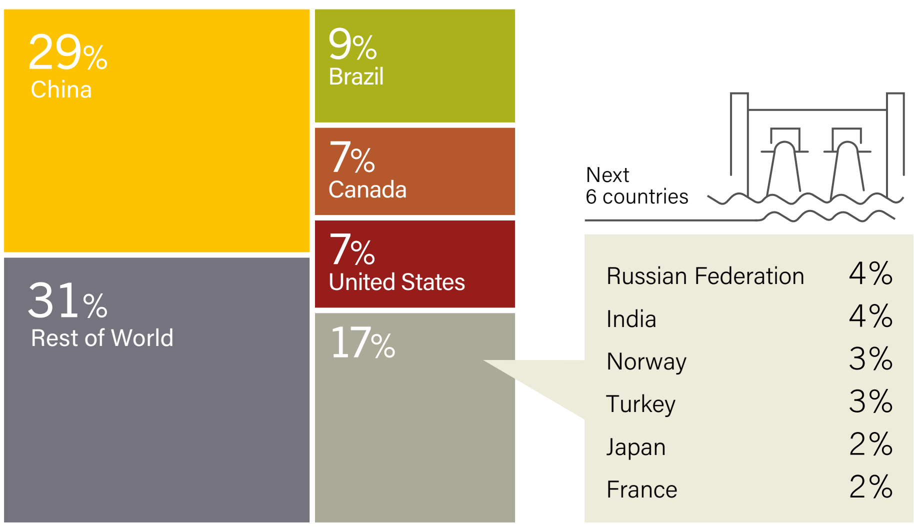
Despite a 24% increase in capacity additions, driven mainly by China[i], the global hydropower market did not recover in 2020 following several years of deceleration.[1] The effects of the COVID-19 pandemic were notable, with the market slowing as construction was halted temporarily, component supply chains were disrupted, and energy demand fell.[2] Capacity additions for the year totalled an estimated 19.4 GW, bringing the total installed capacity to 1,170 GW[ii].[3] The top 10 countries for total capacity did not change and were, in order of installed capacity: China, Brazil, Canada, the United States, the Russian Federation, India, Norway, Turkey, Japan and France, together representing more than two-thirds of the global total.[4] (→ *See Figure 23 and* ***Reference Table 2*** *in GSR 2021 Data Pack.*)

China regained the lead from Brazil in commissioning new hydropower capacity (both large and small installations), followed by Turkey, India, Angola and the Russian Federation.[5] (→ *See Figure 24.*) As large and economically viable hydrological

i China's share represented 65% of global total capacity additions; if China is excluded, worldwide installed capacity decreased 44% between 2019 and 2020.

ii Where possible, all capacity numbers exclude pure pumped storage capacity unless otherwise specified. Pure pumped storage plants are not energy sources but rather means of energy storage. As such, they involve conversion losses and are powered by renewable and/or non-renewable electricity. Pumped storage plays an important role in balancing grid power and in the integration of variable renewable energy resources.

FIGURE 23.
Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2020



Source: See endnote 4 for this section.

resources become more limited, markets increasingly have developed the remaining untapped potential that is available mainly from marginal resources and pumped storage.[6]

Global pumped storage capacity (which is counted separately from hydropower capacity) increased 1.5 GW (0.9%) in 2020, primarily from new installations in China and Israel.[7]

Global hydropower generation increased 1.5% in 2020 to reach an estimated 4,370 TWh, representing around 16.8% of the world's total electricity generation.[8] While some yearly variations in global hydropower generation are due to changes in installed capacity, most are the result of fluctuations in weather patterns and in local operating conditions[i].

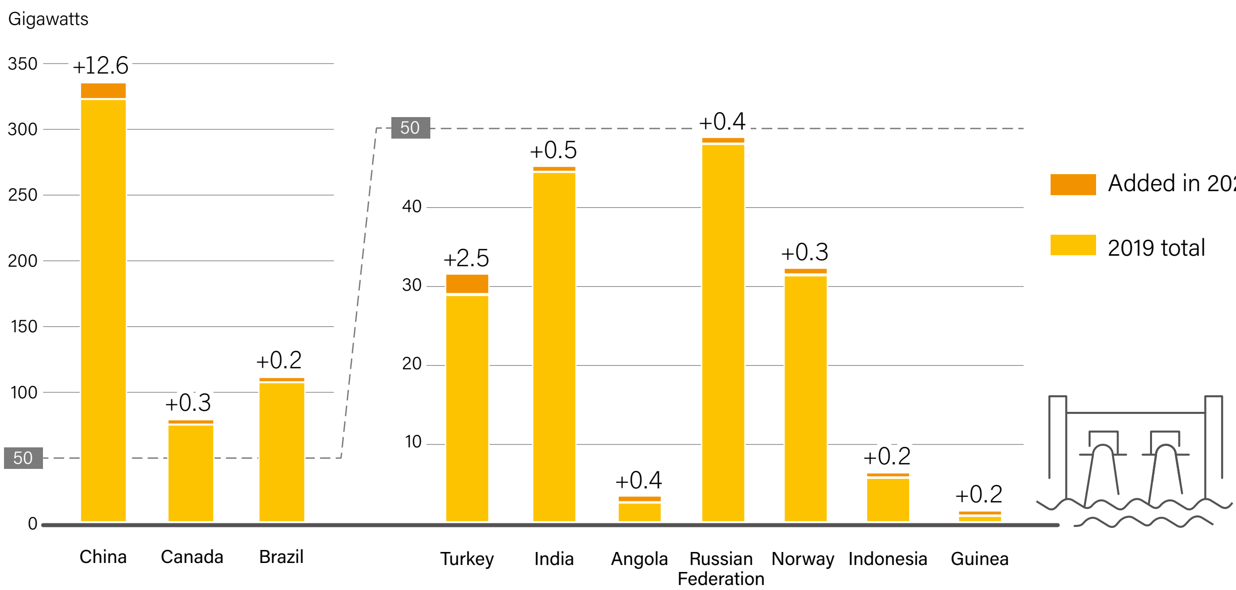
China added 12.6 GW of hydropower capacity in 2020, its highest amount in the previous five years, reaching 338.7 GW by year's end.[9] The country's capacity increased 15% during the 2015-2020 period, and new hydropower plants represented 7% of China's total newly installed power generation capacity in 2020.[10] The largest additions included the 1.6 GW Datengxia plant in the Guangxi Zhuang autonomous region, with eight 200 MW turbines, and the five 850 MW units commissioned at the Wudongde plant between Yunnan and Sichuan provinces.[11] Wudongde will be the seventh largest plant in the world upon completion, with 10.2 GW of total installed capacity.[12]

Other hydropower projects in China included the completed reconstruction of the 1.5 GW Fengman plant and the ongoing construction of the 16 GW Baihetan mega project, with commissioning scheduled for 2021.[13] China's total hydropower output reached 1,360 TWh, up 4.1% from 2019 and representing 18% of the country's electricity supply; meanwhile, the Three Gorges Dam set a new world record for annual electricity output in 2020.[14]

China added 12.6 GW of
hydropower capacity
in 2020, its highest amount in the previous five years.

i Fluctuations in weather patterns lead to modifications in hydrological conditions. Hydropower operations may vary due to price fluctuations in electricity markets, the contribution to grid stability through balancing services using storage capacities (reservoirs) and water supply management.

FIGURE 24.
Hydropower Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Source: See endnote 5 for this section.

MARKET AND INDUSTRY TRENDS

Turkey added 2.5 GW of new hydropower capacity – its largest increase since 2013 – for a total of 30.9 GW.[15] The fast pace of commissioning was driven in part by the pending expiration of the country's feed-in tariff scheme, applying to facilities brought online before the end of the year.[16] By early 2021, a new FIT was announced for 2021-2025 that reduced the hydropower tariff by around one-third.[17] The largest hydropower facilities that went online in 2020 were the 540 MW Yusufeli dam, the 500 MW Lower Kaleköy plant, the 420 MW Çetin plant and the 1.2 GW Ilisu dam (the second largest dam in the country, located on the Tigris River, which began production after some delays).[18]

The intense drought in the Black Sea region in 2020 reduced Turkey's hydropower production 12% compared to 2019.[19] Hydropower represented nearly one-third of the country's power capacity mix by the end of 2020 and around 56% of the new power generating capacity added that year.[20]

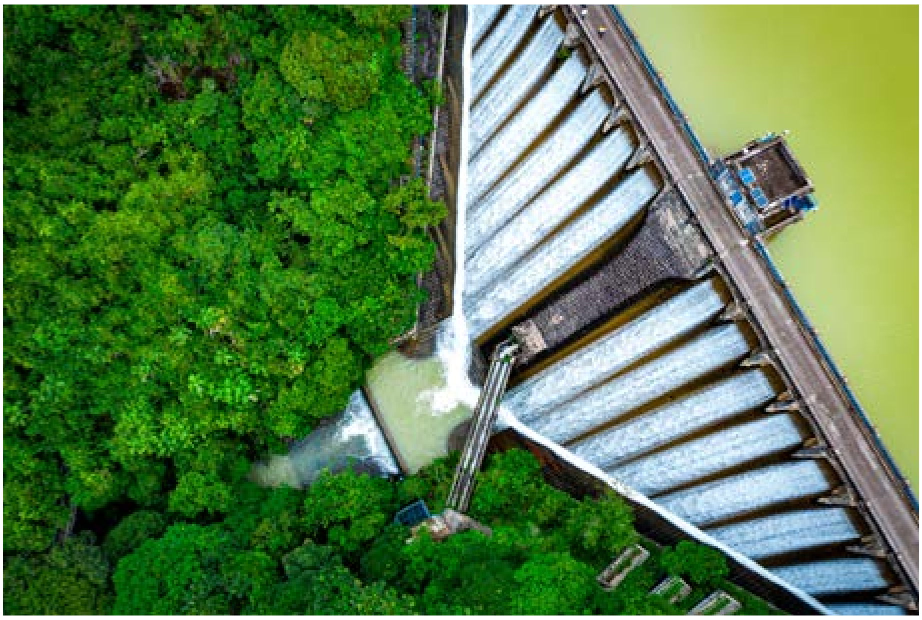
India added 473 MW of net hydropower, for a total capacity of 45.8 GW.[21] The government has promoted hydropower as a source of grid stability and flexibility, with a target of 70 GW of installed capacity by 2030.[22] Around 13 GW of capacity was under construction in 2020.[23] After eight years of delays following protests related to safety concerns and other potential negative impacts, construction resumed on the 2 GW Subansiri project along the Assam-Arunachal Pradesh border.[24] In mid-2020, the government proposed a draft Electricity (Amendment) Bill to boost India's renewables sector.[25] The bill includes provisions that define a minimum percentage of electricity that public sector companies[i] must purchase from hydropower sources, in addition to introducing a purchase obligation and providing incentives.[26]

Indonesia added 240 MW in 2020 for a total installed capacity of 6.1 GW, and Lao People's Democratic Republic (PDR) added 180 MW to reach nearly 7.4 GW.[27] The 260 MW Don Sahong project, commissioned in 2019, began commercial operations, and commissioning was completed on the first unit of the 70 MW Xelalong 1 plant.[28] In Vietnam, 119.5 MW of hydropower was added in 2020, bringing the total installed capacity to 17.1 GW.[29] The commissioning of the 220 MW Thuong Kon Tum hydropower plant and the expansion of the 1,920 MW Hoa Binh plant, both expected by the end of the year, were postponed to 2021.[30]

In Uzbekistan, several facilities were finalised with modernisation of the 15 MW Kadyrinskaya 3 plant, two power plants totalling 22.4 MW on the South Ferghana Canal and a 15 MW plant on the Bozsu Canal.[31] In Georgia, the Shuakhevi installation on the Adjaristsqali River, the country's largest hydropower plant built since 1978[ii], began commercial operations, adding 178 MW to the grid; the facility is one of two plants in a 187 MW scheme.[32] Georgia ended 2020 with a total installed capacity of 3.4 GW, representing around 80% of the country's power generating capacity and 76% of its electricity production.[33]

The European hydropower market has reached near-maturity, and possibilities for new, large installations are limited. Norway added 324 MW of capacity – with nearly half of this consisting of plants of less than 10 MW – in addition to several larger facilities, including a 77 MW plant.[34] The country's total installed capacity reached 32 GW in 2020, representing 89% of national electricity production.[35] In France, the 97 MW Romanche-Gavet plant was commissioned after a decade of construction, replacing six power plants and five dams built around 1910.[36] To reduce the facility's visual impact, the developers located the plant underground and replaced the previous structures with a single dam; in addition, local species were replanted along the dam banks for ecological restoration.[37] In Albania, which relies entirely on hydropower generation and electricity imports, the 197 MW Moglicë plant – the second of two plants that are part of the 269 MW Devoll Hydropower Scheme – started delivering electricity.[38]

The Indian government has promoted hydropower as a source of **grid stability and flexibility.**



i The public sector companies subject to renewable power purchase obligations are power distribution companies, energy producers and certain consumers.
ii The 1,300 MW Engurhesi hydropower plant was completed in 1978, and the 130 MW Zhinvalhesi plant was completed in 1986.

Installed capacity in the Russian Federation reached 48.5 GW after 380 MW was added in 2020.[39] The largest project to come online was the 346 MW Zaramagskaya plant in North Caucasus.[40] New small hydropower plants in the region also added more than 22 MW of capacity across four facilities.[41] The sixth of seven units was commissioned at the Ust-Khantayskaya facility under renovation in the Krasnoyarsk region, where 63 MW units are being replaced with 73 MW units to increase the installed capacity to 511 MW.[42]

Several projects were completed in Africa, including in Angola, Ghana and Guinea. Angola continues to focus its long-term electrification strategy on hydropower, with more than 4 GW planned or under study.[43] To achieve this, generation facilities are being developed, upgraded or restored.[44] Angola added 401 MW of hydropower capacity in 2020, bringing the sixth (and final) unit of the Laúca plant into commercial operation to reach an installed plant capacity of 2.1 GW.[45] By year's end, Angola's total installed capacity was 3.8 GW.[46]

In Malawi, the Phalombe 3 MW plant reached its final phase before commissioning, and the last two units at the 8.2 MW Ruo-Ndiza hydroelectric power station were commissioned.[47] In Rwanda, four installations came online in 2020: three of these totalled slightly more than 2 MW, while the 9.8 MW Giciye III came online after 18 months of construction.[48] Rwanda's total installed capacity reached 121 MW by year's end.[49] In Uganda, the Bukinda 6.6 MW facility was commissioned, and the 600 MW Karuma project along the Nile River in the western region was nearing completion after years of delays as well as recent pandemic-related challenges.[50] Once commissioned, the Karuma plant will increase Uganda's total hydropower capacity to more than 1.5 GW and will provide power to neighbouring Rwanda, northern Tanzania, Kenya and the Democratic Republic of the Congo through new regional transmission lines.[51]

In Ethiopia, the more than 6 GW Grand Ethiopian Renaissance Dam moved towards completion, despite a lack of agreement with Egypt and Sudan on filling and operating the dam.[52] The Ethiopian government considers this facility fundamental to the country's economic development, as half of the population lacks access to the grid, and electricity supply blackouts are frequent.[53] In line with this economic objective, the launch of commercial operations at the 254 MW Genale Dawa 3 hydropower project increased Ethiopia's overall power capacity around 6%.[54] The country's year-end hydropower installed capacity was 4.1 GW.[55]

In Guinea, 225 MW came online after the commissioning of two units of the Souapiti dam, bringing the country's total installed capacity to 0.7 GW.[56] Ghana finalised the retrofit of the 160 MW Kpong facility, one of three large hydropower facilities in the country, for a total installed capacity of 1.6 GW.[57] Ghana's first small-scale plant, the Tsatsadu micro-hydro project, funded primarily by the Bui Power Authority and by contributions from development funds, also was fully commissioned.[58] The Ghanaian Parliament authorised construction of the 60 MW Pwalugu multi-purpose dam project[i] on the Volta River.[59]

Brazil, Canada and the United States, the largest hydropower markets in the Americas, together added nearly 0.5 GW of capacity in 2020.[60] In Canada, the two large projects expected during the year were delayed largely because of the pandemic. The commissioning of the 695 MW Keeyask generation project near Hudson's Bay (owned by Manitoba Hydro and four Indigenous groups[ii]) was pushed to 2021 after Indigenous groups erected blockades, preventing workers from entering when activities resumed.[61] In the province of Newfoundland and Labrador, the first 206 MW unit at the 824 MW Muskrat Falls facility on the Churchill River came online in late 2020, and commissioning began on the second unit.[62] By year's end, Canada had around 82 GW of hydropower capacity, providing around 60% of the country's electricity supply.[63]

The United States commissioned 148 MW of capacity in 2020, primarily following the replacement of turbines and generators at the 122 MW Wanapum Dam, as well as a 3 MW expansion at Shoshone Falls.[64] Two new installations totalling less than 30 MW were added, and a 6 MW facility was retired.[65] This resulted in a slight increase in the US total installed capacity, to 79.9 GW.[66] After a three-year decline, generation rose to 291 TWh, representing 7.2% of the country's total electricity supply.[67]

In Latin America, the 104 MW Patuca III plant, the second largest hydropower plant in Honduras and the country's first project financed by China, went into operation, increasing Honduras' total installed capacity to around 0.8 GW.[68] In Colombia, installed capacity increased slightly from the previous year, with 24 MW of additions and a total capacity of 11.9 GW by year's end.[69] Preparations also began at the 2.4 GW Hidroituango project to install the first two turbines after a 2018 accident that flooded and damaged the powerhouse, displacing around 600 residents and destroying infrastructure along the Cauca River.[70]

i The dam will store water to generate electricity from hydropower, irrigate agricultural fields downstream and provide a flood protection system for populations living in the White Volta basin.

ii The Indigenous peoples who own part of the project include the Tataskweyak Cree Nation, War Lake First Nation, York Factory First Nation and Fox Lake Cree Nation.

Brazil, after nearly a decade of adding capacity in the gigawatt range, commissioned only 213 MW in 2020, mainly divided among small-scale facilities of 11 MW or less.[71] This sharp contraction from the previous year was due to rising environmental concerns associated with the country's remaining exploitable hydropower potential.[72] By the end of 2020, Brazil had 109 GW of hydropower capacity, representing 62% of its total operational power capacity.[73]

Brazil's ageing hydropower fleet[i] has negatively affected the reliability of the country's electricity supply, causing frequent service disruptions.[74] In 2017, outages at hydropower plants reduced total electricity production by 65 TWh, which is the equivalent of 67% of the overall energy losses in Brazil's electrical transmission and distribution system.[75] One study estimated that rehabilitating the seven hydropower plants that were least available that year due to forced outages would provide an additional 1.9% of overall hydropower energy.[76]

Peru commissioned the 20 MW Manta hydropower plant with an investment of USD 43.6 million.[77] Commercial operation of the 84 MW La Virgen plant on the Tarma River was delayed after fieldwork was halted for three months in the second quarter of the year.[78] Chile commissioned 206 MW in 2020.[79]

Globally, the pumped storage installed capacity increased 1.5 GW in 2020, bringing the total capacity to 160 GW.[80] Israel's first pumped storage facility (300 MW) started operation during the year, and in China 1,200 MW of pumped storage was commissioned.[81] Additional large pumped storage projects in the pipeline include Greece's 680 MW Amfilochia complex, Scotland's 1.5 GW Cloire Glass facility and Turkey's first pumped storage facility, the 1 GW Eğirdir.[82] In India, two identical hybrid projects secured financing: the Pinnapuram and Saundatti facilities each have pumped storage capacity of 1.2 GW combined with 4 GW total of solar and wind power capacity.[83]

With most of Australia's hydropower potential already developed, pumped storage is an increasingly important component of the country's energy expansion, especially its plans to integrate variable renewable energy (VRE) sources.[84] The Snowy 2.0 project, which aims to expand the existing Snowy scheme by 2 GW, received government approval to build related infrastructure, and the Ravine substation was commissioned to power this construction.[85] In Tasmania, Lake Cethana was identified as the first pumped storage project of the Battery of the Nation initiative, with capacity nearing 600 MW.[86] The 500 MW Dungowan and 400 MW Big-T projects under development aim to support VRE integration, providing firm power and grid services.[87]

In Portugal, the 880 MW Gouvães[ii] pumped storage facility was on track for commissioning in 2021, and construction also began on one of Vietnam's first pumped storage projects, the 1.2 GW Bac Ai project.[88] The 250 MW Hatta pumped storage facility in the United Arab Emirates also progressed, with the service tunnels completed and construction of the upper dam under way.[89] In China, the 3.6 GW Fengning project began storing water in its lower reservoir; upon completion, the facility is expected to be the world's largest pumped storage installed capacity, with a record 12 reversible 300 MW turbines[iii].[90]

HYDROPOWER INDUSTRY

The hydropower industry continued to face challenges and opportunities in 2020, augmented by the pandemic-induced recession[iv] as well as by new opportunities stemming from the growing recognition of renewables as a valuable component of a sustainable economic recovery[v].[91] The challenges included operational and technical factors, environmental and social acceptability, a global decline in wholesale electricity prices, and adverse climate impacts on hydropower production and infrastructure.[92] Among the opportunities for industry expansion were technology improvements and increased performance, the remaining untapped potential of smaller resources, synergies with VRE and increased needs for grid flexibility.

i As of 2018, 31% of Brazilian hydropower plants were more than 40 years old.

ii Gouvães will be the first of three plants in the 1.2 GW Tâmega complex, with an estimated project investment of more than EUR 1.5 billion (USD 1.8 billion).

iii The Huizhou and Guangdong pumped storage plants hold the current record for the largest number of turbines, with eight each.

iv With the large decrease in electricity demand, wholesale prices for hydropower fell, jeopardising revenues and capital flows; greenfield development and critical modernisation projects were halted; and current and new government programmes designed to support the sector were postponed or cancelled. See endnote 91 for this section.

v Technologies related to the energy transition (renewables, electric vehicles and battery storage) and digitalisation are among the sectors that have generated the most interest from investors in the post-COVID-19 market.

The disruptive effect of the pandemic-induced recession had an impact on most of the world's major hydropower technology providers[i]. Voith Hydro suffered from a slowing market and reported a 46% decline in orders and a 17% decline in sales.[93] The Americas represented the largest share of Voith's sales, followed by Asia and Europe.[94] GE Hydro Solutions, representing more than 25% of total installed capacity worldwide, reported lower-than-expected revenues.[95] Andritz Hydro registered a 12% decline in revenues but nearly the same level of order intake as in 2019.[96]

Although renewable energy was underrepresented in government recovery packages in 2020, some plans aimed to boost economic growth, create jobs and cut greenhouse gas emissions. The International Energy Agency included hydropower modernisation in its three-year recovery proposal, which calls for spending around USD 20 billion annually over this period to support continued generation and to boost the creation of skilled jobs.[97] Similarly, the International Hydropower Association (IHA) and the International Renewable Energy Agency joined forces to foster development of the 850 GW of hydropower capacity expected to be needed by 2050 to achieve the climate goals of the Paris Agreement.[98]

The modernisation and refurbishment of hydropower plants continued in 2020 and was expected to remain a priority. Worldwide, tens of thousands of ageing water storage facilities have reached their end-of-life, and the 52% of global hydropower capacity that was installed before 1990 could be due for major rehabilitation.[99] Across Europe, North America, Central Asia and Latin America, the refurbishment of ageing facilities has resulted in improved operational efficiency and enhanced resource use.[100] Refurbishment and improvement of the 3.1 GW Yacyretá plant on the Argentina/Paraguay border increased its capacity by 735 MW, and at the 14 GW Itaipu plant on the Brazil/Paraguay border a USD 660 million digitalisation project was announced to replace the original analog technology.[101] In Australia, Voith announced a collaboration with Snowy Hydro to use acoustic sensing equipment, combined with cloud-based data collection and analysis and remote surveillance, to monitor hydropower assets in order to detect malfunctions before they occur and to optimise preventive maintenance.[102]

With the rising penetration of variable renewables in electricity production, grid operators increasingly are looking for resources to boost the flexibility of generation. Hydropower and pumped storage can provide the flexibility and support services that the grid requires through quick ramping and other grid service capabilities, with a lower emission profile than fossil fuel generation assets.[103] Hydropower generators contribute greatly to grid reliability, but their primary revenue stream (market energy prices) does not always compensate for the other ancillary services that they can provide (such as inertial response and voltage regulation). These ancillary services could come at the expense of displacing the maximum operating capacity of the plant to support them.[104]

In the United States, the California Independent System Operator (CAISO) signed contracts in 2019 to explicitly compensate for the inertial and primary frequency response services supplied by hydropower.[105] Under current US market conditions, the cost-benefit ratio of delivering ancillary services versus power generation is under study, and market mechanisms are emerging to monetise other grid services that hydropower provides.[106] In 2019, the UK electricity system operator held its first tender for "grid stability" and in early 2020 it awarded a contract to the 440 MW Cruachan pumped storage station to supply synchronous compensation.[107] The Cruachan facility began providing inertia in mid-2020, using a world-first approach[ii] estimated to save consumers up to GBP 128 million (USD 174 million) over the six-year period.[108]

More than half of **global hydropower capacity** could be due for major rehabilitation.

i Major technology providers included Andritz Hydro (Austria), Bharat Heavy Electricals (India), Dongfang Electric (China), GE (US), Harbin Electric (China), Hitachi Mitsubishi Hydro (Japan), Impsa (Argentina), Power Machines (Russian Federation), Toshiba (Japan) and Voith (Germany).

ii The Stability Pathfinder approach aims to provide inertia and other vital services without generating unnecessary electricity by using technologies such as pumped storage, gas-fired power stations and synchronous condensers. Five six-year contracts were awarded in the first stage in early 2020.

In West Africa, a study found that with adequate management and operation of current and future facilities, hydropower flexibility can support VRE integration while displacing fossil fuel plants.[109] The industry is embracing these trends as projects combining large amounts of solar and wind with hydropower or pumped storage are emerging and costs are becoming competitive.[110] The 500 MW Dungowan pumped storage plant in New South Wales, Australia was designed as part of the 4 GW Walcha Energy Project to provide grid support services and firm power.[111] Relatively low wind power prices in locations such as Québec, Canada, where hydropower is abundant, can shift the dispatching approach by encouraging the use of wind when it is available and storing water until it is needed.[112]

Projects combining hydropower reservoirs and floating solar PV increased in 2020.[113] The major benefits of these hybrid systems include reduced evaporation, lower energy infrastructure costs and generation complementarity due to seasonality[i].[114] In some cases, this approach is proposed to compensate for the declining performance of some hydropower plants.[115] Other synergies being explored include using hydropower to power hydrogen electrolysers. Construction of one of the largest electrolysers using hydropower, with capacity nearing 90 MW, was announced in Canada, while small-scale hydrogen production facilities were being pursued in Iceland.[116]

Innovations in 2020 included the deployment of the world's largest hydropower turbine, a 1 GW turbine at the Baihetan facility built by China Three Gorges Corporation.[117] Advances at small facilities included the use of fish-friendly installations that limit the diversion of river flow by using submerged generators or low-head turbines with blades designed to allow safe fish passage.[118] The US market demonstrated increased commercial viability for pumped storage through an innovative configuration for closed-loop pumped installations[ii] that reduces project costs, environmental impacts and development time.[119]

The industry also is addressing the sustainability of hydropower, using an integrated resource management approach to focus on load balancing, water quality and water supply for non-energy needs (such as irrigation, flood control, sediment management and responding to other requirements from communities and natural resources).[120] Lao PDR and other countries along the Mekong River have experienced frequent extreme low water flows due to reduced rainfall and flow modifications upstream caused by hydropower operations. To promote and co-ordinate sustainable management of the basin, the Mekong River Commission released the Hydropower Mitigation Guidelines to provide risk management and mitigation guidance during the early stages of hydropower facility design.[121] Poor management has resulted in tensions among countries along the Mekong, Nile, Tigris and other rivers.[122] To address the inherent risks facing the industry, particularly in heavily hydropower-dependent regions, hydropower must be transformed into a resilient energy source in the face of climate change.[123]

In 2020, in response to environmental concerns, areas of the Balkans including the Federation of Bosnia and Herzegovina, Montenegro and the Serbian region of Sokobanja faced a surge of restrictions on small hydropower developments.[124] The region's hydropower industry launched an initiative in early 2021 to implement international good practices in development, in line with the IHA Hydropower Sustainability Tools.[125] Another sustainability initiative led by the IHA, the Hydropower Sustainability Assessment Fund, aims to help hydropower developers and operators assess the environmental, social and governance performance of projects that are under preparation and development or already in operation.[126]

i Operators can benefit from more stable yearly generation, as solar will produce more than hydropower in the dry season, and the reverse will occur during the rainy season.

ii The novel closed-loop installation design required the use of a submersible pump turbine in a vertical "well" to replace the traditional underground power-house, which is one of the most expensive and riskiest components of this type of facility.

KEY FACTS

- Ocean power **generation continued to rise in 2020**, surpassing 60 GWh.
- The industry is now moving from **small-scale demonstration and pilot projects towards semi-permanent installations** and arrays of devices.
- **Maintaining revenue support** for ocean power technologies is considered paramount if the industry is to achieve greater maturity.

OCEAN POWER

OCEAN POWER MARKETS

The oceans contain the largest untapped source of renewable energy. While ocean power technologies[i] represent the smallest share of the renewable energy market, they are steadily advancing towards commercialisation. Deployments in 2020 added around 2 MW, bringing the total operating installed capacity to an estimated 527 MW at year's end.[1] Two tidal barrages using mature turbine technologies[ii] represent more than 90% of total installed capacity: the 240 MW La Rance station in France (installed in 1966) and the 254 MW Sihwa plant in the Republic of Korea (2011).[2]

Tidal stream and wave power are the main focus of development efforts. Advancements in these technologies have been concentrated largely in Europe, especially the United Kingdom, which has significant resources. However, generous revenue support and ambitious research and development programmes in Canada, the United States and China are spurring increased development and deployment elsewhere.[3] In 2020, the EU set an ambitious target for 40 GW of ocean power capacity by 2050, including at least 100 MW of pilot projects by 2025 and 1 GW by 2030.[4]

Tidal stream devices are approaching maturity, and pre-commercial projects are under way. Device design for utility-scale generation has converged on horizontal-axis turbines mounted on the sea floor or attached to a floating platform.[5] These devices have demonstrated considerable reliability in performance, with total generation surpassing 60 GWh by the end of 2020 (up from 45 GWh the year before).[6] A range of other concepts are under development, designed to meet specific applications or environmental conditions, such as providing power to remote communities or at low-energy sites.

Wave power devices remain in the prototyping phase, and there is no convergence on design yet owing to the complexity of extracting wave energy from a variety of wave conditions and the wide range of possible operating principles.[7] Developers generally have chosen one of two distinct pathways for wave energy development: devices above 100 kW target utility-scale electricity markets, whereas smaller devices, usually below 50 kW, are intended primarily for specialist applications (oil and gas, aquaculture, maritime monitoring and defence).[8]

i Ocean power technologies harness the energy potential of ocean waves, tides, currents, and temperature and salinity gradients. In this report, ocean power does not include offshore wind, marine biomass, floating solar PV or floating wind.

ii These are the same in-stream technologies used in some types of hydropower plants.

OCEAN POWER INDUSTRY

The ocean power industry faced significant challenges in 2020 as the COVID-19 pandemic slowed manufacturing, delayed deployments and interfered with maintenance schedules. Most planned deployments were postponed to 2021, although some deployments took place and power generation continued despite reduced maintenance. In total, seven **tidal stream** devices were successfully deployed in 2020, including a three-turbine array, a large commercial-scale turbine and smaller demonstration deployments.

In China, the China Three Gorges Corporation (CTG) manufactured a 500 kW tidal turbine, designed by SIMEC Atlantis Energy, and deployed it between two islands in Zhoushan archipelago.[9] The CTG also made progress on the Zhoushan tidal current energy project, deploying a 300 kW turbine.[10] Another project, led by Zhejiang Zhoushan LHD New Energy Corporation Limited (LHD), achieved cumulative power generation exceeding 1.95 GWh in October 2020.[11] The modular device currently comprises two vertical-axis turbines of 400 kW and 600 kW, and LHD is working on adding a 1 MW turbine and increasing the capacity of the platform to 4.1 MW.[12] The main structure, now completed, was planned to be deployed in the first quarter of 2021.[13] The project will be the first to benefit from a temporary feed-in tariff of EUR 0.33 (USD 0.40) per kWh, introduced in 2019.[14]

In the United States, Verdant Power installed a 105 kW array of three tidal power turbines at its Roosevelt Island Tidal Energy Project site in New York's East River, marking the first licensed tidal power project in the country.[15] As of January 2020, the array had operated continuously for three months, achieving 100 megawatt-hours (MWh) of generation in its first 85 days.[16] In Igiugig, Alaska, the Ocean Renewable Power Company (ORPC, US) redeployed its 35 kW RivGen Power System, a submerged cross-flow river current turbine.[17] Combined with microgrid electronics and energy storage, the system will reduce diesel use in Igiugig Village by an estimated 90%.[18] ORPC also continued construction on a second RivGen device, targeting deployment in summer 2021, and received USD 3.7 million in funding from the Department of Energy's Advanced Research Projects Agency.[19]

Two deployments took place in the United Kingdom in 2020. Nova Innovation (UK) completed the installation of its 100 kW turbine in the Shetland Islands.[20] This is the first of three turbines deployed as part of the EnFAIT (Enabling Future Arrays in Tidal) project, a EUR 20 million (USD 24.6) effort to demonstrate a viable cost-reduction pathway for tidal energy.[21] Nova Innovation also continued to successfully operate its 0.3 MW array in the Bluemull Sound in Shetland, where the turbines have generated without incident since 2016.[22] DesignPro Renewables (Ireland) successfully completed deployment and testing of its 60 kW DPR60 turbine at Kirkwall in the Orkney Islands, Scotland.[23]

Minesto (Sweden) installed and commissioned its 100 kW DG100 tidal kite system[i] in the Vestmannasund strait, Faroe Islands.[24] By December, it had successfully delivered electricity to the Faroese grid under a 2019 power purchase agreement (signed with the Faroese utility company SEV) for up to 2.2 MW of installed tidal capacity.[25] Minesto also is seeking the necessary permits to deploy a 100 KW device at the EDF-owned Paimpol Bréhat site in France.[26] Minesto received EUR 14.9 million (USD 18.3 million) in EU funding through the Welsh European Funding Office in 2019 and completed work in 2020 on its Holyhead assembly hall, which will serve as a hub for engineering and operational activities.[27] An array of up to 80 MW capacity is planned for the Holyhead Deep site, eight kilometres off the coast of north-west Wales.[28]

Scotland's MeyGen tidal stream array (the world's largest at 6 MW), owned and operated by SIMEC Atlantis Energy (UK), surpassed 35 GWh of electricity generation in 2020.[29] Having entered its 25-year operational phase in 2018, it generated continuously in 2019, the longest period of uninterrupted generation to date from a commercial-scale tidal array.[30] In 2020, the array faced operational challenges, and three turbines were retrieved for servicing in April 2021.[31] SIMEC holds a seabed lease that would allow it to build the project out to 398 MW.[32] SIMEC also shipped a 500 kW turbine to Japan for installation in early 2021 as part of Kyuden Mirai Energy's demonstrator project in the country's Goto islands.[33]

Tidal stream devices generated **15 GWh** of electricity in 2020.

i Minesto's Deep Green device comprises a turbine integrated with a wing, which is tethered to the seabed and operates in a manner similar to an airborne kite.

In Canada, the government of Nova Scotia offered a feed-in tariff of between CAD 385 and CAD 530 (USD 301 and USD 415) per MWh for demonstration projects.[34] As of the end of 2020, five Canadian developers were approved for a total of up to 22 MW.[35] During the year, NewEast Energy obtained an 800 kW permit under Nova Scotia's demonstration permits programme, which issued permits for a total of 9.3 MW of capacity (of the 10 MW available).[36] Canada committed substantial new funding to tidal projects in 2020, investing CAD 28.5 million (USD 22.3 million) in Sustainable Marine Energy's floating tidal array (up to 9 MW) and CAD 4 million (USD 3.1 million) in Nova Innovation's 1.5 MW array in the Bay of Fundy.[37]

DP Energy and Sustainable Marine Energy (both Canada) continued to advance the Uisce Tapa project under development at the Fundy Ocean Research Centre for Energy (FORCE). The CAD 117 million (USD 91.5 million) project aims to install a 9 MW array of six Andritz Hammerfest turbines and is supported by a Canadian government grant of CAD 29.8 million (USD 23.3 million).[38] BigMoon Power successfully applied to occupy a vacant berth at FORCE.[39] Other provinces also are making progress on ocean power, particularly as a means to provide electricity to remote communities.[40]

Several projects have been progressing in France. The HydroQuest 1 MW marine tidal turbine prototype was deployed at Paimpol-Bréhat in April 2019 and connected to the national grid in June 2019, and has operated continuously since then.[41] Featuring a dual vertical-axes design, this cross-flow turbine turns irrespective of the flow direction, enabling the device to be fixed to its foundation without any efficiency loss. DesignPro Renewables continued testing its 25 kW turbine at the dedicated SEENEOH test site on the Garonne River, where it has been deployed since September 2018.[42] SABELLA (France) is planning to redeploy its grid-connected D10-1000 tidal energy converter on Ushant Island in 2021 and is also working with Morbihan Hydro Energies (France) to deploy two 250 kW turbines in the Gulf of Morbihan.[43] In Normandy, the government approved the transfer of a 12 MW lease in Raz Blanchard to Normandie Hydroliennes, a consortium of partners including SIMEC Atlantis Energy and the Development Agency for Normandy.[44]

In the Netherlands, the Dutch company Tocardo acquired the 1.25 MW Oosterschelde Tidal Power Plant and subsequently resumed full continuous operation.[45] The plant comprises five of Torcado's T-2 tidal turbines mounted on a sluice gate of the Oosterschelde storm surge barrier.

Two **wave power** deployments took place in 2020, with most planned deployments delayed by stalled manufacturing and pandemic-related lockdowns during the year.

In China, a consortium led by the Guangzhou Institute of Energy Conversion deployed a full-scale 500 kW wave energy converter. The Sharp Eagle-Zhoushan converter combines electricity generation with aquaculture and was deployed as part of the Wanshan megawatt-level Wave Energy Demonstration Project, supported by the Ministry of Natural Resources.[46] The Penghu device, based on the Sharp Eagle, completed its 18-month testing period in December 2020.[47] Construction also began on a second 500 kW device, Changshan.[48]

The EU aims to install

40 GW

of ocean power capacity by 2050.

Building on a successful scale test in Denmark, Danish company Wavepiston tested a full-scale device at the Oceanic Platform of the Canary Islands (PLOCAN, Spain). The initial phase of the 200 kW project was deployed in December 2020.[49] The system pressurises sea water, which can then be used to drive a turbine or can be pumped through a reverse osmosis system to obtain desalinated water. A second device that will produce both electricity and fresh water was slated for deployment in 2021.[50]

Existing deployments continued to operate through 2020, passing some significant milestones. The 296 kW Mutriku wave plant in Spain, commissioned in 2011, surpassed a cumulative 2 GWh of electricity production.[51] At the SEM-REV test site in France, the Wavegem hybrid wave and solar platform designed by GEPS Techno reached 18 months of offshore testing, which began in August 2019.[52]

US company Ocean Power Technologies (OPT) reported continuous operation of its device, deployed in the Adriatic Sea, during its first 18 months.[53] The device was leased by Eni, which in March 2020 opted to extend the lease for an additional 18 months.[54] Amid international travel restrictions that delayed deployment of a device in Chile, OPT contracted with SeaTrepid International (US) to conduct a remote installation, training local engineers virtually on technical procedures and installation requirements.[55]

Many companies focused on technology and project development in 2020. For example, Bombora Wavepower (UK) delayed a planned deployment but accelerated design work on a 3 MW project scheduled for deployment in Lanzarote, Spain in 2022.[56] Bombora also entered into an agreement with Technip FMC (UK) to develop a floating offshore wind foundation incorporating wave energy.[57] The first phase of the project will integrate 4 MW of wave power and 8 MW of wind power on a shared floating platform.[58]

Wave Swell Energy (Australia) finalised construction of its 200 kW device, scheduled for deployment on King Island, Tasmania in early 2021.[59] Also in Australia, Carnegie Clean Energy continued to develop its CETO 6 device, after restructuring following the company's entry into voluntary administration in 2018.[60] Carnegie also is developing a wave predictor that uses machine learning to predict wave characteristics up to 30 seconds before they reach the device, thereby increasing efficiency.[61]

US-based company Oscilla Power is finishing construction of a 100 kW device, expected to be installed in Hawaii in 2021.[62] The company also entered the planning stages of a 1 MW demonstration project, targeting deployment off the coast of Kerala in southern India.[63] In the United States, the OEbuoy device developed by Ocean Energy (Ireland), which was transported from the state of Oregon to Hawaii in 2019, is expected to be deployed in 2021.[64]

Other ocean power technologies, such as **ocean thermal energy conversion** (OTEC) and **salinity gradient**, remain well short of commercial deployment, and only a handful of pilot projects have been launched. REDstack (Netherlands) successfully tested its reverse electrodialysis (RED) technology and was planning a first demonstration plant.[65] Akuo Energy (France) announced plans to develop an OTEC plant on Bora Bora, French Polynesia, as part of the EU-funded project, Integrated Solutions for the Decarbonization and Smartification of Islands (IANOS).[66] Puerto Rico (US) is in the early stages of developing the Puerto Rico Ocean Technology Complex (PROtech) and aims to invest an estimated USD 300 million to build a 5 MW to 10 MW OTEC plant by mid-2027.[67]

The Ocean Thermal Energy Association was recently reinvigorated, and a group of member countries of the International Energy Agency's Ocean Energy Systems collaboration are working to assess the current status and global potential of OTEC, with a white paper expected in 2021.[68]

Technology improvements and steep cost reductions are still needed for ocean power to become competitive in utility markets. The industry has not yet received the clear market signals it needs to take the final steps to commercialisation.[69] The lack of consistent support schemes for demonstration projects has proven especially challenging for developers, who have struggled to build a compelling business case, and the sector remains highly dependent on public funding to leverage private investment.[70] Dedicated revenue support is considered paramount for increasing investment certainty by providing predictable returns until the industry achieves greater maturity.

The 2020 announcement of two large private investments provide some positive indications. CorPower Ocean (Sweden) secured EUR 9 million (USD 11 million) in equity funding, and SIMEC Atlantis concluded a share placement agreement, raising an initial investment of GBP 2 million (USD 2.7 million), with the option of increasing this to GBP 12 million (USD 16 million).[71] The UK government is expected to reform its Contract for Difference (CfD) mechanism, separating ocean power from offshore wind, thereby increasing price competitiveness.[72]

As of 2018, more than EUR 6 billion (USD 7.4 billion) had been invested in ocean power projects worldwide, of which 75% was from private finance.[73] A 2018 European Commission implementation plan estimated that EUR 1.2 billion (USD 1.5 billion) in funding was needed by 2030 to commercialise ocean power technologies in Europe, requiring equal input from private sources, national and regional programmes, and EU funds.[74] The industry is collaborating to develop a common evaluation framework for ocean power technologies, aiming to provide clarity for all stakeholders, including public and private investors.[75]

Deploying ocean energy at scale also will require streamlined consenting processes.[76] Uncertainty regarding environmental interactions often has led regulators to mandate significant data collection and strict environmental impact assessments, which can be costly and threaten the financial viability of projects and developers.[77] Current scientific knowledge suggests that the deployment of a single device poses little risk to the marine environment, although the impacts of multi-device arrays are not well understood.[78] This calls for an "adaptive management" approach that responds to new information over time, supported by more long-term data and greater knowledge sharing across projects.[79]

KEY FACTS

- **Solar PV had another record-breaking year in 2020.** Anticipated policy changes drove much of the growth in the top three markets – China, the United States and Vietnam – but several other countries saw noteworthy expansion.
- Favourable economics have boosted interest in **distributed rooftop systems.** In South Australia, the growth of distributed solar PV has made the state's power system the first large-scale system in the world to approach the point at which rooftop solar PV effectively eliminates demand for electricity from the grid.
- The solar PV industry rode a roller coaster in 2020, driven largely by **pandemic-related disruptions**, as well as by accidents at polysilicon facilities in China and a shortage of solar glass. These disruptions, due in large part to heavy reliance on China as the world's dominant producer, combined with concerns about possible forced labour in polysilicon production, led to calls in many countries for the creation of local supply chains.
- New actors entered the sector. **Competition and price pressures** continued to motivate investment to improve efficiencies, reduce costs and improve margins.

SOLAR PHOTOVOLTAICS (PV)

SOLAR PV MARKETS

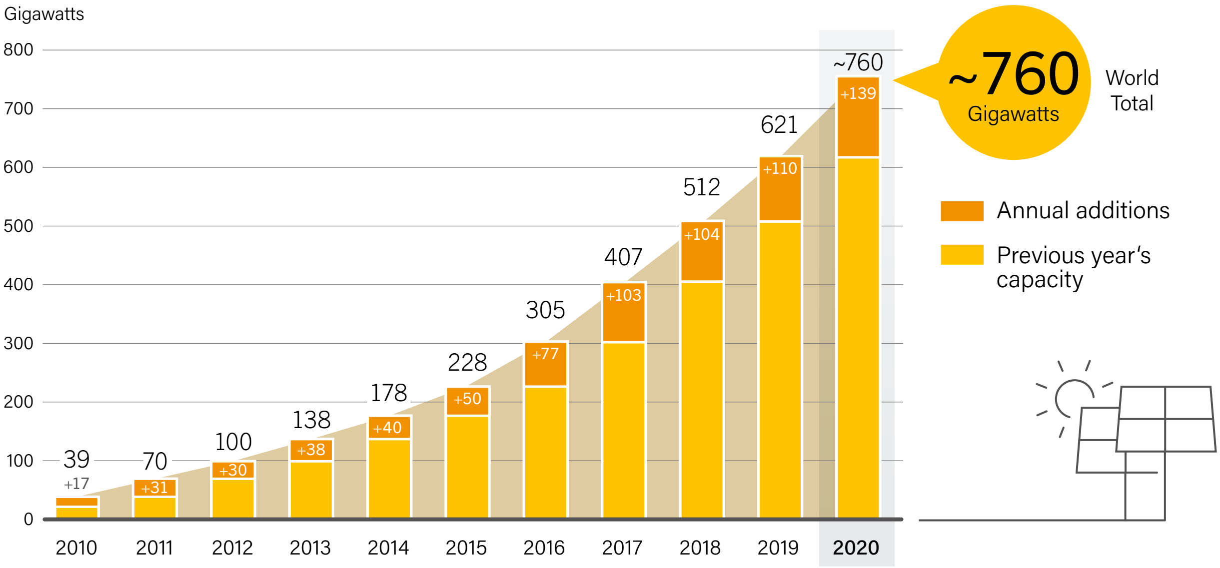
Solar PV had another record-breaking year, with new installations reaching as much as an estimated 139 GW_{DC}[i]; this brought the global total to an estimated 760 GW_{DC}, including both on-grid and off-grid capacity.[1] These preliminary global numbers are uncertain, and the level of uncertainty is increasing year-by-year.

Business closures, stay-at-home orders and restrictions on movement related to the COVID-19 pandemic all reduced electricity consumption and shifted daily demand patterns.[2] The pandemic also resulted in delays in shipping and deliveries of solar panels and related hardware, in customer acquisitions, and in project permitting and construction, exacerbating existing challenges in some markets.[3] Yet, while growth in some markets was below the strong expectations going into 2020, solar PV managed to achieve the largest increase in capacity ever seen in a single year.[4] The distributed[ii] sector was affected more than the utility sector, but several countries saw surges in residential demand.[5] Looming policy changes at the end of the year drove much of the growth in the top three markets (China, the United States and Vietnam), but several other countries also experienced noteworthy market expansion.[6] (→ *See Figure 25.*)

i For the sake of consistency, the GSR endeavours to report all solar PV capacity data in direct current (DC); where data are known to be in AC, that is specified in the text and endnotes. Data are preliminary and a range of estimates exists; global estimates in text are based on data from International Energy Agency Photovoltaic Power Systems Programme and Becquerel Institute. See endnote 1 in this section for further details.

ii Distributed refers to systems that provide power to grid-connected consumers, or directly to the grid, but on distribution networks rather than on bulk transmission or off-grid systems. See endnote 5 for this section. For more on distributed off-grid systems for energy access, see Distributed Renewables chapter.

FIGURE 25.
Solar PV Global Capacity and Annual Additions, 2010-2020



Note: Data are provided in direct current (DC). Totals may not add up due to rounding.
Source: Becquerel Institute and IEA PVPS. See endnote 6 for this section.

Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of locations, both for residential and commercial applications and increasingly for utility-scale projects – even without accounting for the external costs of fossil fuels.[7] This also is becoming the case for solar-plus-storage in an increasing number of markets.[8] In 2020, an estimated 20 countries added at least 1 GW of new solar PV capacity, up from 18 countries in 2019, and all continents contributed significantly to global growth.[9] By the end of 2020, at least 42 countries had a cumulative capacity of 1 GW or more.[10]

Solar PV plays a meaningful role in electricity generation in a growing number of countries. By the end of 2020, at least 15 countries had enough capacity in operation to meet at least 5% of their electricity demand with solar PV.[11] Solar PV accounted for around 11.2% of annual generation in Honduras and for notable shares also in Germany (10.5%), Greece (10.4%), Australia (9.9%), Chile (9.8%), Italy (9.4%) and Japan (8.5%), among others.[12] Spain and the United Kingdom broke solar generation records early in the year, due largely to new capacity as well as to higher output resulting from clearer air during COVID lockdowns; clearer skies during lockdowns also enabled nearly 10% more sunlight to reach solar panels in Delhi and contributed to increased output in the United Arab Emirates.[13] However, smoke from wildfires in Australia and the US state of California had the reverse effect on output, while also negatively affecting solar variability and forecasting.[14]

There are still **challenges** to address for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, unreliable or insufficient grid infrastructure, and financial and bankability challenges.[15] As the level of penetration rises, the variability of solar PV is having an increasing effect on electricity systems, raising the importance of effectively integrating solar energy under varying technical and market conditions in a fair and sustainable manner.[16] In general, opposition to solar PV deployment from local incumbents is lower than a decade ago, with many utilities now actively engaged in solar PV deployment and operations, including distributed generation; however, opposition persists in several countries and among some actors, particularly in the fossil and nuclear energy industries.[17]

The cost-competitiveness of solar PV is increasingly a driver of investment, but generally it is insufficient on its own.[18] In most countries, there is still a need for adequate **regulatory frameworks and policies** governing grid connections to overcome cost or investment barriers in some markets and to ensure a fair and level playing field.[19] Government policies continued to propel most of the global market in 2020, with feed-in tariffs (FITs) and tenders the leading policy drivers[i] of the centralised market, and FITs and incentivised self-consumption or net metering the primary drivers of the distributed market.[20] (→ *See Distributed Renewables chapter for off-grid solar and related policies for energy access.*)

i In the United States, tax credits also continued to play an important role. See endnote 20 for this section.

Self-consumption continued to represent an important and growing share of the market for new distributed systems in several countries.[21] Although still a small share of the annual market, a number of purely competitive (without direct government support) large-scale systems were being constructed in 2020; interest in this segment is considerable and growing rapidly.[22]

For the eighth consecutive year, Asia[i] eclipsed all other **regions** for new installations, accounting for nearly 58% of global additions; even excluding China, Asia was responsible for around 23% of new capacity in 2020.[23] Asia was followed by the Americas (18%), which moved ahead of Europe (16%).[24] China continued to dominate the global market (and solar PV manufacturing), with a share of nearly 35% (up from 27% in 2019).[25]

The top five national markets – China, the United States, Vietnam, Japan and Germany – were responsible for almost 66% of newly installed capacity in 2020 (up from 58.5% for the top five in 2019 but down from around 75% in 2018, as the global market becomes somewhat less concentrated); the next five markets were India, Australia, the Republic of Korea, Brazil and the Netherlands.[26] The annual market size required to rank among the top 10 countries remained at around 3 GW[ii].[27] The leading countries for cumulative solar PV capacity continued to be China, the United States, Japan, Germany and India, and the leaders for capacity per capita were Australia, Germany and Japan.[28] (→ *See Figure 26.*)

China added 48.2 GW of solar PV capacity in 2020 (including 32.7 GW of centralised and 15.5 GW of distributed[iii] solar PV), making the year second only to 2017 (52.9 GW) for annual additions.[29] The market increase of 60% – driven largely by pending changes to the country's FIT structure – followed two consecutive years of contraction, and came despite project construction delays early in 2020 caused by pandemic-related labour shortages and supply chain disruptions.[30] The central, eastern and southern regions of China accounted for about 36% of additions, with 64% in the western and northern regions.[31] The leading provincial installers were Guizhou (5.2 GW), Hebei (4.9 GW) and Qinghai (4.1 GW).[32] At year's end, China's total grid-connected capacity exceeded 253.4 GW, well above the official 13th Five-Year Plan (2016-2020) target for the year (105 GW).[33]

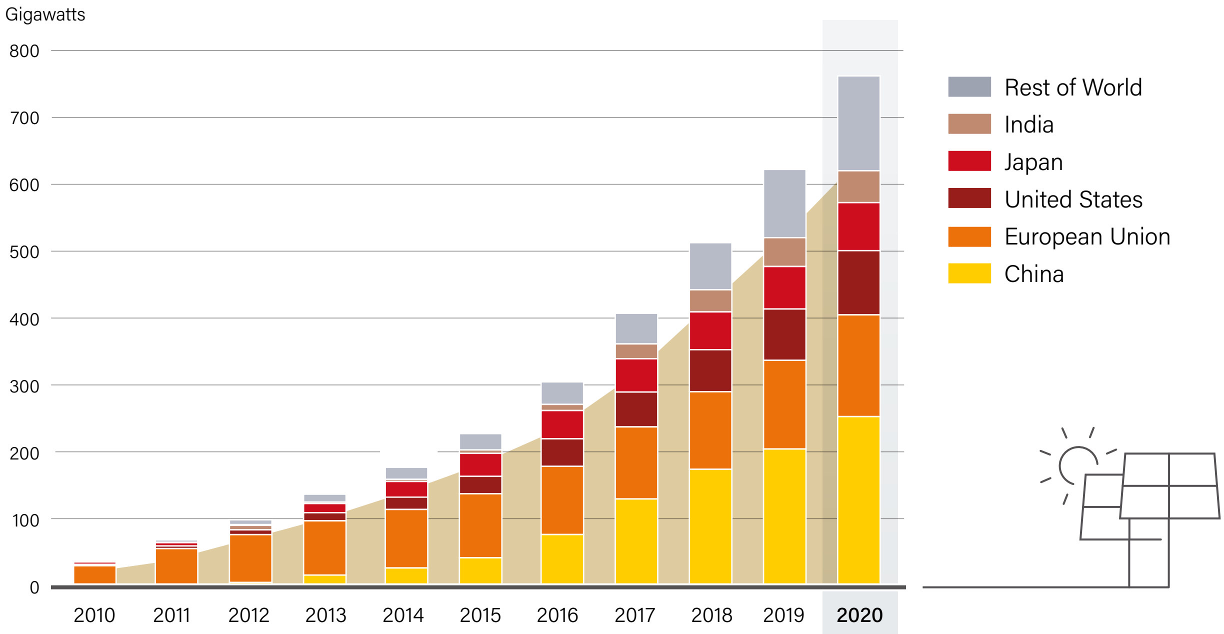
A major driver of China's solar PV market was a rush to install projects before the national FIT was phased out at year's end for centralised as well as commercial and industrial distributed systems.[34] The policy changes result from a mounting deficit in China's Renewable Energy Development Fund, which has caused a backlog of outstanding FIT payments for existing projects (only worsened by the pandemic), and from the central government's belief that solar (and wind) power is capable of competing without subsidies with coal-fired power.[35]

i Note that Turkey is considered to be part of the Asia region for purposes of the GSR.

ii This is the capacity addition of the Netherlands, which ranked tenth for annual installations.

iii "Distributed" solar PV in China includes ground-mounted systems of up to 20 MW that comply with various conditions, in addition to commercial, industrial and residential rooftop systems. Distributed generation consists largely of commercial and industrial systems and, increasingly, residential and floating projects. See endnote 29 for this section.

FIGURE 26.
Solar PV Global Capacity, by Country and Region, 2010-2020



Note: Data are provided in direct current (DC). European Union includes the United Kingdom throughout the 2010-2020 period. Germany's share of the EU total has declined from over 58% in 2010 to just under 36% in 2020 due to growth in other EU markets.

Source: See endnote 28 for this section.

Vietnam added an estimated 11.1 GW in 2020, up from 4.8 GW in 2019 and 0.1 GW in 2018.

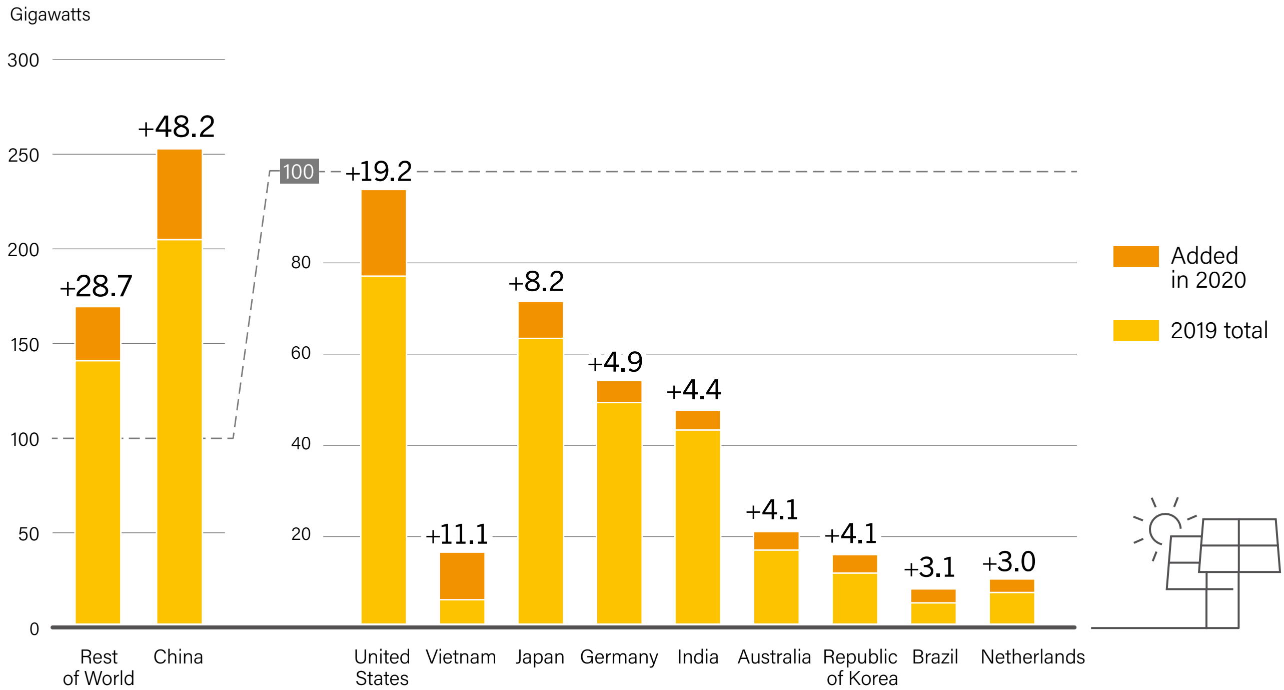
China's market for centralised utility systems (greater than 20 MW) expanded considerably, up nearly 83% in 2020.[36] The increase is thanks in part to the completion of enormous hybrid projects – combining solar PV, wind power and energy storage – by some of the biggest state-owned companies.[37] China's largest solar-plus-storage project (2.2 GW of solar PV plus nearly 203 MW of battery storage) was connected to the grid in late 2020 in the desert of Qinghai province.[38] Total distributed installations also rose (27%) during the year, with annual additions of residential systems almost doubling relative to 2019 (to 10.1 GW) and more than making up for a decline in commercial and industrial installations (5.4 GW).[39] Most of the residential capacity was added in Shandong province (4.57 GW) and Hebei greater area (4.1 GW).[40]

Curtailment of solar energy in China averaged 2% for the year, unchanged from 2019, although the average rate was higher during pandemic-related lockdowns in January (2.8%) and February (5.6%) due to reduced electricity consumption.[41] The curtailment rate continued to be highest in northwest China, particularly in Xinjiang and Gansu, but the region's annual average declined to 4.8%.[42] Minimising curtailment is a national priority and is considered particularly important for utility-scale "grid parity" projects, which were introduced in 2019 to help China move away from subsidies.[43] China's output from grid-connected systems increased more than 16% in 2020, to 261 TWh, bringing solar PV's share of electricity generation (from grid-connected sources) to 3.4% in 2020 (up from 3% in 2019).[44]

The central and provincial governments are focused increasingly on renewable energy integration. In 2020, China's central government issued guidance to ensure that renewable electricity is consumed locally, to the extent possible, and governments at all levels increasingly link solar PV support and bidding rounds to energy storage and local grid capacities.[45] By the end of 2020, one-third of China's provinces mandated that new solar PV installations be combined with energy storage.[46]

Vietnam saw another surge in installations: after adding 4.8 GW in 2019 (up from 106 MW in 2018 and 8 MW in 2017), the country brought an estimated 11.1 GW into operation in 2020, raising it to third place globally for additions and eighth for total solar PV capacity.[47] (→ *See Figure 27, and* ***Reference Table R15*** *in GSR 2021 Data Pack.*) Whereas growth in 2019 was driven by the pending expiration of Vietnam's FIT1 scheme, which encouraged large ground-mounted projects, most of the increase in 2020 was in rooftop systems, racing to qualify for the FIT2 before it expired at year's end.[48]

FIGURE 27.
Solar PV Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Note: Data are provided in direct current (DC).
Source: See endnote 47 for this section.

In total, nearly 83,000 rooftop systems were installed in Vietnam in a single year, increasing rooftop capacity from less than 0.4 GW to 9.7 GW (with 6.7 GW connected in December alone), and bringing the country's total solar PV capacity to 16.4 GW.[49] Vietnam's interest in solar PV is largely to meet rising electricity demand – which has increased 10% annually on average in recent years due to population growth and economic expansion – as well as to ensure energy security and reduce carbon emissions.[50] The rapid growth in solar generation has placed additional stress on the country's underdeveloped grid, leading to curtailment, and as of early 2021 Vietnam was considering options for financing necessary system upgrades.[51]

The third largest market in Asia and the fourth largest globally was Japan.[52] Following four years of contraction, Japan added 8.2 GW (up more than 16%) for a total of 71.4 GW – surpassed only by China and the United States.[53] However, Japan's market continued to face challenges related to land availability and grid constraints, which are helping to keep the country's large-scale solar PV costs among the highest in the world.[54] In 2020, the country's FIT was revised to focus support on systems for locally consumed generation (self- and community-consumption), the ability to isolate in the event of blackouts, and agricultural PV (see later discussion).[55] Solar PV accounted for an estimated 8.5% of Japan's total electricity generation in 2020, up from 7.4% in 2019, with the highest local contributions in Shikoku (13%) and Kyushu (14%).[56]

India's solar PV market contracted again, to the lowest level in five years, and investments in the solar sector were down 66% relative to 2019.[57] Despite the ongoing decline, India ranked sixth globally for additions and fifth for total capacity.[58] Around 4.4 GW[i] of solar PV capacity was added during the year, bringing the national total to 47.4 GW.[59] In the large-scale market, pandemic-related lockdowns and labour shortages delayed project construction and auctions.[60] These setbacks further aggravated existing challenges, such as the lack of transmission infrastructure and land permits, the reluctance of distribution companies to sign power purchase agreements (PPAs) (due to expectations that project bids at auction will continue to fall at a rapid pace), the extension of duties on imported solar equipment and the cancellation of some projects awarded under earlier auctions due to regulatory delays.[61]

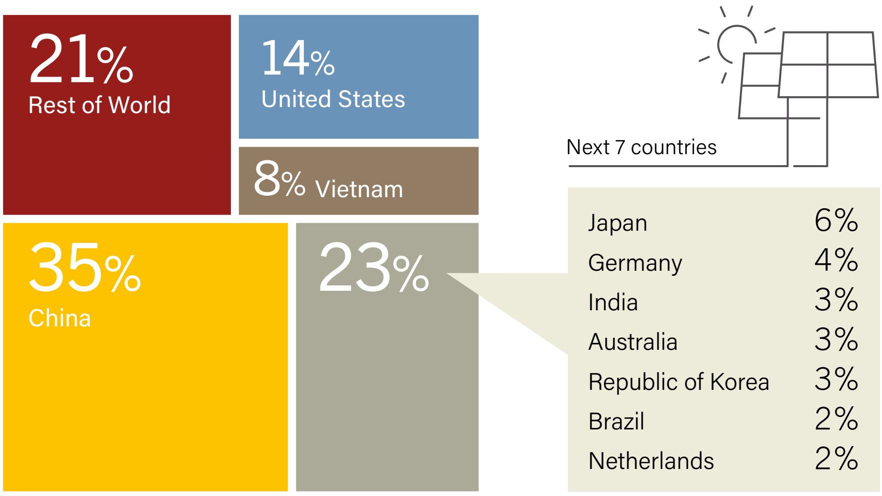
The rooftop market (1.3 GW) in India has been hampered by inconsistent government policy and restrictions, as well as by uncertainties related to the pandemic and pressure by distribution companies to discontinue net metering and adopt grid usage charges.[62] After falling through much of 2020, demand for rooftop systems rose towards the end of the year as government incentives enticed residential consumers, and as the commercial and industrial sectors (the primary rooftop markets) saw solar as a means to reduce their operational costs.[63]

Other Asian countries that added substantial capacity in 2020 included the Republic of Korea (4.1 GW), Chinese Taipei (1.7 GW) and the Philippines (1.1 GW).[64] The Republic of Korea moved up two steps in the global rankings for capacity added, to eighth place, and continued to rank ninth for total capacity (15.9 GW).[65] Turkey added an estimated 1 GW for a total of 9.5 GW.[66] The Turkish market was driven by a new net metering law and self-consumption, representing a shift away from the traditional market of megawatt-scale projects.[67] Pakistan also added capacity, as did Kazakhstan, which held auctions and brought online at least two large projects in 2020.[68]

The **Americas** represented around 18% of the global market in 2020, due largely to the **United States**, which continued to rank second globally for both new installations and total capacity.[69] (→ *See Figure 28.*) The country added a record 19.2 GW – up 43% over 2019 and 27% above the previous peak in 2016 – for a total approaching 96 GW.[70] Solar PV was the leading source of new power capacity for the second consecutive year, accounting for 43% of all US power capacity additions in 2020 (compared with 4% a decade earlier), the largest share to date.[71] The market continued to be more geographically diverse, with 27 states adding more than 100 MW, even as the top states for additions remained California (3.9 GW), Texas (3.4 GW) and Florida (2.8 GW).[72] Utility-scale solar PV (87.7 TWh) plus grid-connected small-scale systems (41.7 TWh) generated a total of 129.5 TWh, or 3.2% of US net generation in 2020.[73]

i For details on India, see endnote 59 for this section.

FIGURE 28.
Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2020



Note: Totals may not add up due to rounding.
Source: See endnote 69 for this section.

The US market was led by the utility-scale sector, which was up 67% to nearly 14 GW, for a year-end total of 59.8 GW.[74] The significant jump came as developers rushed to qualify for the federal investment tax credit (ITC) before the expected rate reduction at the end of the year (the rate ended up being extended for two years in December 2020).[75] The volume of new projects announced in 2020 reached 30.6 GW, bringing the pipeline of US utility-scale solar PV projects under contract at year's end to 69 GW.[76] Growth in this sector is driven by several factors, including self-enforced utility carbon reduction plans, the expansion of state-level mandates through renewable portfolio standards (RPS laws), and large corporations with renewable or carbon reduction goals (→ *see Feature chapter*).[77]

Non-residential[i] installations declined (down 4%) for the third consecutive year and faced the worst pandemic-related delays of any sector, adding 2.1 GW for a total of 16.7 GW.[78] In contrast, the residential market rose 11% compared with 2019, with a record 3.2 GW added for a total of 19.1 GW.[79] The pandemic caused great disruption in this sector as well, with installers laying off thousands of employees and some filing for bankruptcy, and it forced many installers to shift sales from in-person to online and to make serious price cuts.[80] Battles to weaken state net metering laws also continued during the year.[81] Despite the challenges, the market picked up considerably in the second half of 2020 due in part to increased interest in home improvements.[82] Residential solar PV with battery installations also rose, particularly in California following rolling power outages due to massive wildfires.[83]

Increased interest in home improvements during the pandemic helped drive demand for **new residential systems** in several countries.

Demand for solar-plus-storage systems was up in all US sectors in 2020. It accounted for nearly 6% of behind-the-meter solar systems and for more than one-fourth of all contracted utility-scale projects.[84] Utility commissions in some states (e.g., Nevada) established goals for energy storage procurement, and some utilities brought into operation new solar-plus-storage plants, while others released solicitations for new capacity.[85] Interest in energy storage for large-scale plants has been driven by falling costs (of both solar generation and batteries) combined with rising solar energy penetration, which improves the business case for projects that can dispatch this power to meet evening peak demand.[86] Demand is also growing for hybridised solar and wind power plants, encouraged by falling costs and looming tax credit deadlines, and as a means to optimise land use and transmission capacity and to increase revenue.[87] (→ *See Systems Integration chapter.*)

A handful of countries in **Latin America and the Caribbean** continued to expand their solar PV capacity, despite challenging economic conditions, thanks largely to an abundance of solar resources, falling prices and favourable policies in some countries.[88] The region's top four installers in 2020 were Brazil (adding 3.1 GW), Mexico (1.5 GW), Chile (0.8 GW) and Argentina (0.3 GW).[89]

i Includes commercial, government, non-profit and community solar PV systems.

Brazil maintained its regional lead for annual additions and surged past Mexico (5 GW) for total capacity, ending the year with 7.7 GW.[90] Annual installations in Brazil were up 68.6% over 2019.[91] For the second year running, Brazil's distributed segment (defined as less than 5 MW) led the market for capacity added (2.5 GW), investments and job creation, driven by a national net metering regulation and electricity prices rising above inflation rates.[92] Residential systems accounted for the largest portion of distributed installations (74.4%), but commercial and rural systems also saw rising shares.[93]

During 2020, the debate regarding proposed changes to Brazil's net metering mechanism was interrupted as the National Congress turned its focus to the pandemic, but a new legal framework for distributed generation was under development in early 2021 and expected to soon become law.[94] Public energy auctions for large-scale power plants were postponed, also due to the pandemic, but new tenders (including for solar PV) were scheduled for the years 2021-2023.[95] Large projects also moved ahead in the private sector: Brazil's largest-ever solar PPA was signed in March for the 330 MW Atlas Casablanca plant, which will provide electricity for Anglo-American mining operations.[96]

The mining industry also helped drive new installations in **Chile**, where a copper mining company signed a PPA in 2020 for around-the-clock solar energy (with battery storage) to cover 12% of the Collahuasi mine's electricity needs.[97] Also in Chile, an existing plant reportedly became the world's first utility-scale solar PV facility licensed to deliver commercial ancillary services to the grid.[98] Chile's solar PV capacity was approaching 3.5 GW at year's end, with another 3.9 GW under construction.[99]

Europe followed the Americas for additions in 2020, with more than 22 GW added for a year-end total of 162.7 GW, maintaining its second-place regional ranking for total operating capacity.[100] Installations in the EU-27 were up significantly relative to 2019, and noteworthy additions also occurred elsewhere in the region.[101] The Russian Federation nearly doubled its operating capacity, adding more than 0.7 GW for a total of 1.9 GW.[102] The United Kingdom added 0.5 GW, above installations in the previous year but well below the 2015 peak (4.1 GW), bringing total capacity to 13.9 GW.[103] However, several additional large-scale projects without direct subsidies were under construction in the country, some incorporating energy storage to access higher market prices.[104] As part of the effort to accelerate decarbonisation, the UK government announced plans to reopen access to Contracts for Difference[i] auctions for solar PV (and onshore wind power), for the first time since 2015.[105]

Installations in the EU-27 were well below expectations due to the pandemic; nevertheless, 2020 turned out to be the region's second-best year on record, and solar PV provided more new power capacity than any other generating technology.[106] Around 19.3 GW was brought online, raising total solar PV capacity by about 15%, to 140.5 GW.[107] Most EU markets have moved beyond FITs and are propelled by the competitiveness of solar generation – in many EU Member States, solar PV is now the cheapest incremental source of electricity and the fastest to install.[108] Economic competitiveness is elevating interest in self-consumption and corporate renewable power sourcing (including via direct bilateral PPAs), and is encouraging governments that are looking to meet national renewable energy targets through tenders.[109] At the same time, new challenges are emerging, including access to grid connections, land availability and planning permission (particularly in areas that already have a large installed base), and a shortening of PPA time periods with the shift towards merchant projects[ii,110]

i The Contracts for Difference (CfD) is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).

ii Merchant projects are those with no regulated or contracted income. The electricity generated is sold into competitive wholesale markets.

Small-scale rooftop systems alone accounted for

6.5%

of Australia's total electricity generation in 2020.

In 2020, 22 of the 27 EU Member States added more capacity than they had installed in 2019; even so, nearly three-fourths of new capacity came online in only five countries.[111] Germany regained its top position (held for most of the past two decades) from Spain, and was followed by the Netherlands (3 GW), Spain (2.8 GW), Poland (2.6 GW) and Belgium (1 GW).[112] The top EU countries[i] for total capacity at year's end were Germany, Italy, Spain, France and the Netherlands.[113]

Germany saw another large jump in installations (up 27%), with nearly 4.9 GW added for a total approaching 53.9 GW.[114] The commercial segment saw slower growth in 2020, but still expanded slightly and accounted for 59% of the total market.[115] The large-scale segment (>750 kW, mostly ground-mounted) accounted for less than 18% of the market, but it saw substantial growth (up 61%) as a result of special tenders.[116] Demand for residential rooftop systems (<10 kW) nearly doubled relative to 2019, and the sector accounted for 23% of the annual market (up from 15%) as homeowners became increasingly motivated by environmental concerns and the desire for energy independence and electric mobility.[117] More than half of the new rooftop systems (<10 kW) were installed with battery storage.[118]

The 52 GW cap[ii] on solar PV systems under Germany's feed-in law was officially removed in July, only weeks before the limit was reached.[119] In late 2020, the federal government set new targets for 83 GW by 2026 and 100 GW by 2030 under the new Renewable Energy Sources Act (EEG).[120] As solar PV penetration continues to rise, feed-in management is playing an increasingly important role. The EEG includes specific requirements for solar systems, depending on plant size, to enable the grid operator to remotely modulate the amount of electricity fed into the grid, as needed.[121] Solar PV produced an estimated 50.6 TWh in 2020, accounting for 10.5% of Germany's electricity generation.[122]

The Netherlands has seen steady market growth for several years, driven by net metering for residential and small business systems and tendering for larger plants.[123] More than 3 GW was added in 2020 (nearly half of which was commercial rooftop systems) for a total of 10.2 GW.[124] Interest in floating solar PV plants and solar carports increased during the year, and the country's largest ground-mounted plant (110 MW) became operational.[125] For all of 2020, grid-connected solar PV covered around 6.6% (7.92 TWh) of the country's electricity demand.[126]

Spain added around 2.8 GW in 2020 for a total of 12.7 GW.[127] Whereas much of the capacity added in 2019 had been due to tenders held in 2017, in 2020 a large portion of installations was private PPAs for projects without direct public support.[128] This marks the first time that such a sizeable amount of capacity has been grid-connected in Europe without a government subsidy or auction programme.[129] Spain's self-consumption market expanded nearly 30%, with tremendous growth in the residential sector.[130] Solar PV capacity accounted for 6.1% of Spain's electricity generation in 2020, up from 3.5% in 2019.[131]

The annual market in Poland more than doubled in 2020 (2.6 GW added for a total of 3.9 GW), driven by favourable self-consumption policies and low-interest loans.[132] Industrial consumers have started turning to renewables, including solar PV, in place of coal-fired generation.[133] Other notable developments in Europe included: Switzerland saw a record market increase (up at least 30%), driven in part by a rising desire for energy self-sufficiency; in Denmark a solar initiative was under way to enable more than 400,000 residents to become shareholders in solar parks (totalling 1 GW) across Denmark and Poland; and Lithuania reportedly became the first country in the world to launch an online platform that enables consumers to buy electricity from a remote solar panel.[134]

In the **South Pacific**, Australia continued to be the largest market by far, ranking seventh globally for both additions and total capacity.[135] The first half of 2020 was challenging due to devastating bushfires, delays in finalising grid connections as well as the pandemic, all of which caused a lull in utility-scale installations early in the year.[136] But the fires also affected thousands of kilometres of transmission and distribution lines, which drove interest in – and policies supporting – micro grids and stand-alone power systems, particularly solar PV, in remote and rural areas.[137] Overall, Australia added an estimated 4.1 GW of solar PV capacity in 2020 for a total exceeding 20.4 GW.[138] Despite the impacts of fires on solar output across much of the country, solar PV generation rose more than 24%, to 22.5 TWh, or 9.9% of Australia's total; small-scale rooftop systems alone accounted for 6.5% of total generation.[139]

The rooftop sector continued to contribute most of the capacity added in Australia, with new records set for both solar PV and home battery storage installations.[140] More than 2.6 GW of solar PV systems under 100 kW was installed on rooftops of homes and small businesses in 2020, up from about 2.3 GW in 2019, for a total exceeding 13 GW.[141] Households added an estimated 23,796 small-scale battery systems (up 5% over 2019), with a combined capacity of 238 MWh.[142]

The surge in demand for both solar PV and home storage systems in Australia was driven by several factors, including concerns about climate change, rising electricity costs, supportive policies, the desire for energy independence and pandemic-related impacts (home energy bills rose due to remote work, even as solar prices continued to fall, and people had more time to devote to home improvements).[143] By one estimate, nearly 2.7 million homes and businesses across the country had rooftop solar systems by the end of 2020.[144] As of early 2021, the share of dwellings with solar PV systems exceeded 20% in every state and territory except Tasmania; the top three were Queensland (41%), South Australia (40.3%) and Western Australia (33.2%).[145]

i The United Kingdom ranks third in Europe for total capacity, following Germany and Italy.

ii Exceeding the 52 GW cap would have ended feed-in payments for new systems up to 750 kW. The revised law, passed in December, maintains the feed-in payment for systems up to 300 kW. See endnote 119 for this section.

The state of South Australia has achieved one of the highest levels of solar penetration in the world and faces a widening mismatch between supply and demand. On many days, the amount of electricity entering the grid is well above the level of demand, making the state's power system the first large-scale system in the world to approach zero operational demand due to the growth of distributed solar PV, and requiring a number of measures to maintain grid stability and manage the electricity system.[146] In response, new tariffs were introduced to encourage a shift in consumption to peak solar hours, as well as new technical requirements that enable the market operator to turn off systems remotely.[147]

Across Australia, transmission infrastructure has not kept pace with the growth of renewables, especially large-scale solar (and wind) power projects.[148] Grid challenges, including insufficient system strength and congestion combined with a lack of clarity about state and federal policies, have resulted in delayed and cancelled renewable power projects, and have raised barriers to investment.[149] In early 2020, frustration over grid congestion led Victoria to break away from national electricity market rules in order to enact legislation to upgrade transmission infrastructure and prioritise storage and other projects to ensure a resilient energy system.[150]

To address challenges related to utility-scale projects in particular, the Australian Energy Market Operator (AEMO) was developing plans in 2020 for several Renewable Energy Zones (REZs) across five Australian states; the REZs will host solar and wind power projects co-located with energy-intensive industry, along with energy storage and strong grid connections.[151] In addition, Australia has seen a surge in small utility-scale systems (especially around 5 MW), which are relatively easy to grid-connect and face fewer transmission constraints.[152]

Other markets in the South Pacific remained small in comparison. In 2020, New Zealand commissioned a 1 MW floating array atop a wastewater treatment lake, the country's largest installation, and the Cook Islands, Fiji, Micronesia, New Caledonia, Papua New Guinea and the Kingdom of Tonga were among the small island states setting targets, commencing pilot programmes or launching tenders for solar PV (plus storage in many cases) in their efforts to reduce reliance on fuel imports and provide universal electricity access.[153] Fiji has seen rapid growth in commercial rooftop systems since 2015 and, in 2020, moved closer to its target of 100% renewable energy with plans to add at least 15 MW to the national grid.[154] As of 2020, Micronesia generated more than 11% of its electricity with solar PV.[155]

The **Middle East and Africa** combined added an estimated 4 GW in 2020 for a year-end total as high as 24 GW.[156] An increasing number of countries across the region had net metering policies in place (e.g., Israel, United Arab Emirates) or introduced or passed new laws to that effect (e.g., Egypt, Ghana, Kenya, Morocco, Nigeria).[157] Several countries also published requests for qualification (Saudi Arabia), floated tenders or awarded capacity for solar PV projects (e.g., Israel, Malawi, Syria, Tunisia, United Arab Emirates, Zimbabwe).[158]

In the Middle East, social impacts of the pandemic, combined with a decline in oil and gas prices[i], slowed progress in the planning and completion of new solar PV projects.[159] At the same time, the pandemic highlighted the importance of energy security and increased awareness of and political support for more-sustainable energy sources.[160] The largest installers in the region were Israel (0.6 GW), Oman (0.4 GW) and the United Arab Emirates (at least 0.3 GW).[161] Dubai (UAE) completed phase 3 (totalling 0.8 GW) of its Mohammad Bin Rashid Solar Park, Jordan brought online a 46 MW plant, and Oman's first renewable independent power producer (125 MW) began commercial operations.[162] Oman also announced plans for a 3.5 GW project to produce hydrogen with solar PV and is targeting thousands of residential rooftop installations in Muscat.[163]

Focus on distributed rooftop generation is increasing across the Middle East as a means to provide energy access and to reduce electricity bills for residential, commercial and industrial consumers.[164] In 2020, Saudi Arabia launched its first regulatory framework for 1-2 MW grid-connected systems, and several other countries in the region were creating initiatives to advance distributed solar PV in the commercial and industrial sectors.[165] At year's end, the top countries in the Middle East for total operating capacity were the United Arab Emirates (almost 3 GW), Israel (2.5 GW) and Jordan (1.5 GW).[166]

i The decline in oil and gas prices decreased revenue in some countries, while falling energy prices due to lower demand also reduced the incentive to shift to renewable energy. See endnote 159 for this section.

Across Africa, as costs of solar PV (as well as batteries) fall, solar PV is viewed increasingly as a means to achieve a variety of objectives, depending on the country. These include improving reliability and security of electricity supply, diversifying the energy mix (and either reducing energy imports or increasing exports), providing energy access, and meeting rising electricity demand while limiting the growth of CO_2 emissions.[167] (→ *See Distributed Renewables chapter for more on solar PV for energy access.*) Interest in solar energy for hospitals and other critical facilities also increased as part of national responses to the pandemic.[168] Considerable challenges remain, including a lack of suitable financing tools, lack of transparency, ongoing subsidies for fossil fuels in many countries, social and political unrest in some countries, and a heavy reliance on tenders for new capacity combined with a race to the bottom in bid prices.[169] Yet, some of the challenges (such as lack of regulatory frameworks for independent power producers and weak transmission grids) are helping to drive commercial and industrial markets for distributed solar PV.[170]

Ground-mounted systems are **growing ever larger** as developers work to further reduce the price of solar electricity through economies of scale.

Several countries across Africa commissioned new capacity in 2020. West Africa's largest plant (50 MW) came online in Mali, where hydropower accounts for around half of the country's installed capacity but provides increasingly variable output due to hydrological changes.[171] Medium-to-large projects were commissioned or began construction in several other countries, including Egypt, Ethiopia, Ghana, Somalia and South Africa.[172] The Egyptian government's gradual removal of subsidies on retail electricity prices is increasing the appeal of distributed solar PV for residential, commercial and industrial uses.[173] At year's end, Africa's top countries for total capacity were South Africa with 3.8 GW (added 1.1 GW), Egypt with around 2 GW and Algeria with 0.5 GW.[174]

Around the world, favourable economics are raising interest in distributed rooftop systems, which gained market share relative to large utility-scale projects, from around 35% in 2019 to around 40% in 2020; this was due mainly to strong growth in Vietnam, as well as increases in Australia, Germany and the United States.[175] Utility-scale capacity also rose during the year, and the size and number of large-scale projects continued to grow.[176] (Even the size of distributed systems is trending larger in many countries.[177]) The move towards **ever-larger ground-mounted systems** is due at least in part to the growing use of tenders and auctions, and increasingly also to PPAs, as developers work to further reduce the price of solar electricity through economies of scale in construction and in operations and maintenance.[178]

During 2020, around 80 plants of 50 MW and larger were completed (exceeding 21 GW in combined capacity), and such plants were operating in at least 49 countries[i] by year's end.[179] Developers completed at least 30 projects with capacity of 200 MW or larger.[180] In addition to those mentioned earlier, new facilities included Spain's 500 MW Nuñez de Balboa, Europe's then-largest solar PV plant, which will serve several clients through PPAs; and India's 2.2 GW[ii] Bhadla solar park, which became the world's largest with the completion of an additional 300 MW.[181] Numerous other large projects around the globe were either under way, completed construction or came online.[182]

If ground-mounted solar PV plants are well-designed and -built, competition over land can be reduced, and studies have shown that they can help to conserve biodiversity; however, large-scale ground-mounted plants can cover vast areas and their increasing numbers and scale are raising concerns about potential impacts on ecosystems and landscapes, grid-connection challenges and the use of agricultural lands and groundwater supplies (for cleaning).[183] As a result, there is increasing interest in alternatives. The potential for rooftop solar systems remains enormous, and many countries have established large rooftop programmes and targets.[184] There are also several **niche markets** that minimise land requirements, including building-integrated PV (BIPV), which is progressing only slowly, and the emergence of plans among mainstream auto manufacturers, particularly in Asia, to incorporate solar cells into electric vehicles.[185] Several BIPV projects were completed during 2020, including in India and the United States; in Europe the sector is driven mainly by France and Italy, which have targeted support schemes.[186]

The relatively small market for **floating solar** also continued its rapid expansion, driven by the limited availability and high costs of land in many places, as well as by design innovations that are helping to reduce costs.[187] Floating projects bring new risks and generally higher costs than ground-mounted facilities, but they also provide benefits (e.g., reducing land use for solar projects, reducing evaporation), especially where land is scarce or where they can be combined with hydropower.[188] Economies of scale in project sizes are helping to reduce associated costs.[189]

i Countries that added their first plants of 50 MW and larger in 2020 include Mali and Oman. See endnote 179 for this section.

ii This project totals 2,245 MW (45 MW larger than China's plant in Quinghai).

Most floating solar PV projects are sited in Asia, but they can be found in virtually every region.[190] By one estimate, more than 60 countries had such projects under way or in operation, and total global capacity reached around 2.6 GW in 2020.[191] Projects that became operational during the year included: in the Netherlands, Europe's largest floating plant (27.4 MW) was connected to the regional grid; in Ghana, the first section (5 MW) of a floating project was connected to the transmission system of a dam on the Black Volta River; and Chile's largest floating project was deployed under the country's net billing scheme.[192] As of early 2021, the largest floating solar plant in operation was a 181 MW plant off the west coast of Chinese Taipei.[193] Interest in moving offshore is rising, despite the additional challenges associated with currents, waves and salt water.[194]

Agricultural PV – the use of the same site for both energy and crop production – also is a rapidly emerging sector that can address concerns associated with land use, especially with the growing availability of bifacial systems (see later discussion).[195] Rising interest in this sector is also driven by concerns about potential impacts of climate change on crops and livestock.[196] While costs are higher relative to traditional ground-mounted systems, several studies have highlighted the advantages, including improved crop yields, reduced evaporation, rainwater harvesting (with modules), provision of shade for livestock or crops and protection against extreme weather events, prevention of wind and soil erosion, as well as additional income for farmers associated with electricity production.[197] Agricultural PV projects have been deployed for a number of years in Japan, the Republic of Korea and India, where there are active programmes to encourage deployment, and numerous pilot projects were under way during 2020 across Europe, China, Israel and the United States.[198]

SOLAR PV INDUSTRY

The solar PV industry rode a rollercoaster in 2020, with shockwaves of disruption driven largely by the pandemic. In early 2020, China – the dominant producer and global supplier of solar PV cells and modules – closed manufacturing and distribution facilities in several provinces.[199] As China began reopening by the second quarter, further disruption was triggered by pandemic-forced halts in the construction of solar projects in Europe, then the United States and elsewhere; at the same time, widespread economic closures reduced electricity demand and created uncertainties over future wholesale prices in many countries, slowing investment in new projects and the signing of PPAs.[200] By the third quarter, restrictions were eased and project construction resumed in many markets.[201] Also, however, starting mid-year, accidents at polysilicon facilities in Xinjiang, China, as well as a shortage of solar glass, drove up module prices[i],[202] Despite the many challenges, new actors continued to enter the sector, and competition and price pressures have motivated investment in technologies across the value chain to improve efficiencies, reduce the levelised cost of energy (LCOE) and improve margins.[203]

In response to COVID-related challenges, **several countries supported their domestic solar industries** by extending completion deadlines for awarded capacity or modifying tenders (e.g., Germany, France, India), or by extending deadlines for projects to receive incentives (e.g., the United States).[204] Spain's Royal Decree explicitly included solar PV as a key part of the national economic recovery, as did Italy's Relaunch Decree, while national and state governments in India took steps to support solar PV (and wind power) operations and new investment, including granting must-run status to insulate generators from declining electricity demand.[205] (→ *See Policy Landscape chapter.*)

Agricultural PV is rapidly emerging as an option for addressing concerns related to land-use as well as for mitigating the potential impacts of climate change on crops and livestock.

i Glass prices rose sharply due to a combination of stagnating supply and the global year-end rush for solar PV installations, combined with rising interest in larger modules as well as bifacial panels. Stagnating supply resulted from a cap on glass production capacity in China (home to 90% of global production capacity) in response to past overcapacity in the building industry as well as environmental concerns associated with glass production. By one estimate, shortages pushed up global solar glass prices more than 70% between July and November 2020. See endnote 202 for this section.

Disrupted supply chains and other pandemic-related challenges also elevated calls in many countries and regions for the **creation of local supply chains** to reduce heavy reliance on a limited number of manufacturers in a single region (Asia, and mostly China).[206] Governments acted through both trade policy and the direct promotion of manufacturing in an attempt to regain some control over the supply and price of solar products.

In the United States, tariffs on solar-related imports from China and several other countries continued throughout 2020.[207] In November, the on-off exemption for bifacial cells and modules was again revoked, and new duties were imposed on silicon metal imports from Bosnia, Herzegovina, Iceland and Kazakhstan.[208]

India extended the safeguard duty on imported solar cells and modules for another year and, in December 2020, imposed a countervailing duty on solar glass imported from Malaysia.[209] The country also promoted increased self-reliance through the "Make in India" initiative, and launched tenders and incentives linked to the development of domestic cell and module manufacturing capacity.[210]

In 2020, the European Commission began working with industry to promote and support solar research and development, as well as investment in manufacturing of solar technology along the whole value chain.[211] The governments of Turkey as well as several countries in the Middle East also were encouraging the development of domestic industries.[212] In Egypt, for example, a project was launched to develop a sand-to-cell complex to boost local manufacturing.[213] Several additional countries had measures in place to encourage domestic production or to penalise the use of foreign-made products.[214]

At the start of 2020, China announced that it would extend duties on polysilicon from the United States and the Republic of Korea for five more years to build a self-sufficient domestic industry.[215] China accounted for about 80% of global polysilicon production as of 2020, up from 26% in 2010.[216]

More than 45% of the world's **polysilicon** is produced at facilities in China's Xinjiang province, with producers drawn to the region by low costs of labour and energy (mostly coal-fired generation).[217] In late 2020, concerns arose among investors and others across the industry regarding allegations of the use of forced labour for polysilicon production in Xinjiang.[218] Although the Chinese government and China's solar industry trade group have denied these claims, solar industry groups in the United States and Europe have called for increased transparency and the upholding of human rights throughout the global supply chain, and concerns have been raised in Australia and Japan as well.[219]

In response to these concerns, the top trade group for the US solar industry began publicly encouraging companies to move their supply chains out of Xinjiang and, in late 2020, announced that it was developing a supply chain traceability protocol.[220] The leading industry group in Europe called for strengthening the EU solar industrial base to help diversify and improve Europe's position in the solar supply chain.[221] The situation has further highlighted the high dependence of the industry on a relatively small number of manufacturers, located in a single region.[222]

Globally, **average module prices** fell 8% between late 2019 and the end of 2020, from an average USD 0.36 per watt-peak (Wp) to USD 0.33 per Wp.[223] This was despite shortage-induced price increases for both polysilicon and glass, which module manufacturers could not pass along to consumers.[224] By one estimate, the global benchmark LCOE[i] of utility-scale solar PV declined 4% from the second half of 2019 until early 2020, to USD 50 per MWh.[225]

In 2020, **tenders and auctions** again saw bid prices[ii] drop to new lows.[226] The lowest bid prices were seen in Portugal, Abu Dhabi (UAE) (USD 13.5 per MWh) and Qatar (just under USD 15.7 per MWh), for the country's first utility-scale project.[227] Portugal's second solar auction, for a total 700 MW under three separate remuneration categories (including a new category for solar-plus-storage), saw a winning bid at USD 13.2 per MWh for a 10 MW solar PV system plus storage[iii,228]

i Energy costs vary widely according to solar resource, regulatory and fiscal framework, trade policies, project size, customer type, the costs of capital, land and labour, exchange rates and other local influences. Distributed rooftop solar PV remains more expensive than large-scale solar PV but has followed similar price trajectories, and is competitive with (or less expensive than) retail electricity prices in many locations. In addition, price is not equal to cost and is influenced by several factors unrelated to the costs of production including government support policies, competing technologies, level of competition, price expectations and end-user tastes. See endnote 225 for this section.

ii Note that bid levels do not necessarily equate with costs. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors.

iii Under the auction's rules, Portugal's winning projects in the Fixed Premium for Flexibility remuneration modality are required to build energy storage capacity accounting for at least 20% of tendered solar capacity to address variability, provide flexibility and other grid regulation services, and to compensate the network for peaking power prices in the spot market for 15 years. See endnote 228 for this section.

India set its own low bid record (USD 26.9 per MWh) in a Gujarat auction, following a continuous decline in bid prices across the country throughout the year.[229] Average tariffs awarded during 2020 were below those in 2019 and among the lowest in the world, driven by a mix of government support policies, bidder assumptions about future equipment prices, and the participation of international developers with access to low-cost financing.[230]

Falling bids in tenders and auctions have prompted efforts to renegotiate prices under existing PPAs, an additional challenge to the industry. In India, attempts to renegotiate prices in several states have left institutions and investors reluctant to finance projects under government PPAs.[231] In South Africa, the state-owned utility Eskom announced plans to renegotiate PPAs with renewable independent power producers from the first two bid rounds of the national procurement programme.[232] Similar renegotiation efforts were under way in Saudi Arabia during 2020.[233]

Outside of locations with a low cost of finance and excellent solar resources, such as Abu Dhabi or Qatar, a broad range of experts believe that very low bids, such as Portugal's winning price, often are driven by extreme competition and the desire to access grid connections and markets.[234] In such instances, low bids are thought to be possible only because firms make overly optimistic assumptions about future cost reductions (ahead of project construction) or plan for merchant sales at the end of the contract period, betting on the merchant price (until the end of project lifetime) to supplement revenues.[235] In 2020, manufacturers and developers across much of the solar PV industry experienced low margins.[236]

Direct bilateral PPA prices saw mixed developments during the year. In North America, average PPA prices rose throughout 2020, after falling continuously since early 2018, due to grid connection delays, permitting challenges, the step-down of the federal investment tax credit as of January 2020, as well as pandemic-related challenges.[237] An exception was seen in New Mexico, with record-low prices for a solar PV plant (USD 15 per MWh) and a solar-plus-storage facility (USD 21 per MWh), which together will replace a natural gas steam plant[i] due to be retired in 2022.[238] In Europe, PPA prices declined slightly, at least in the fourth quarter, with the lowest price reported in Spain (EUR 35, or USD 43, per MWh).[239] Prices also were low in Germany, Denmark and Sweden, due at least in part to high levels of renewable energy penetration, which depressed electricity market prices.[240]

Global shipments of cells and modules were down in the first half of the year, but for all of 2020 they increased 7% relative to 2019.[241] Of the estimated 131.7 GW of cell/module volume shipped in 2020, around 86% was shipped by Chinese firms (including their facilities in Southeast Asia).[242] The top 10 companies accounted for 71% of shipments, and all were Chinese based with the exception of US-based First Solar (with 4%).[243] First Solar continued to dominate global thin film shipments, which accounted for 5% of the year's total cell/module shipments.[244]

Despite the challenges in 2020, many companies achieved major increases in **production capacity** during the year. Most of the expansions occurred in China, but there was activity elsewhere as well.[245] For example, Mexican solar module manufacturer Solarever opened the first module assembly line (500 MW per year) of three at its third facility in Mexico, and Turkey's Kalyon facility (500 MW per year) came online, with processes for manufacturing ingots, wafers, cells and modules.[246]

By the end of 2020, global crystalline and thin film commercial cell production and module assembly capacities[ii] were estimated to be 203.7 GW (cell) and 248.6 GW (module), up 33% and 34% respectively over 2019.[247] An estimated 66% of commercial[iii] cell production capacity and 60% of module assembly capacity was located in China; the United States and Europe each were home to around 1% of cell capacity and 2% of module capacity, and most of the rest was elsewhere in Asia (particularly Malaysia and Vietnam) with much of that owned by Chinese firms.[248]

Manufacturers and developers across much of the solar PV industry experienced low margins in 2020.

i Four additional solar PV-plus-storage plants in New Mexico, due for commissioning in mid-2022, will replace a large coal-fired generator in the US state. The utility will pay in the range of USD 18-25 per MWh. See endnote 238 for this section.

ii Cell capacity is MW or GW of semiconductor (cell) capacity available to a manufacturer; module assembly capacity is that available to assemble cells into modules.

iii Commercial capacity is not the same as nameplate capacity of the equipment, which is the stated capacity under ideal conditions. P. Mints, SPV March Research, *The Solar Flare*, 26 February 2021, p. 7.

Throughout the year, manufacturers announced plans to further increase production capacity in 2021 and beyond.[249] Most planned expansion was by Chinese producers of polysilicon, wafers, cells and modules.[250] Tongwei Solar, for example, revealed plans to expand polysilicon production and to raise its cell production capacity from 20 GW to 30 GW in 2021, with a goal of expanding to 60 GW by 2022.[251]

Elsewhere, several European manufacturers looking to regain market share opened or announced plans for new facilities in Europe.[252] For example, Ecosolifer AG (Hungary) started commercial production of heterojunction[i] (HJT) cells at a 100 MW factory, the Hevel Group (Russian Federation) launched HJT cell production, and Meyer-Burger Technology (Switzerland) announced that it would shift from merely selling its production equipment to using its technology to manufacture HJT cells and modules, with plans to scale up to 5 GW module production capacity in Germany by 2026.[253] In Africa, Mondragon Assembly (Spain) provided assembly lines for new module production facilities in Algeria and Egypt.[254]

The year also saw **consolidation** among manufacturers and installers, driven by pandemic-related challenges as well as longer-term concerns. In China, the pandemic resulted in the closure of several relatively small solar manufacturers, relieving the central government of its plans to eliminate them.[255] The largest solar PV manufacturer to fall in 2020, Yingli (China), was the world's biggest panel maker as recently as 2013.[256] Aggressive borrowing alongside a plunge in solar prices led to years of losses and rising debt; the company entered restructuring in 2020 and was brought under government control and renamed "New Yingli".[257]

In addition, Panasonic (Japan) and Tesla (US) ended their partnership and, in early 2021, Panasonic, which entered the solar sector in 2008, announced plans to cease all production of cells and modules by 2022, due to the pandemic and highly competitive pricing.[258] A subsidiary of Inventec (Chinese Taipei) announced that it would end cell production in 2021, due to margin constraints.[259] SunPower (US), another long-lived manufacturer of cells and modules, spun off its panel manufacturing and sales to Maxeon (Singapore) and, in early 2021, announced plans to close its remaining US panel manufacturing facility to focus on solar and battery sales and services.[260] First Solar (US) sold its operation and maintenance business in North America due to falling margins to focus on module manufacturing.[261]

Also in 2020, the leading US residential solar, battery storage and energy services company, Sunrun, acquired Vivent (US), a leading competitor, representing the largest rooftop solar consolidation yet.[262] In August, solar manufacturer Hanwha Q Cells (Republic of Korea) acquired energy storage solutions company Growing Energy Labs, Inc. (GELI, US) to expand into the US solar-plus-storage market.[263]

As in the wind power industry, **new actors** including fossil fuel companies continued to enter the solar sector.[264] Several European oil and gas companies are acquiring existing solar PV projects as investments or are constructing and operating new projects.[265] In 2020, BP announced a partnership with Chinese module manufacturer JinkoSolar to provide clean energy for commercial and industrial customers in China, and Spanish gas grid operator Enagás signed an agreement with Anpere Energy (Spain) to jointly produce hydrogen with solar PV, with plans to inject hydrogen into Spain's gas network.[266]

Other fossil fuel companies are engaging in research and development (R&D) or moving into production. US oil and gas company Hunt Consolidated announced that its R&D work with perovskite cells had achieved efficiency performance levels of 18%; as of late 2020, the company owned the largest portfolio of perovskite solar patents in the United States and one of the largest in the world.[267] In India, state-owned Coal India (the world's largest coal producer) received approval in December to set up an integrated solar wafer manufacturing facility.[268]

i HJT combines advantages of conventional crystalline silicon solar cells with good absorption and other benefits of amorphous silicon thin film technology.

Competition and price pressures have encouraged **investment in solar PV technologies** across the entire value chain, particularly in solar cells and modules, to further improve efficiencies and reduce the LCOE.[269] As in previous years, several new record cell and module efficiencies were achieved during 2020.[270] Monocrystalline[i] cell technology – which lost its lead to multicrystalline in 2002 and retook it in 2019 – continued to gain market share (up 26 percentage points to 88% of shipments), and it accounted for all expansions of silicon ingot crystallisation capacity in 2020.[271] As the cost differential between technologies has fallen, a higher priority has been placed on the higher efficiency potential of monocrystalline technology.[272]

Economics also have played a role in driving ever larger wafers and modules.[273] Manufacturers started enlarging wafers (used to make solar cells) around 2017 to optimise costs, and because it was the easiest way to increase the power of modules.[274] By 2020, most of the sector was increasing sizes again and, by year's end, most major module manufacturers were preparing to produce panels based on larger wafers.[275] The rapid shift has left many smaller companies behind and has raised manufacturing costs throughout the supply chain.[276] As a result, by early 2021 Trina and several other large module manufacturers were working to standardise wafer sizing.[277]

Demand for higher-efficiency modules helped to steer a shift towards passivated emitter rear cell (PERC)[ii] technology, which accounted for the majority of cell shipments in 2020.[278] Yet, while monocrystalline PERC has been the focus of most manufacturing capacity expansions in recent years, the industry is already looking beyond PERC, with the first large manufacturers starting to produce new cell technologies that promise even higher efficiencies and output and offer the potential to improve margins.[279] Passivated contact cells[iii] (TOPCon) might be the next evolutionary step, requiring the upgrading of PERC production lines, while HJT cell technology (which requires completely new production lines) also offers higher efficiencies and can be manufactured at low temperatures and with fewer production steps than other high-efficiency cell technologies.[280]

The industry is rapidly shifting to
new cell technologies
to increase cell efficiencies and output and to improve margins.

Researchers also continued working to circumvent the theoretical efficiency limits of silicon-based solar cells by stacking cells of different types and developing more efficient cell technologies.[281] Perovskites[iv], in tandem with crystalline silicon or a thin film base, continued to attract substantial research funding in an effort to move closer to commercialisation.[282] Oxford PV (UK) set a new record for perovskite-silicon tandem cell efficiency (29.5%) and started ramping up production at its facility in Germany.[283] Saule Technologies (Poland) began printing perovskite cells with inkjet printers, with plans to supply a Swedish construction company (Skanska Group) in 2021 for use on building façades.[284] Researchers continued to focus on a number of challenges, including addressing the long-term stability issues and lead content of perovskites, developing new cell designs and encapsulation strategies, and bringing down costs.[285]

Improvements in cell technology and module design have enabled the development of modules with higher power ratings.[286] Manufacturers were pushing 400 W in 2019, and several introduced modules with ratings of 500 W and higher during 2020.[287] Raising the power rating increases electricity output per module, thereby reducing the number needed for a project, reducing space requirements and associated shipping, land, installation and other costs.[288]

Interest continued to increase in bifacial modules, which capture light on both sides, and offer potential gains in output and thus a lower LCOE.[289] Power gains range from 5% to as much as 30% depending on cell technology, system design and location.[290] Uncertainties about the performance of bifacial systems are falling away as the increasing number of systems in operation demonstrates the benefits.[291] However, a growing demand for bifacial modules, which generally are made with two glass panes (unlike most traditional modules), contributed to a shortage in solar glass supply, helping to push up prices in the second half of 2019.[292]

i Crystalline technologies account for nearly all cell production. Historically, monocrystalline cells have been more expensive but also more efficient (more power per unit of area) than multi- or poly-crystalline cells, which are made of multi-faceted or multiple crystals. See endnote 271 for this section.

ii PERC is a technique that reflects solar rays to the rear of the solar cell (rather than being absorbed into the module), thereby ensuring increased efficiency as well as improved performance in low-light environments.

iii Tunnel-oxide passivated contact (TOPCon) cells adapt a sophisticated passivation scheme to advance cell architectures for higher efficiencies. See endnote 280 for this section.

iv Perovskite solar cells include perovskite (crystal) structured compounds that are simple to manufacture, can be made at low temperatures, and are expected to be relatively inexpensive to produce. Perovskites can be printed onto substrates of other materials or made as thin sheets. They have achieved considerable efficiency improvements in laboratories. See endnote 282 for this section.

The scale of manufacturing and demand is such that solar PV has become the major driver of growth in polysilicon production and accounts for a large and growing share of global demand for glass and other materials and resources.[293] As with other energy technologies and electronics, solar panels are resource intensive, relying heavily on aluminium, copper and silver, and on smaller amounts of minerals such as zinc, indium and lead.[294] Between 2010 and 2020, solar PV use of silver more than doubled, with the industry's share of global demand rising from 5.7% to more than 11%, even as silver use per cell declined 80%.[295]

Once produced, solar panels have technical lifetimes of 25-30 years or longer.[296] Nonetheless many solar plants are already being repowered[i], and the volume of **decommissioned panels** in the coming decade is expected to be large.[297] Repowering is due mainly to ageing components, particularly inverters, but the opportunity to increase output per installation (made possible by rapid technology advances and falling prices) is leading many developers to replace panels much earlier.[298]

There is a growing market for second-hand panels (which might or might not be recycled later), but most decommissioned, damaged or faulty solar panels go to existing waste treatment or recycling facilities that do not yet recover many of the materials that represent some of their potential value (e.g., silver, copper and silicon) and environmental impact (e.g., lead).[299] Nearly 95% of a solar panel is recyclable but, for now, many materials that could be reclaimed do not cover the costs of recycling.[300] It is a matter of economics and volume: finding markets for the reclaimed materials and scaling up treatment lines to drive down per-unit costs, both of which require a relatively high volume of solar panels that have reached the end of life.[301]

Mandates on producers to collect and recycle panels (such as takeback legislation), and required financing, can create the guaranteed supply of panel waste that is needed to make recycling economical.[302] As of 2020, only the EU and the US states of New York and Washington mandated solar panel recycling.[303] Japan required facilities of 10 kW or larger (installed under the FIT system) to pay into a decommissioning fund for 10 years after 2022; some Australian states had bans on electronic waste in landfills (and South Africa has a similar ban, due to take effect in August 2021); and other countries were considering or in the process of developing requirements.[304]

As of early 2021, only Europe had a single treatment line (in France) that is dedicated to recycling of crystalline silicon panels.[305] Other facilities in Europe (e.g., in Belgium, Germany, Italy and Spain) have integrated the treatment of silicon-based solar panels into existing treatment lines (for laminated flat glass products, for example).[306] A handful of facilities operate in other countries: Japan has at least two facilities; India has a pilot recycling plant; and, in the United States, a small number of industry-driven facilities can handle parts of panels, and thin film manufacturer First Solar has in-house capabilities.[307] In Australia, Reclaim PV is testing a pyrolysis process and starting to ramp up a nationwide collection network, and other companies in Australia are working on recycling.[308] In China, leading manufacturers have begun to research options.[309]

On a related note, in 2020 the Republic of Korea introduced carbon footprint rules for solar modules – new projects will be prioritised according to their life-cycle emissions; the rules are similar to those applied in France[ii] for large-scale tenders.[310] In addition, several companies from across the solar PV value chain launched the Ultra Low-Carbon Solar Alliance in 2020, pledging to build market awareness and to accelerate the deployment of solar PV modules with lower embodied carbon to reduce the carbon footprint of solar systems.[311]

i In the United States, for example, utility-scale projects generally pay for themselves in about seven years; repowering the project resets the clock on the federal investment tax credit. See endnote 297 for this section.

ii France's tenders for large-scale solar PV plants prioritise projects using modules with low carbon footprints.

KEY FACTS

- **CSP markets grew slowly in 2020** as a result of increasing cost competition from solar PV, the expiry of CSP incentive programmes and operational issues at existing facilities. Spain and the United States, the market leaders in cumulative installed CSP capacity, have not added new capacity in seven and five years, respectively.
- **More than 1 GW of new capacity was under construction in 2020** in the United Arab Emirates, China, Chile and India, although construction did not begin on any new projects. China was the only country to add new capacity during the year.
- CSP costs fell 50% during the 2010s, and there are several **examples of CSP facilities with thermal energy storage co-located with solar PV** to lower costs and increase capacity factors.

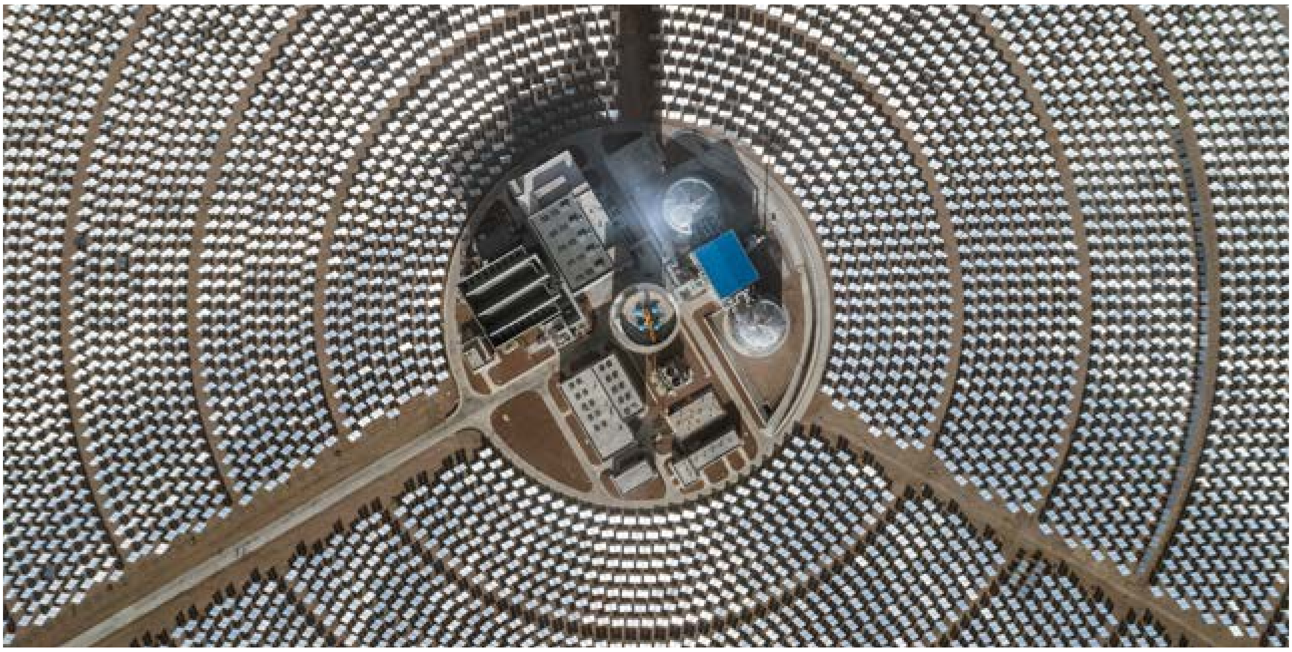
CONCENTRATING SOLAR THERMAL POWER (CSP)

CSP MARKETS

Global CSP[i] capacity grew just 1.6% in 2020 to 6.2 GW, with a single 100 MW parabolic trough project coming online in China.[1] This was down from the 600 MW commissioned in 2019 and was, along with 2017, the lowest annual market growth in over a decade.[2] (→ *See Figure 29 and* ***Reference Table R16*** *in GSR 2021 Data Pack*.) Reduced market growth comes on the back of several challenges faced by the CSP sector in recent years, including increasing cost competition from solar PV, the expiry of CSP incentive programmes and a range of operational issues at existing facilities.[3] Market growth also was impacted by construction delays and stoppages in China, India and Chile.[4]

More than 1 GW of CSP projects was under construction during 2020 in the United Arab Emirates, China, Chile and India, although no new projects commenced construction during the year.[5] This was the seventh consecutive year in which no new CSP capacity came online in Spain, still the market leader in cumulative operating CSP capacity. The United States, which ranks second in cumulative capacity, has seen no new capacity additions in five years.[6]

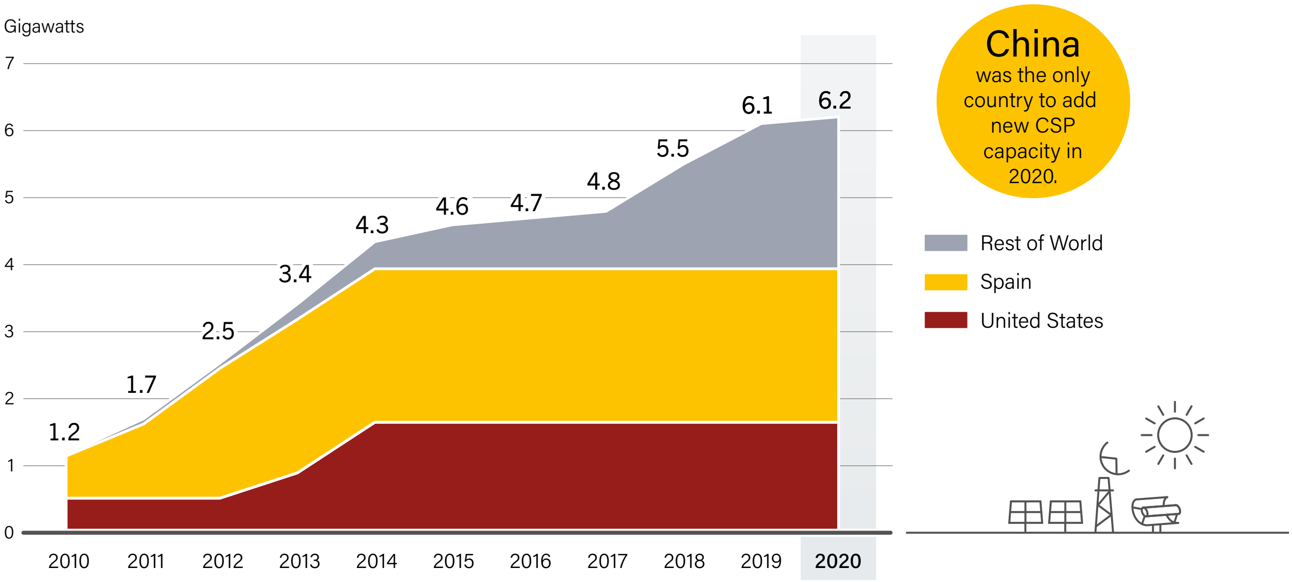
The majority of projects under construction during 2020 were based on parabolic trough technology.[7] At year's end, the plants under construction worldwide included just over 1 GW of trough systems, just under 0.3 GW of tower systems and a 14 MW Fresnel system.[8] With the exception of two hybrid CSP-natural gas plants,[ii] all of these plants are to include thermal energy storage (TES).[9]



i CSP is also known as solar thermal electricity (STE).

ii These hybrid plants are integrated solar combined-cycle (ISCC) facilities, hybrid plants that use both solar energy and natural gas to produce electricity.

FIGURE 29.
Concentrating Solar Thermal Power Global Capacity, by Country and Region, 2010-2020



Source: See endnote 2 for this section.

In China, the 100 MW CSNP Royal Tech Urat project commenced operations in January 2020, bringing the country's total installed capacity to 520 MW.[10] The project, based on parabolic trough technology, incorporates 10 hours or around 1,000 MWh[i] of thermal storage based on molten salts, and is the largest of the country's 10 operational CSP facilities.[11] A number of CSP plants were under construction in China during 2020, although several were delayed or taken over by new owners and contractors due to a range of implementation challenges.[12]

In the United Arab Emirates, construction continued on the Mohammed bin Rashid Al Maktoum Solar Park, consisting of a 600 MW parabolic trough facility (11 hours; 6,600 MWh), and a 100 MW tower facility (15 hours; 1,500 MWh).[13] A key milestone was achieved with the commissioning of the 262-metre solar tower, the highest in the world.[14] Once operational, the facility will bring cumulative CSP capacity in the United Arab Emirates to 800 MW.[15] Elsewhere in the Middle East, construction continued on the 50 MW Duba 1 Integrated Solar Combined Cycle project in Saudi Arabia.[16]

Several CSP facilities totalling around 300 MW were being built in India in recent years, although some projects faced protracted delays, and anticipated completion dates remained unclear.[17] The country operated 225 MW of CSP capacity as of end-2020.[18]

Chile was the only other country with CSP capacity under construction during the year, in the form of the 110 MW Cerro Dominador tower project (17.5 hours; 1,925 MWh).[19] The plant, which will be the first commercial CSP facility in Latin America

The world's largest **CSP project,** at 700 MW, was under construction in the United Arab Emirates.

i The total TES capacity in MWh is derived from the sum of the individual storage capacities of each CSP facility with TES operational at the end of 2019. Individual TES capacities are calculated by multiplying the reported hours of storage for each facility by their corresponding rated (or net) power capacity in MW.

and is expected to be operational in 2021, achieved several construction milestones in 2020 including installation of the 220-metre solar tower and the commencement of salt melting.[20]

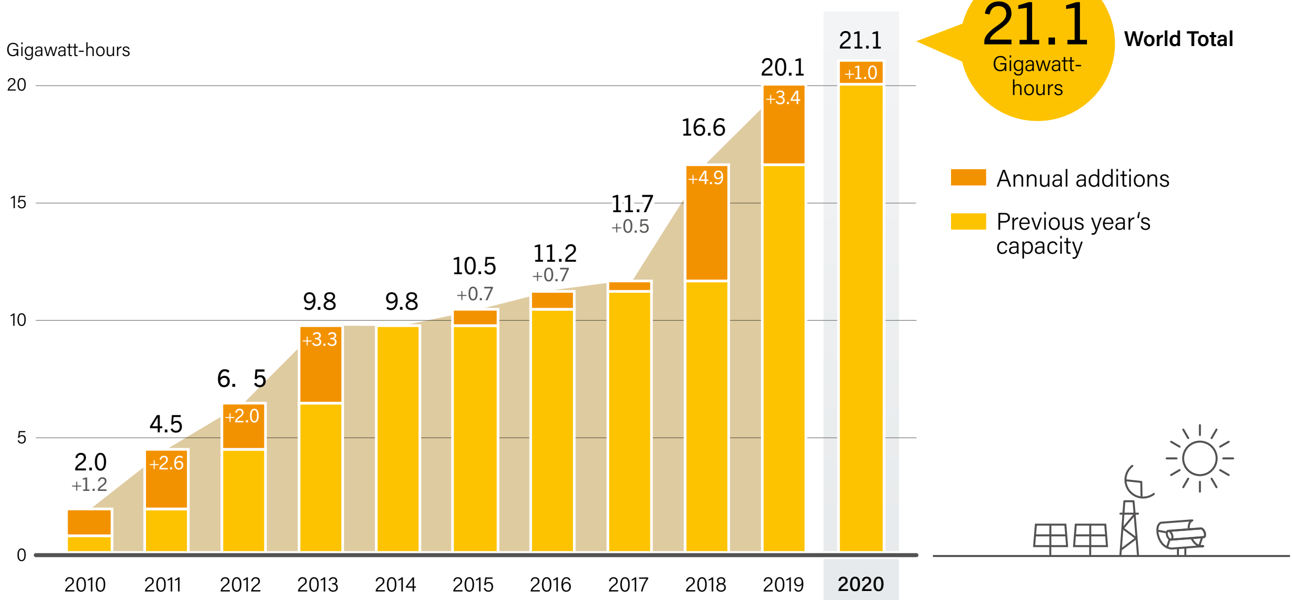
While no CSP capacity was added on the African continent, the 800 MW Midelt CSP project in Morocco was approaching the construction phase, and the tendering process for Zambia's first CSP project, a 200 MW parabolic trough facility, was completed and contractors were subsequently appointed to carry out the project's civil construction works.[21] In neighbouring Botswana, a new integrated resource plan released in 2020 targets 200 MW of CSP capacity by 2026.[22]

For cumulative capacity in operation, Spain remained the global leader with 2.3 GW at the end of 2020.[23] With no new capacity additions in seven years, Spain's share of global CSP capacity in operation declined from a high of nearly 80% in 2012 to just under 40% by the end of 2020.[24] However, production from the existing CSP fleet has increased in recent years as a result of operational improvements, and a draft energy and climate plan released by the Spanish government during 2020 targets the procurement of 600 MW of new CSP capacity by 2025.[25] There were also plans to enhance the performance of several Spanish CSP plants by retrofitting them with energy storage.[26] Following Spain in cumulative CSP capacity was the United States with just over 1.6 GW of commercially operational CSP, or just under 30% of global capacity.[27]

At the end of 2020, an estimated 21 GWh of thermal energy storage, based almost entirely on molten salts[i], was operating in conjunction with CSP plants across five continents.[28] (→ *See Figure 30.*) Of the 24 CSP plants completed globally since the end of 2014, only two do not incorporate TES: an integrated solar combined-cycle (ISCC) facility in Saudi Arabia and the Megalim plant in Israel.[29] TES capacity, installed mainly alongside CSP, represents a significant proportion of global non-pumped hydropower energy storage capacity: while global installed solar PV capacity is more than 100 times greater than CSP, the quantity of TES installed at CSP facilities around the world is almost double that of utility-scale batteries.[30]

i More than 95% of global TES capacity in operation on CSP plants is based on molten salt technology. The remainder use steam-based storage.

FIGURE 30.
Thermal Energy Storage Global Capacity and Annual Additions, 2010-2020



Source: See endnote 28 for this section.

CSP INDUSTRY

After several years of diversification of the CSP industry beyond Spain and the United States to markets across Africa, the Middle East and Asia, the majority of construction activity in the sector was concentrated in the United Arab Emirates and China. CSP projects that either entered operations or were under construction during 2020 involved lead developers and investors from Saudi Arabia, China, India and the United States.[31] Contractors were based in China, Spain, the United States and India, with Chinese companies involved in almost half of the completed or active projects.[32] By contrast, before 2015 most CSP companies hailed from the United States and Spain.[33]

The Saudi company ACWA Power remained the leading CSP project developer in 2020, with more than 700 MW of projects under construction.[34] Other notable developers, investors or owners of CSP plants that either entered operations or were under construction during the year included Royal Tech (China), EIG Global Partners (United States) and at least six other developers from around the world.[35] Some of the leading companies involved in the engineering, procurement and construction of CSP facilities included Abengoa (Spain), Acciona (Spain), Brightsource (US), China Shipbuilding New Power Company (China) and Shanghai Electric (China).[36]

During the decade prior to 2020, CSP costs decreased 68%, the largest decline for all renewable energy technologies with the exception of solar PV, which experienced a more than 80% cost decline over the same period.[37] CSP costs have improved as a result of multiple factors, including technological innovation, improved supply chain competitiveness, as well as increased growth in CSP capacity in high irradiance regions which, along with increased TES capacity, has boosted the overall capacity factor of the global CSP fleet.[38]

In many cases CSP and TES capacity are co-located with solar PV capacity to lower costs and increase capacity values. For example, the Cerro Dominador plant in Chile is being built alongside an existing 100 MW solar PV plant.[39] Other developments aim to integrate CSP, TES and solar PV more closely: in Morocco, the Midelt plant will be the first to incorporate an electric heater to allow for storage of energy from the adjacent solar PV facility using the molten salt storage system.[40] The hybridisation of CSP with solar PV reflects a shift away from direct competition between CSP and other generation resources to a more integrated and complementary approach that emphasises the unique benefits of CSP systems that include TES, such as long-duration energy storage.[41]

Several CSP plants are being located alongside solar PV facilities to lower overall costs and boost capacity factors.

In some cases, older CSP plants without energy storage are being retrofitted with TES to greatly improve their overall functionality and economics. Some estimates indicate that the costs of implementing new TES at existing CSP plants are much lower than the costs of implementing equivalent battery capacity with existing solar PV.[42]

Several research and development activities focused on CSP and TES were under way in 2020. Areas of development included the integration of CSP and TES with other generation and storage technologies, the improved reliability of mechanical systems, the use of alternative heat transfer mediums and the application of more efficient power conversion cycles.[43] The US Department of Energy announced USD 39 million in funding to support a pilot CSP project that aims to demonstrate improved efficiencies through the application of a supercritical carbon dioxide power cycle.[44]

KEY FACTS

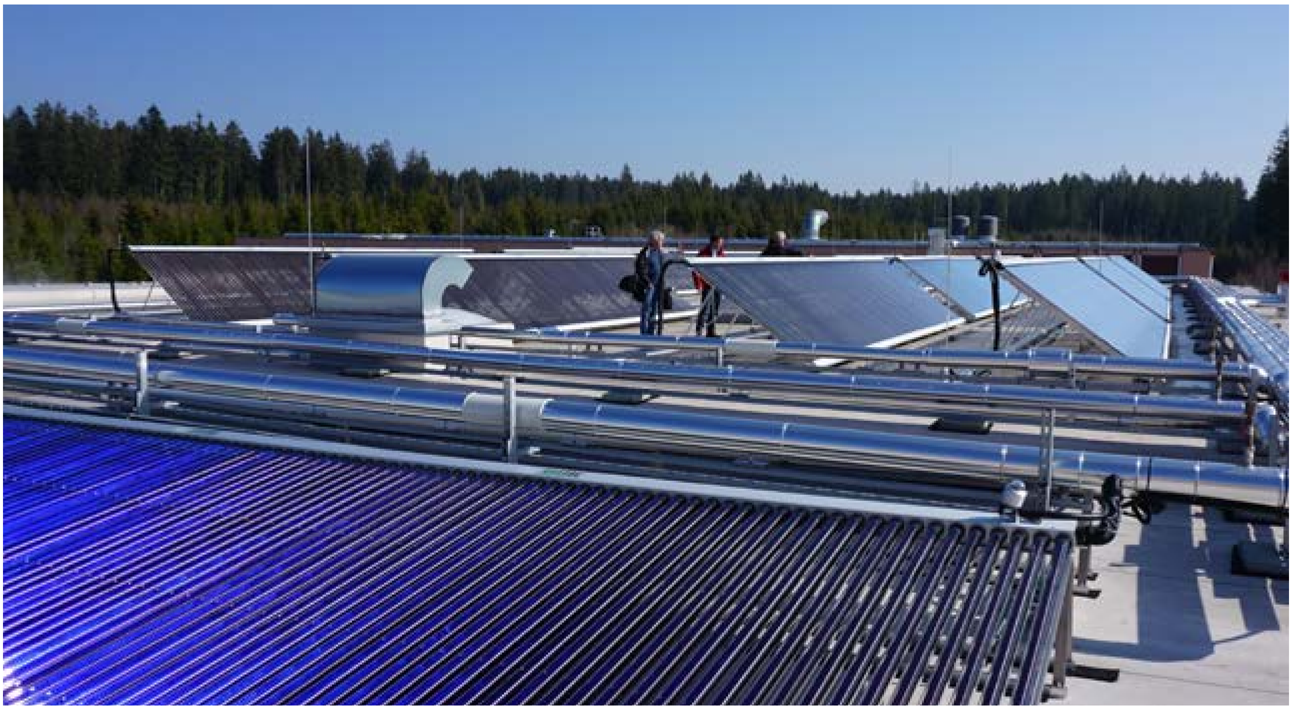
- An estimated 25.2 GW_{th} of new solar thermal capacity came online in 2020, with **China, Turkey, India, Brazil and the United States** leading in new installations.
- Residential, commercial and industrial clients in **at least 134 countries operated 501 GW_{th}**, enough to provide heat equivalent to the energy content of 239 million barrels of oil.
- China and Germany took the lead from Denmark in **solar district heating**, thanks to policy support in both countries.
- A new generation of manufacturers of **innovative concentrating collectors** unveiled the first demonstration or commercial projects.

SOLAR THERMAL HEATING

The global solar thermal market continued a gradual decline in 2020, with an estimated 25.2 GW_{th} of capacity added[i] worldwide, down 3.6% from 26.1 GW_{th} in 2019.[1] Most large solar thermal markets were constrained by challenges associated with COVID-19, such as pandemic-related restrictions and postponed investment decisions by commercial clients, including industries and hotels. However, the reduction was smaller than expected due to various stabilising factors.

In most of the largest solar thermal markets, continuous business in the construction sector during the pandemic helped maintain a steady demand for systems. In many countries, the effects of trade and travel restrictions on the solar thermal market were offset at least partly by higher demand from residential owners who spent more time at home and invested in infrastructure improvements.[2] In markets that depend strongly on subsidies, changes in policy support in 2020 had a much greater influence (positive or negative) on solar thermal demand than did the pandemic.[3]

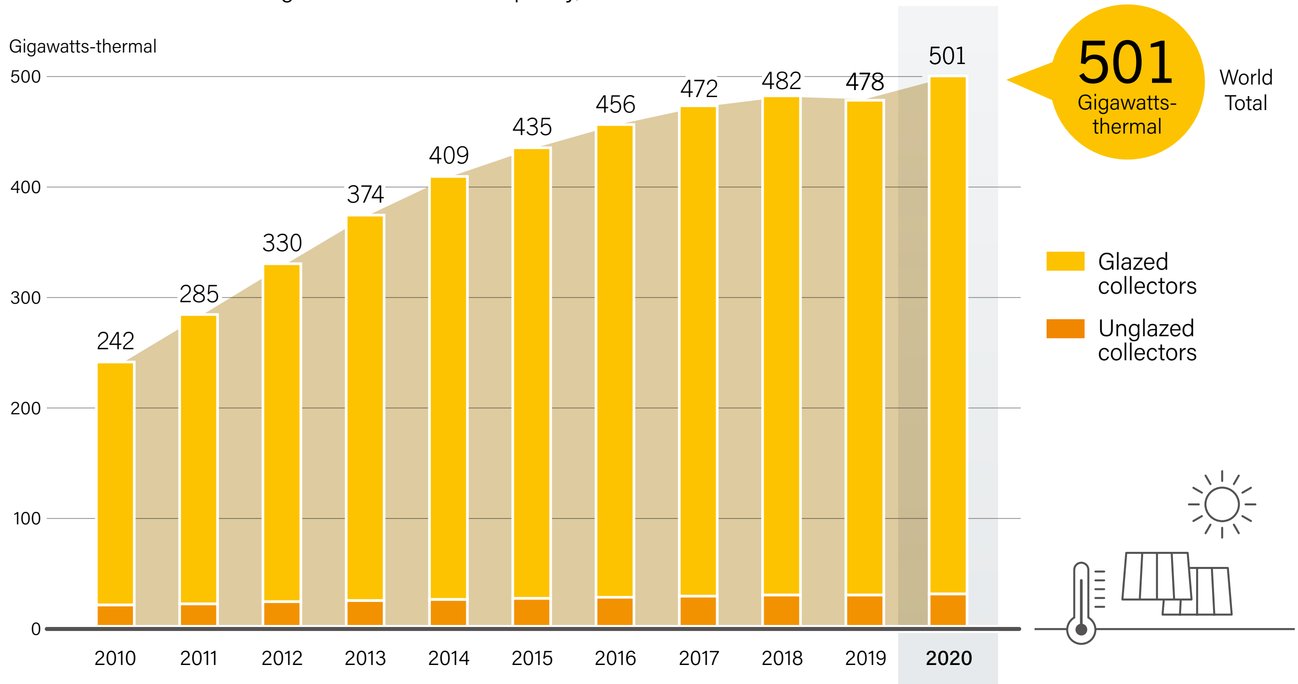
By the end of 2020, millions of residential, commercial and industrial clients in at least 134 countries were benefiting from solar heating and cooling systems.[4] The total operating capacity for glazed (flat plate and vacuum tube) and unglazed collectors (used mainly for heating swimming pools) reached an estimated 501 GW_{th} by year's end, up 5% from 478 GW_{th} in 2019[ii].[5] (→ *See Figure 31.*) These collector types provided around 407 terawatt-hours (1,465 petajoules) of heat annually, equivalent to the energy content of 239 million barrels of oil.[6]



i Added capacity or new additions in this section are gross additions, whereas total capacity counts only net additions (replacement of decommissioned systems is not included).

ii Annual additions for China in 2019 were revised (see endnote 1 for this section), and the assumptions for estimating new solar thermal capacity additions beyond the largest 20 markets were adapted for 2019 and 2020 (see endnote 5 for this section), which also had an impact on estimates for total global capacity.

FIGURE 31.
Solar Water Heating Collectors Global Capacity, 2010-2020



Note: Data are for glazed and unglazed solar water collectors and do not include concentrating, air or hybrid collectors. The drop in 2019 was caused by revised annual additions for China in 2019 (see endnote 1 for this section) and new assumptions for projecting total capacity in operation for 2019 and 2020 (see endnote 5 for this section).

Source: IEA SHC. See endnote 5 for this section.

In addition to the three main types of collectors, other technologies such as hybrid, concentrating and air collectors are available to meet specific heat needs. Because annual additions of these technologies are small, they are not yet included in global and national capacity statistics. By the end of 2020, hybrid – or solar photovoltaic-thermal (PV-T) – technologies provided 635 MW_{th} of thermal capacity (and 232 MW of electric power capacity) for space and water heating.[7] In addition, 566 MW_{th} of concentrating solar thermal capacity provided hot water or steam for industrial and commercial customers at year's end.[8] Around 1 GW_{th} of air collectors for drying and space heating was in operation in 2019 (latest data available).[9]

The leading countries for new glazed and unglazed installations in 2020 were again China, Turkey, India, Brazil, the United States, Germany and Australia.[10] (→ *See Figure 32.*) China dominated the market, accounting for 71% of new global sales, followed by Turkey and India (5% each).[11] Most of the top 20 countries for solar thermal installations (glazed and unglazed collectors) in 2019 remained on the list in 2020; the exceptions were Denmark, the State of Palestine and Switzerland, which were replaced in the rankings by the Netherlands, Morocco and Portugal.[12] The top 20 countries accounted for an estimated 96% of the global market in 2020.[13]

Germany's green heating policy

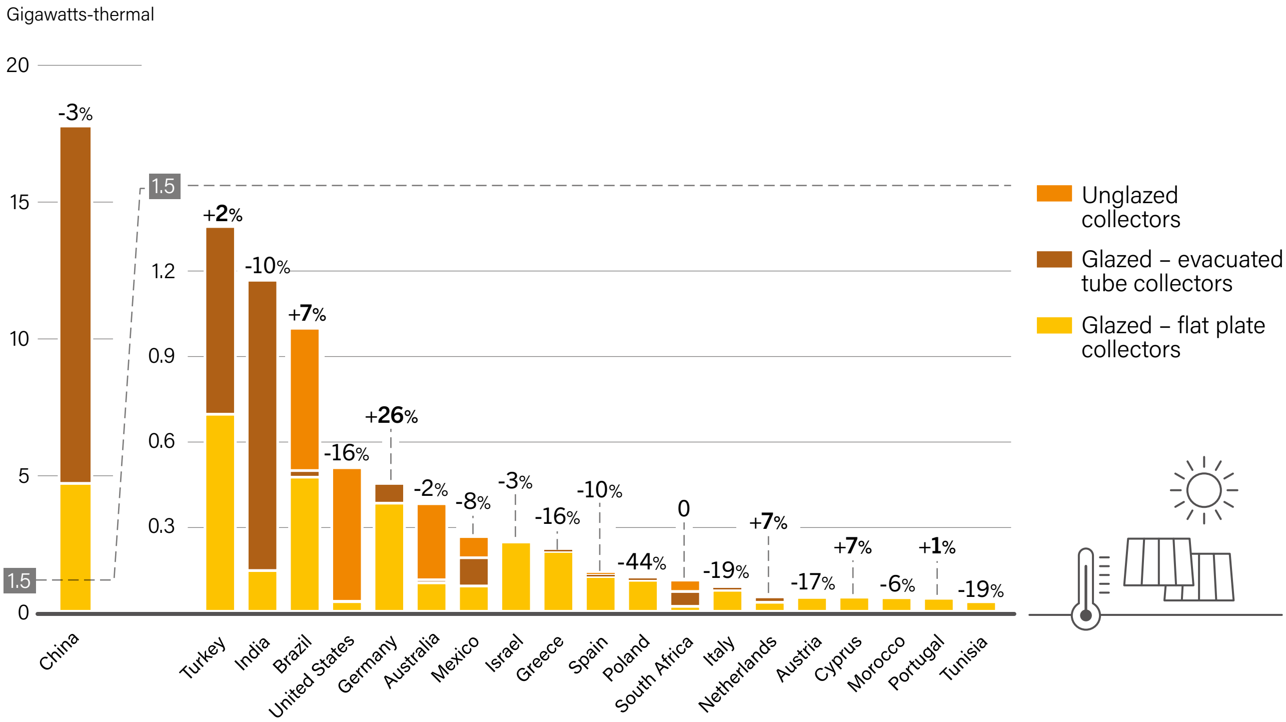
helped drive a 26% increase in sales in 2020.

In China, the solar thermal market ended 2020 on a high note, with sales in the second half of the year nearly making up for the delays in construction activity related to COVID-19 during the first six months.[14] Installations in 2020 totalled 18 GW_{th} (25.7 million square metres (m^2) of collector area), resulting in a decline of only 3% from 2019 (compared with a 21% drop in 2019 relative to 2018).[15] At year's end, China's operating capacity was 364 GW_{th}, or 67% of the global capacity in operation.[16]

The large project market in China[i] – covering a wide range of customer groups including industry, large-scale residential projects, agriculture, and public institutions such as hospitals and schools – remained stable and contributed to nearly three-quarters (74%) of total sales in 2020, while the market for small retail solar water heaters made up the remaining 26%.[17] Within the large project market, the most dynamic growth was in the solar space heating segment, totalling 1.7 GW_{th} of newly added capacity, or 10% of all new installations.[18] Prior to 2020, a total of only around 0.6 GW_{th} of solar space heating projects was put online.[19]

i Chinese statistics differ between standardised small residential solar water heaters and "engineered" solar thermal solutions, which are called the "large project market" in the GSR and refer to larger systems used in, for example, industry, agriculture, public institutions and residential housing projects.

FIGURE 32.
Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added, 2020



Note: Additions represent gross capacity added. For the Netherlands, the shares of flat plate and vacuum tube collectors were estimated based on actual shares in 2019. For Morocco, the share of collector types was not available.

Source: See endnote 10 for this section.

Although vacuum tube collectors still accounted for 73% of China's newly installed capacity, the market continued to transition from vacuum tubes to flat plate systems.[20] China's market for new vacuum tube collectors contracted 6% in 2020 (to 13.1 GW_{th}), while new flat plate collector area grew 6% (to 4.9 GW_{th}).[21] Sales of flat plate collectors have been driven by building codes mandating the use of solar thermal systems (or heat pumps) in new construction and major renovations as a means to reduce local air pollution.[22] These regulations have increased the demand for both façade- and balcony-integrated applications, where flat plate collectors have been the preferred solution.[23]

Turkey's solar thermal market, the second largest for new sales worldwide, expanded slightly (up 2%) in 2020, following stagnating sales the previous year, resulting in 1.35 GW_{th} of newly installed capacity.[24] The 18.4 GW_{th} of solar thermal capacity in operation at year's end accounted for 4% of the global total.[25] The pandemic affected Turkey's market in two opposing ways. In the residential sector, sales of solar water heaters increased as Turkish residents moved away from urban areas and apartment buildings to villages and individual houses, boosting the renovation business and the prefabricated housing market and triggering solar thermal sales. Meanwhile, sales of solar thermal systems for hotels and resorts declined.[26]

India's demand for glazed collectors fell 10% in 2020 to 1.16 GW_{th} (1.66 million m^2) due to the restrictions on production, sales and installation during the country's full lockdowns in April and May and partial lockdowns over several months.[27] Even so, India again ranked third for annual additions. As in Turkey, Indian solar thermal manufacturers reported opposing trends: for example, precautionary health measures, such as more frequent hot baths, increased the demand for solar water heaters, partly offsetting the negative impact of the pandemic.[28]

> Demand from homeowners for **solar water heaters** increased in Turkey, India and Brazil during the pandemic.

The market share of vacuum tube collectors in India grew to 88% of newly installed capacity in 2020 (up from 85% in 2019), mainly because flat plate collector sales declined more strongly (down 24%) due to higher prices resulting from rising material costs.[29] Furthermore, there was a decrease in the number of public tenders that mandated systems certified by the Bureau of Indian Standards, which so far can be fulfilled only by flat plate collectors.[30]

Karnataka state again dominated capacity additions, representing nearly 65% of India's total market (up from 50% in 2019), followed by Gujarat and Maharashtra.[31] The driving force in Karnataka was again a strict policy mandating use of the systems, overseen by local electric utilities that deny grid access to households not equipped with a solar water heater.[32]

Brazil continued its growth trajectory, adding 992 MW_{th} (up 7%) of solar thermal capacity in 2020 despite COVID-19 worries, following a 6% increase in 2019.[33] The pandemic caused demand to fall in the first six months of the year, as commercial clients put plans on hold and wholesalers closed their doors.[34] Sales then rose in the second half of the year, a development attributed in part to the recovery of the residential sector as people spent more time at home and invested in infrastructure improvements (such as solar pool heating and solar hot water systems); commercial clients also took advantage of the lower interest rates available for financing to identify energy-saving solutions that could give them a competitive edge.[35]

For the first time, Brazil's unglazed collector market, aimed mainly at swimming pool heating, pulled ahead of the US market, the long-term leader for this type of collector.[36] Brazil added 498 MW_{th} of new unglazed capacity, followed by the United States (473 MW_{th}) and Australia (266 MW_{th}).[37]

Brazil's strong market in 2020 resulted almost solely from the competitiveness of domestically manufactured solar thermal systems compared to other water heating options, as well as the ongoing reduction in value-added tax (VAT), enjoyed by solar thermal products but not other water heating options.[38] Meanwhile, the implementation of two previously announced policy support programmes was temporarily postponed because of the pandemic.[39] The federal government delayed the launch of the new social housing programme Casa Verde e Amarela, which was to succeed Minha Casa Minha Vida, the main programme behind the increase in Brazil's solar thermal capacity between 2009 and 2014.[40] Law PL 107 from 2019, stipulating the use of solar energy in all municipal and federal government institutions in the city of São Paulo, also did not enter into force.[41]

The United States, the fifth largest market for the three main types of solar thermal collectors in 2020 (with 505 MW_{th}), suffered a sharp decline (down 16%).[42] This resulted from a severe drop in sales of glazed collectors (down 71%) due to COVID-19 restrictions and to the end of a major support scheme, the California Solar Initiative, in July 2020.[43] Meanwhile, demand in the unglazed segment fell only 3%, which led its share in newly added capacity to increase to 94% (from 81% in 2019).[44] The United States continued to rank third globally for total operating capacity, with 18 GW_{th} at the end of 2020.[45]

Australia ranked seventh, following Germany for solar thermal sales, adding 380 MW_{th} of new capacity in 2020, down slightly from 2019.[46] The Australian solar thermal market has been dominated by unglazed collectors, which have fluctuated between 260 MW_{th} and 280 MW_{th} each year since 2013.[47]

Preliminary numbers for glazed collectors suggest a decline in 2020 (down 7%), with new installations totalling around 114 MW_{th}.[48] Sales of glazed collectors contracted, while heat pumps gained a larger share of the residential new-build market; in addition, restrictions on the number of workers allowed at worksites during several months of the pandemic affected solar thermal sales[i,49]

The European Union (EU-27) remained the second largest regional market after Asia in 2020.[50] However, additions (estimated at 1.4 GW_{th}) were down 15% from 2019.[51] The total capacity in operation in Europe at the end of 2020 was an estimated 37.5 GW_{th}, accounting for 7% of the global total.[52] The four leading countries in 2019 (Germany, Greece, Poland and Spain) saw mixed results in 2020, with strong growth in Germany and declines in Greece, Poland and Spain, resulting largely from changing policies and the impacts of the pandemic.[53]

Germany extended its leading position in Europe and reversed its decade-long market decline, ranking sixth globally for new installations. Annual sales were up 26% in 2020, to reach 450 MW_{th}, or around 83,000 new solar thermal systems for the year.[54] A key driver of growth was the new national support scheme to accelerate decarbonisation of the heat sector, launched at the start of 2020, which covers 40% of the cost of replacing an outdated oil heater with a new solar-supported gas condensing boiler.[55]

A high volume of grant applications in the last quarter of 2020 helped fuel optimism for continued growth in 2021.[56] Germany reached 13.9 GW_{th} in operation at the end of 2020, accounting for 3% of total global capacity.[57]

The solar thermal market in Greece, again the second largest for new additions in Europe, contracted significantly (16%) in 2020 (for the first time since 2013), with only 213 MW_{th} installed.[58]

i The restrictions affected the glazed solar thermal market more than the unglazed market because the glazed market is aligned heavily with new home builds.

The drop was caused by reduced sales during lockdowns in the first half of the year, when shops were closed and internet sales were insufficient to offset the decline in direct sales.[59]

Spain came in third place in Europe in 2020, ahead of Poland (due to a large market decline in Poland, rather than to expansion in Spain). The Spanish solar thermal market fell 10% (adding 131 MW_{th}), in line with the year's housing market decline, whereas Poland's market plunged 44%, with 113 MW_{th} added.[60] The contraction in Poland was attributed to the pandemic and to a phasing out of the emission reduction programme, which aimed to improve local air quality by subsidising renewable heating systems purchased and distributed by municipal administrators.[61]

Although most solar thermal capacity continued to be installed for the purpose of water heating in individual buildings, the use of **solar thermal technology in district heating** expanded further during 2020, and in an increasing number of countries. The vast majority of new solar district heating capacity added was again (in descending order) in China, Germany and Denmark.

In China, the solar district heating market shifted in 2020 from being purely state-financed to being partly commercial, with large orders from the housing industry. Whereas in 2019, three publicly funded solar district heating systems were commissioned in Tibet (totalling 52 MW_{th}), in 2020 only one such plant (7.9 MW_{th}) was erected, at a college in Lhasa.[62] Across China, newly installed solar thermal capacity for space heating (for both district heating and heating of large buildings) increased by a significant 1.7 GW_{th}, due to green heating policies aimed at replacing coal boilers in the country's north to improve air quality.[63] For this new capacity, the statistics do not differentiate between central space heating projects for blocks of flats or larger buildings (which would be considered solar district heating) and decentralised space heating units for rural, single-family houses.[64]

Germany passed Denmark for new installations of solar district heating by bringing online six new plants (totalling 22 MW_{th}) in 2020, following the completion of five new systems (totalling 7.1 MW_{th}) in 2019.[65] The 2020 additions included Germany's then-largest solar district heating plant, in Ludwigsburg, with a solar capacity of 10.4 MW_{th}.[66] By year's end, the country had 41 solar district heating plans in operation totalling 70 MW_{th} of capacity.[67] Five additional plants, with a combined capacity of 22.5 MW_{th}, were being planned or in the installation phase and were expected to come online in 2021; they included a 13.1 MW_{th} system in Greifswald that, once operational, will overtake the Ludwigsburg plant to become the country´s largest solar district heating plant.[68]

The strong market in Germany was driven by supportive framework conditions, including grants from two programmes: the Municipal Climate Change Showcase Programme and Heat Networks 4.0. The Municipal Showcase Programme has provided grants since January 2020 to cover up to 80% of the investment cost of municipal activity in the areas of greenhouse gas reduction, smart infrastructure and wastewater treatment.[69] Heat Networks 4.0 has provided support to utilities since mid-2017 for feasibility studies and the construction of fourth-generation district heat networks[i], where at least half of the heat injected into the grid must come from renewables.[70] Thanks in part to these programmes, German utilities increasingly consider solar heat to be an economically feasible alternative, promising stable heat prices over a period of 25 years, compared to the volatile prices of natural gas and biomass.[71]

Denmark continued to lead globally for total district heating capacity, with more than 1 GW_{th} in operation at the end of 2020.[72] However, the country brought online only one small solar district heating plant and three extensions during the year, increasing total capacity by 10 MW_{th}.[73] This is down sharply from 2019, when 10 new district heating plants and 5 extensions were added for a total of 134 MW_{th}.[74] The market contraction was due to increasing competition from heat pumps, driven by policy changes.[75] As of mid-June 2019, solar heat was no longer eligible to fulfil the energy savings mandates for utilities, whereas heat pumps were included in the mandate until the end of 2020.[76] At the beginning of 2020, the Danish Energy Agency also began providing grants for heat pumps, triggering additional demand.[77]

The top markets for
solar industrial heat
in 2020 were China, Mexico and Germany.

i Fourth-generation heat networks operate at lower temperatures of around 60 degrees Celsius (°C) to reduce heat losses, extend pipe lifetimes and create the best conditions for injecting heat produced with renewable sources.

Demand for new solar district heating systems increased in other existing European markets as well. In France, the market picked up in response to an attractive investment grant for large solar heat systems.[78] At the start of 2020, France had only a handful of solar district heating plants, with the largest commissioned in 2018 (1.6 MW_{th}) in Châteaubriant; by the end of 2020, three additional systems were under construction with a combined capacity of 7.4 MW_{th}, including a 4.2 MW_{th} field in Narbonne that will be France's largest solar district heating plant when it comes online in 2021.[79]

Austria's subsidy scheme for large and innovative solar thermal projects again saw results in 2020, with the inauguration of three new solar district heating fields totalling a combined 4.7 MW_{th}.[80] This represented a change from 2019, when no solar district heating plants were commissioned in Austria.[81] A much higher budget for the subsidy scheme, starting in April 2021, is expected to drive up demand for large-scale applications in the coming years.[82]

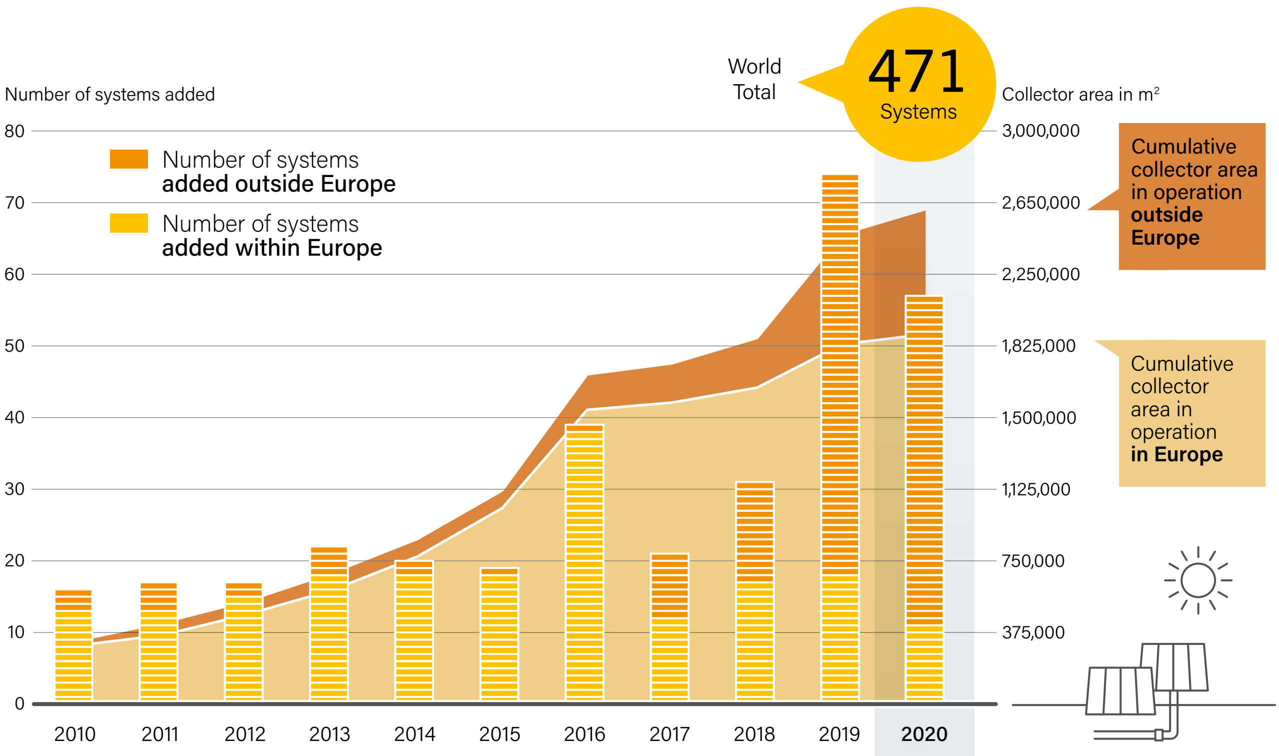
Sweden also had a new plant under construction at the end of 2020. Once completed in 2023, the 1.5 MW_{th} solar district heating plant in Härnösand, north of Stockholm, will be the country's largest solar district heating field using concentrating collectors.[83]

The global solar district heating market also diversified into new markets in both Europe (Croatia, Kosovo and Serbia) and Asia (Mongolia, driven by public funding for pre-feasibility and feasibility studies). In Mongolia, the European Bank for Reconstruction and Development (EBRD) funded a study on 20 different renewable and energy efficiency options for decarbonising the district heating grid for over 1 million people in the capital city of Ulaanbaatar; among the options is a 49 MW_{th} solar district heating plant.[84]

With support from the EU project KeepWarm, pre-feasibility studies for the integration of solar fields in district heating networks with a total capacity of 37.5 MW_{th} were carried out in the Croatian cities of Samobor, Velika Gorica and Zaprešić.[85] Solar district heating also attracted more attention in Serbia and Kosovo during 2020 because of the continued support from the EBRD for (pre-) feasibility studies.[86] In early 2021, feasibility studies were under way in Pančevo (Serbia) and Priština (Kosovo) for at least 70 MW_{th} of solar district heating plants.[87] The Serbian towns of Bor and Novi Sad had completed pre-feasibility studies, and Novi Sad's municipal council was proceeding with the next planning step.[88]

In addition to solar district heating, **central solar hot water systems** for large residential buildings, hospitals, sport clubs and prisons sold well in Brazil, China and Turkey during 2020. In total, at least 57 large solar thermal systems of at least 350 kilowatts-thermal (500 m^2) each, used either for district heating or for central hot water, were added globally in 2020.[89] These capacity additions of 93 MW_{th} brought the total number of large collector fields to at least 471 systems (1.8 GW_{th}) by year's end (including glazed and concentrating solar thermal collectors).[90] (→ *See Figure 33*).

FIGURE 33.
Solar District Heating, Global Annual Additions and Total Area in Operation, 2010-2020



Note: Includes large-scale solar thermal installations for residential, commercial and public buildings. Data are for solar water collectors and concentrating collectors.

Source: See endnote 90 for this section.

The additions in 2020 appear to represent a decline from the 74 large systems reported by technology suppliers as commissioned in 2019.[91] However, one large Chinese project developer, which was responsible for 36% of the plants completed in 2019, failed to report any large systems for 2020 despite completing several projects; this suggests that the world market remained more or less stable in 2020.[92]

Also during the year, several international organisations published a joint report emphasising the need to decarbonise industrial heat demand.[93] However, this urgent call for carbon-free heat solutions did not appear to stimulate demand for the use of new solar thermal systems to provide process heat for industry. Only 74 **solar heat for industrial processes (SHIP)** projects, with a total capacity of 92 MW_{th}, came online in 2020, down from 86 projects and 251 MW_{th} in 2019.[94] Multiple factors contributed to the relative decline: for example, the pandemic delayed the closing of contracts and the installation of ordered projects, and India's SHIP market declined in 2020 following the expiry in March of the national support programme for solar concentrating systems.[95] In the United States, Glasspoint, which was responsible for a large share of the global SHIP capacity added in 2019 (180 MW_{th} of solar steam capacity commissioned in Oman), closed its doors in May 2020.[96]

By year's end, at least 891 SHIP systems totalling more than 792 MW_{th} were supplying process heat to factories worldwide.[97] The top markets in 2020 were again China (30 new projects), Mexico (16) and Germany (10), followed distantly by India and Spain (3 each).[98] China's demand for solar industrial heat was triggered by government support policies to activate the economy after the pandemic, which helped drive an increase in the reported number of new projects from 26 in 2019 to 30 in 2020.[99]

Solar industrial heat plants in Mexico are cost competitive with fossil fuels such as liquefied petroleum gas (LPG), fuel oil and diesel, suggesting the potential for further market growth.[100] In many other countries, however, achieving competitiveness against oil and natural gas depends on investment support subsidies for SHIP systems or the elimination of fossil fuel subsidies.[101] In Germany, continued funding since 2012 resulted in the commissioning of 10 new plants (totalling 1.5 MW_{th}) in 2020.[102] Only one or two industrial solar heat systems were commissioned each in Austria, Belgium, Cyprus, Italy, Malaysia, Morocco, the Netherlands, Niger and Turkey.[103]

Although many solar technology suppliers reported delays in installation and construction, some megawatt-size plants were successfully commissioned in 2020. The top plants for new capacity demonstrated the variety of collector types typically used for SHIP plants globally. The largest new installation, at 10.5 MW_{th}, used flat plate collectors to heat the greenhouses of a freesia farm in the Netherlands.[104] The largest plant with vacuum tube collectors (4.6 MW_{th}) supplies heat in China to a factory in Sanya in Hainan province.[105] The largest SHIP plant with concentrating collectors (3.9 MW_{th}), used for drying agricultural products, started operation in May 2020 in Ganzhou, Tibet (China).[106] Two 3.5 MW_{th} plants also came online – one in Tibet with vacuum tube collectors for greenhouse heating, and one in Turkey with parabolic trough collectors providing heat to a packaging factory.[107]

Hybrid or PV-T collectors, which are solar thermal collectors mounted beneath solar PV modules to convert solar radiation into both electrical and thermal energy, have supplied only niche markets in recent years; thus, their capacity is not included in global and national capacity statistics. Since PV-T collectors have begun to gain popularity in a number of countries in recent years, market data are included in this report for the first time.[108] In 2020, 36 manufacturers globally reported PV-T capacity of at least 60.5 MW_{th} (connected to 24 MW-electric), up strongly from 46.6 MW_{th} in 2019.[109]

The largest markets in new PV-T additions in 2020 were, in order of capacity added, the Netherlands, China, France, Ghana and Germany.[110] Demand among residential and commercial clients in these countries has been driven by the ability to produce both heat and electricity from the same roof space, therefore generating a higher yield per area.[111] In the Netherlands, China and Germany, subsidy schemes also have played a role in triggering demand.[112]

SOLAR THERMAL HEATING INDUSTRY

The global solar thermal industry experienced mixed results in 2020. Most large manufacturers reduced production volumes due to disruptions in the movement of labourers and goods during several months of the pandemic.[113] However, a small number of producers profited from growing demand triggered by new support policies (as in Germany) and from continuously high national demand from the construction industry and solar mandates in some provinces (as in China).[114]

China's solar thermal industry, which saw virtually no impact from COVID-19, continued two major trends from previous years: a high share of large systems for domestic commercial clients, and increasing domestic sales of flat plate collectors.[115] Consequently, Chinese companies again dominated the list of the world´s largest manufacturers of flat plate collectors, holding the top six positions: in the lead was SunEast Group (including the Sunrain and Micoe brands), followed by Jinheng Solar (with its export brand BTE Solar), Haier (the majority owner of the Austrian company Greenonetec[i] until December 2020), Linuo Paradigma, Sangle and Fivestar.[116]

Excluding Greenonetec, which had no sales in China, the other six Chinese flat plate collector producers increased their combined sales volume 12% in 2020, growing faster than the domestic flat plate collector market overall (up 6%).[117] Industry consolidation in China continued, with only large solar equipment manufacturers implementing the rising number of solar space heating projects and responding to central procurement offers for solar water heating equipment for big construction projects.[118] Outside China, the combined sales volumes of the 14 largest flat plate collector manufacturers fell 9% on average in 2020, buffered slightly by strong sales growth in Germany.[119]

Global leaders in large solar heat project development also were affected by declines in the number of contracted projects and setbacks in project development in 2020. Arcon-Sunmark, the market leader in solar district heating from Denmark, closed its collector factory and stopped project development in mid-June, after several years of high fluctuations in turnover and low margins in contracted projects.[120] The company continued to operate a small maintenance unit to fulfil its long-term service and warranty contracts with clients.[121]

Despite the demise of Arcon-Sunmark's manufacturing and development division, the company's know-how and assets remained partly available in the sector. Greenonetec (Austria) acquired the production line for large-scale collector panels, targeting the growing solar district heating market in Europe.[122] In addition, Viessmann (Germany) engaged a team of Arcon-Sunmark's planners and sales experts to strengthen its commercial solar heat project development unit, and Solareast Group (China) bought shares in the company's Asian business.[123]

US-based Glasspoint closed its doors as well in 2020, due in part to uncertainty resulting from the COVID-19 pandemic. In March, the company was forced into liquidation after existing shareholders from the oil industry decided to halt the additional funding that was required to keep it operational.[124] Glasspoint had been in charge of installing the world's largest solar steam-producing plant in Oman, which reached a capacity of 360 MW_{th} in early 2020.[125] The company's difficulties started in 2019, when implementation of a 850 MW_{th} solar steam-producing project in the Belridge oilfields of California was delayed due to a lack of financing; this was followed by a halt in the extension of the Oman project because the client did not approve the third phase at the beginning of 2020.[126]

Medium-sized European technology suppliers signed a number of new contracts during 2020 using improved business models that help to reduce the risk and the heat costs for clients investing in large-scale solar heat systems; these included solar heat contracts and sales of complete production lines. NewHeat (France) secured a bank loan of EUR 13 million (USD 16 million) in September for a pool of five large commercial solar heat systems in France, totalling 28 MW_{th}.[127] As an energy service company, NewHeat offers solar heat contracts to two industrial sites and three district heating utilities.[128]

COVID-19 restrictions **slowed installation work** on solar industrial heat plants already under contract.

i In December 2020, Greenonetec founder re-acquired the 51% ownership stake that was sold to Chinese Haier in May 2017.

In April 2021, Kyotherm (France), which specialises in financing renewable heat projects, commissioned, together with its subcontractors (among others NewHeat, Savosolar of Finland and Sunoptimo of Belgium), Europe's largest solar industrial heat plant, a 10 MW_{th} project for a malting facility in France.[129] Kyotherm, with its network of solar thermal project developers, continued contractual negotiations with commercial heat consumers in the United States and India, with the first contracts expected to be signed in 2021.[130]

In early 2021, Absolicon (Sweden) signed its 13th letter of interest thus far, with a potential buyer for its complete parabolic trough collector production line, which has a typical annual capacity of 100,000 m^2.[131] The purchasers intend to invest in new production lines and are located around the globe, including in Ecuador, Ghana, India, Kenya, Mexico, Spain, Turkey and Uruguay.[132] With this strategy, Absolicon aims to reduce technology costs by enabling its buyers to produce solar collectors close to a large number of potential heat customers in sun-rich countries.[133]

Concentrating solar heat solutions are commonly used to produce temperatures above 100°C, even though other collector types, such as high-vacuum flat plate collectors, are able to reach temperatures up to 180°C.[134] Such systems use concentrating collector technologies with smaller dimensions (length and width) than for concentrating solar thermal power plants and provide heat for processing as well as for steam networks in hospitals or district heating. An increasing number of collector manufacturers have met the challenge of providing such high-temperature solutions. By the end of 2020, 23 solar industrial heat suppliers based in China, Europe, Mexico and North America were producing concentrating collectors, dominated by parabolic trough producers (14 companies) then Linear Fresnel (7) and concentrating dish (2) producers.[135]

A new generation of developers and manufacturers of innovative concentrating collector technologies established in recent years revealed their first demonstration or commercial projects in 2020. These technology providers rely on a wide range of concepts aimed at further lowering the cost of energy by reducing the quantity of material input per unit and by improving performance. The largest new producer, established in 2016, is WuCheng Energy based in Inner Mongolia, China, which signed contracts in 2021 to build a commercial 82 MW_{th} district heating plant with parabolic trough collectors in the northern Chinese city of Handan, slated to start construction in summer 2021.[136]

Solarflux Energy Technologies (US) relies on a dish receiver that, as of early 2021, had been shipped to China, India, Mexico, Qatar and the United States to be used in demonstration projects (totalling 650 m^2).[137] Four other start-ups – Skyven Technologies (US), True Solar Power (Spain), Umbral Energia (Mexico) and Heliac (Denmark) – were developing new solar collectors that consist of a heliostat array focusing on a receiver.[138] Concentrating collector companies in the technology prototype stage included Alto Solution (France), with a new parabolic trough unit, and Heliovis (Austria), which is developing a concentrator housed in an inflatable cylindrical foil-walled tunnel.[139]

Increasing awareness of solar thermal technologies by end-customers in the Russian Federation fuelled optimism in 2020 for investing in solar component factories. During the year, St. Petersburg saw the ramping up of two factories by privately owned Russian companies: the engineering firm Silagnis started producing heat pumps and solar collectors, and Solar Fox increased its manufacturing volume of solar air collector units.[140]

A strong and committed supply chain of around 80 turnkey SHIP suppliers offered solar heat solutions to industrial clients in 2020, despite the challenges of the pandemic.[141] Four out of five companies confirmed that the pandemic delayed the closing of SHIP contracts in 2020, because of economic uncertainty among potential customers.[142] Three out of four suppliers also confirmed that COVID-19 restrictions slowed installation work on plants already under contract.[143] Consequently, only 15 of the around 80 SHIP suppliers commissioned at least one project during the year, compared to 25 companies that put up at least one plant in 2019.[144]

Linuo Paradigma (China) was the 2020 market leader in both new projects and newly added SHIP capacity, reporting 22 projects totalling 58 MW_{th} in 2020.[145] High demand in China was triggered by government support policies to activate the economy, which helped industrial clients invest in SHIP plants.[146] Modulo Solar (Mexico) realised the second largest number of SHIP plants, with 13 new small systems that totalled 0.8 MW_{th}.[147] The second largest company for SHIP capacity in 2020 was SunEast Group (China), which reported the completion of five systems with a total of 8 MW_{th}.[148]

Project developer Kyotherm had to postpone (to 2021) the commissioning of its 10 MW_{th} SHIP plant at a malting factory in central France because of travel restrictions in Europe during the pandemic.[149] Similar restrictions affected other manufacturers, such as VSM Solar (India) and Absolicon (Sweden), which were unable to execute confirmed orders.[150] Although the number and capacity of new SHIP plants were down in 2020, the large number of delayed plants under contract fuels hope that the market will increase again in 2021.[151]

KEY FACTS

- The world added a **record 93 GW of wind power capacity in 2020**, led by China and the United States. Both countries broke national records for new installations, driven in part by pending policy changes. The rest of the world commissioned about the same amount as in 2019, but several additional countries had record-breaking years.
- For the first time, global capital expenditures committed to **offshore wind power** in 2020 surpassed investments in offshore oil and gas.
- The industry continued to face perennial challenges exacerbated by the pandemic, but maintained **momentum in technology innovation** in continuous pursuit of an ever lower levelised cost of energy.
- Wind power accounted for a **substantial share of electricity generation** in several countries in 2020, including Denmark (over 58%), Uruguay (40.4%), Ireland (38%) and the United Kingdom (24.2%).

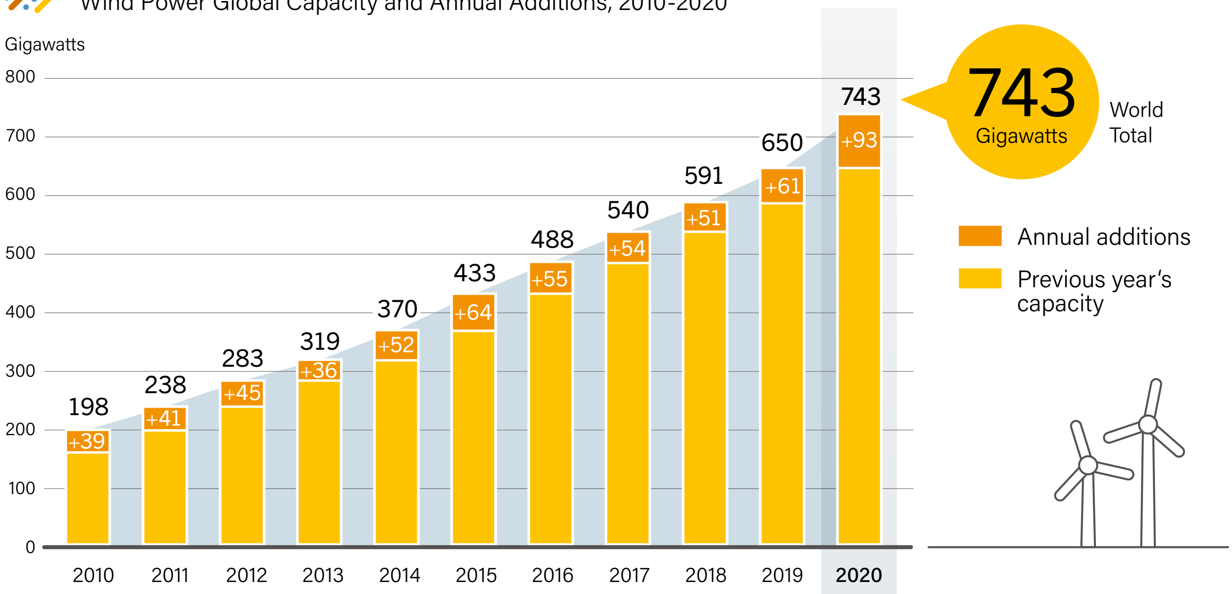
WIND POWER

WIND POWER MARKETS

An estimated 93 GW of wind power capacity was installed globally in 2020 – including more than 86.9 GW onshore, the highest yet, and nearly 6.1 GW offshore.[1] This record-breaking market was 45% above the previous high, in 2015 (63.8 GW), and represents an increase of nearly 53% relative to 2019 installations.[2] For several months of 2020, pandemic-related restrictions disrupted supply chains, rendered much of the wind energy workforce unavailable, resulted in postponed or cancelled auctions and delayed investments, and forced delays or cancellations to project construction in many countries, particularly in the onshore sector.[3] But even with the global health, economic and political challenges, by year's end total global wind power capacity was up 14% over 2019 and neared 743 GW (707.4 GW onshore and the rest offshore); this was double the capacity in operation worldwide only six years earlier, at the end of 2014.[4] (→ *See Figure 34.*)

The rapid growth in 2020 was due to a dramatic increase in China as well as to a jump in the United States in advance of policy changes; the rest of the world installed about the same amount of (net) additional capacity as it did in 2019.[5] The pandemic added to previously existing financing, infrastructure, policy and regulatory challenges in some countries, while other countries (in addition to China and the United States) saw record installations during 2020, including Argentina, Australia, Chile, Japan, Kazakhstan, Norway, the Russian Federation and Sri Lanka.[6] New wind farms reached full commercial operation in at least 49 countries, down from 55 countries in 2019, and at least one country, Tanzania, brought online its first commercial project.[7] By the end of 2020,

FIGURE 34.
Wind Power Global Capacity and Annual Additions, 2010-2020



Note: Totals may not add up due to rounding.
Source: GWEC. See endnote 4 for this section.

more than 100 countries had some level of commercial wind power capacity, and 37 countries – representing every region – had more than 1 GW in operation.[8]

Rapidly falling costs per kilowatt-hour (both onshore and offshore) have made wind energy ever more competitive and allowed onshore wind power to compete head-to-head with fossil fuel generation in a large and growing number of markets, often without financial support.[9] The economics of wind energy have become the primary driver for new installations.[10] Outside of China (which had a feed-in tariff, or FIT) and the United States (with tax credits and state renewable portfolio standards, or RPS), global demand for wind power in 2020 was driven largely by other policy mechanisms including auctions (or tendering).[11] Corporate power purchase agreements (PPAs) are playing a growing role in some markets, particularly in the United States and Europe but also increasingly in Latin America and Asia. In 2020, however, the capacity contracted globally through corporate PPAs was down 29% relative to 2019, to 6.5 GW.[12]

Wind power provides a substantial **share of electricity** in a growing number of countries. In 2020, wind energy generated enough to provide an estimated 15% of the annual electricity consumption in the EU-27, and much higher shares in at least five individual Member States.[13] Wind energy met an estimated 48% of Denmark's electricity demand in 2020 and accounted for nearly 58.6%[i] of the country's total generation.[14] Other European countries with wind generation shares of at least 20% for the year included Ireland (38%), the United Kingdom (24.2%), Portugal (24%), Germany (23.2%) and Spain (21.9%).[15] Uruguay (40.4%) and Nicaragua (27.6%) also achieved high shares of generation from wind energy, and shares were high at the sub-national level in several countries.[16] Globally, wind power capacity in operation accounted for an estimated more than 6% of total electricity generation in 2020.[17]

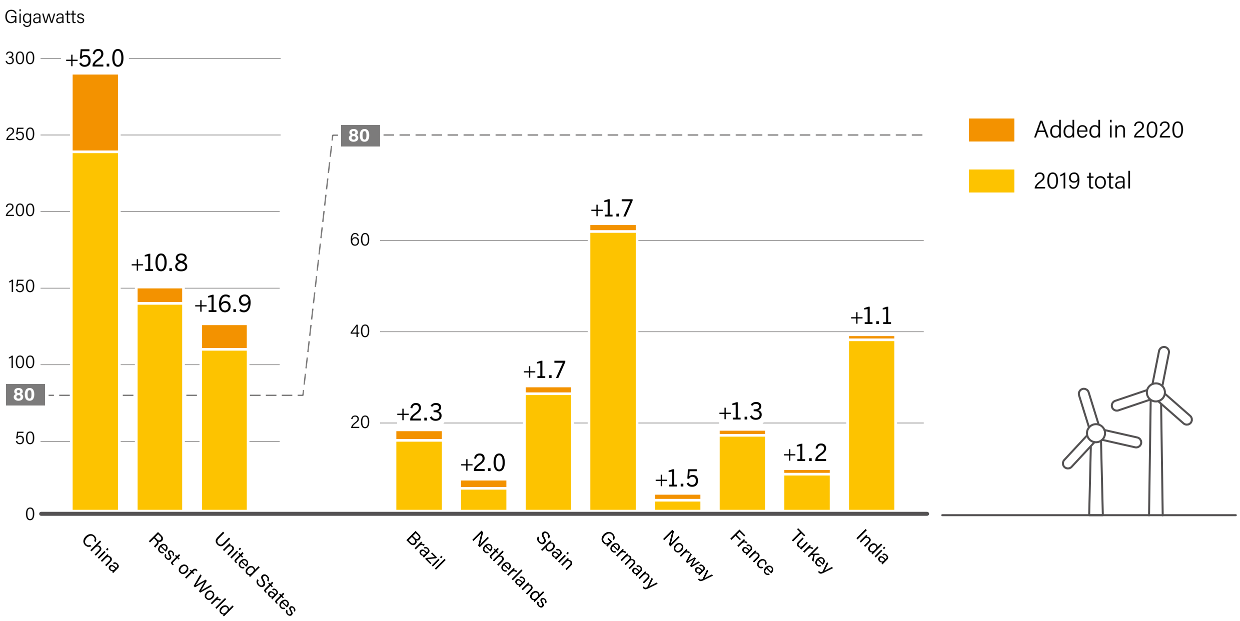
For the 12th consecutive year, Asia was the largest **regional market**, representing nearly 60% of added capacity (up from 50% in 2019), with a total of nearly 348.7 GW by the end of 2020; almost 56% of new capacity was in China alone.[18] Most of the remaining installations were in North America (18.3%), Europe (14.8%) and Latin America and the Caribbean (5.0%).[19] The only regional markets that did not expand in 2020 were Europe, where the pandemic pushed many installations into 2021, and Africa and the Middle East, which remained stable.[20]

China widened its lead for new capacity (both onshore and offshore) and was followed distantly by the United States, which was well ahead of Brazil, the Netherlands and Spain; these five countries together accounted for just over 80% of annual installations, with China and the United States alone responsible for nearly 74%.[21] Other countries in the top 10 for total capacity additions were Germany, Norway, France, Turkey and India.[22] (→ *See Figure 35 and* ***Reference Table R18*** *in GSR 2021 Data Pack.*) Although the list of the biggest markets changed significantly relative to 2019, the top 10 countries[ii] for cumulative capacity were unchanged from those in both 2018 and 2019.[23]

i The difference between generation (electricity produced within a country's borders) and consumption is due to imports and exports of electricity, as well as to transmission and distribution losses (which vary considerably across countries).

ii The top countries by additions in 2019 were China, the United States, the United Kingdom, India, Spain, Germany, Sweden, France, Mexico and Argentina. The top 10 for cumulative capacity in the years 2018-2020 were China, the United States, Germany, India, Spain, the United Kingdom, France, Brazil, Canada and Italy.

FIGURE 35.
Wind Power Capacity and Additions, Top 10 Countries for Capacity Added, 2020



Note: Numbers above bars are gross additions, but bar heights reflect year-end totals. Germany's net additions were slightly below those of Norway.

Source: See endnote 22 for this section.

China had its biggest year yet for new installations, despite pandemic-related delays to grid connections early in the year.[24] The estimated 52 GW (48.9 GW onshore and 3.1 GW offshore) added in 2020 was about what the entire world installed in 2018, and almost double China's 2019 installations, and brought the country's total wind power capacity to an estimated 288.3 GW.[25] Around 72 GW (including 3.1 GW offshore) of wind power capacity was integrated into the national grid in 2020, with 281 GW[i] considered officially grid-connected by year's end.[26]

The Chinese market was driven primarily by a rush to install onshore projects that had to be grid-connected before the end of 2020 to receive the expiring national feed-in tariff.[27] The offshore market also faces a FIT qualification deadline (see discussion later in this section).[28] During the year, the central government reaffirmed plans for onshore wind power (and solar PV) to achieve grid parity by 2021.[29] The policy changes result from a mounting deficit in China's Renewable Energy Development Fund, which has caused a backlog of outstanding FIT payments for existing projects (only worsened by the pandemic), and from the central government's belief that wind (and solar) power is capable of competing without subsidies with coal-fired power.[30] In 2020, China accounted for 67% of the 33.7 GW onshore wind capacity awarded globally in auctions, and most of China's awarded capacity was based on the grid-parity scheme.[31]

The majority of China's wind power capacity continues to be in the north and west of the country, and at the end of 2020 wind power accounted for more than 20% of total capacity in several provinces in these regions.[32] However, deployment has continued to shift towards China's demand centres in the more populated regions in the central east and south, which together accounted for 40% of newly installed capacity in 2020.[33] The top regions and provinces for official grid-connected additions during the year were East Inner Mongolia (6.8 GW), Henan (6.6 GW), Shanxi (5.5 GW) and Hebei (5.2 GW).[34] As the main wind regions in China approach saturation, with ongoing curtailment and fewer sites available for deployment, the country's wind sector is increasingly looking to distributed options and in particular to offshore wind along China's extensive coastline, where economic activity is concentrated.[35]

Overall, an estimated 16.6 TWh of potential wind energy was curtailed in China during 2020 – an average of 3% for the year, down from 4% (16.9 TWh) in 2019, and below the national government's targeted cap (5%).[36] Curtailment remained concentrated mainly in Xinjiang, Gansu and Western Inner Mongolia, but all three regions continued to see reductions relative to previous years.[37] China's generation from wind energy was up 15% (to 466.5 TWh), and wind energy's share of total generation continued to rise steadily, reaching 6.1% in 2020 (up from 5.5% in 2019).[38]

Elsewhere in Asia, Turkey's annual installations nearly doubled relative to 2019, with 1.2 GW added for a total approaching 9.3 GW (all onshore).[39] For the first time since 2017, Turkey was among the top 10 countries globally for capacity added, ranking ninth.[40] Around 5 GW of new capacity was under construction as of early 2021.[41] Turkey is working to expand its renewable energy capacity to lessen the country's heavy reliance on imported energy, create jobs and reduce the national carbon footprint.[42] Wind energy accounted for 8.4% of Turkey's electricity generation in 2020.[43]

India fell from fourth to tenth place globally for additions, experiencing its lowest annual additions since at least 2006; however, it continued to rank fourth for total capacity at the end of 2020.[44] India added 1.1 GW for a year-end total of 38.6 GW, all operating onshore.[45] Installations peaked in 2017 (4.1 GW) and (aside from a slight uptick in 2019) have declined since auctions were introduced to the wind tendering process in 2017.[46] The number and diversity of local investors in India's wind power sector also have declined since the shift to auctions, while installations have become more concentrated geographically.[47]

At the end of 2020, the top Indian states for total capacity were Tamil Nadu (9.4 GW), Gujarat (8.2 GW) and Maharashtra (5 GW), which together accounted for nearly 59% of the country's total wind power capacity.[48] Across India, wind energy generated around 5% of all electricity during 2020; despite the increase in capacity, output fell 24% during the peak wind season (June to September) compared to 2019, due mainly to a significant and unusual drop in wind speeds, and it was down 5% for the year.[49]

The United States
added more capacity
in the final three months of 2020 than in any previous year except 2012.

i Statistics differ among Chinese organisations and agencies as a result of what they count and when. See endnote 26 for this section.

India's wind sector has faced challenges associated with grid connection and permitting, land acquisition and (during the pandemic) significant project construction delays.[50] By mid-year, a large amount of the capacity tendered in 2017-18 was not yet online, due to these challenges and to low winning tariffs that some developers have deemed unviable, making it difficult to obtain financing.[51] The Indian government announced plans to remove tariff caps from future wind (and solar) power tenders, eliminating a key limitation on investor interest; even so, in late 2020, two European companies stated that they would not participate in India's auctions, despite the country's large resource potential, due to low tariffs combined with land acquisition and grid connection problems.[52]

Japan placed fourth in Asia with record additions of almost 0.6 GW (double the country's 2019 installations) for a total of 4.4 GW.[53] The increase in projects under development both onshore and offshore was driven by the country's generous feed-in tariff.[54] Kazakhstan brought 0.3 GW online during the year, as the oil-rich country looks to green its energy mix and achieve 50% renewable electricity by 2050.[55] Other countries in the region that installed new wind power capacity in 2020 included Chinese Taipei (74 MW), Pakistan (48 MW added), the Republic of Korea (160 MW, including 60 MW offshore), Sri Lanka (88 MW) and Vietnam (125 MW), where the market was driven by a planned FIT expiration, a decline in the capital cost of wind turbines and rapid growth in electricity demand.[56]

The **Americas** added a record of nearly 22 GW (up 62% over 2019), with most (72%) installed in the United States.[57] The country commissioned 16.9 GW of new capacity in 2020, up 85% over 2019 installations.[58] US capacity brought online in the fourth quarter alone exceeded annual additions for every preceding year except 2012.[59] For the ninth year running, the oil and gas state of Texas was the leader in annual wind power installations (4.2 GW), followed by Iowa (1.5 GW), Wyoming (1.1 GW), Illinois (1.1 GW) and Missouri (1 GW).[60] At year's end, US total capacity reached 122.5 GW, enough to power more than 38 million average US homes.[61] Texas continued to lead for total capacity (33.1 GW), with 27% of the US total; if Texas were a country, it would rank fifth globally for cumulative installations.[62]

As in past years with record additions, the US market was propelled by the impending phase-out of the 100% federal production tax credit[i] (PTC) at year's end, which was granted a one-year extension in late 2019, and extended again at the end of 2020.[63] Demand from corporations also played a role, as did utilities (through direct ownership and, primarily, through PPAs) aiming to meet customer preferences, sustainability goals and mandates under state RPS laws.[64] US wind power PPAs for the year totalled 5.4 GW, down relative to the previous two years due at least in part to uncertainty caused by COVID-19.[65]

Wind energy accounted for 8.4% of US utility-scale electricity generation in 2020, up from 7.3% in 2019 and nearly four times the share a decade earlier.[66] In Texas, the country's largest electricity consumer by far, wind energy passed coal for the first time and accounted for nearly 20% of the state's utility-scale generation.[67] Wind energy saw higher shares for the year in at least 10 other states, including Iowa (58%), Kansas (43%), Oklahoma (35%) and North Dakota (31%).[68] The Southwest Power Pool (SPP), a regional transmission organisation, became the first US grid operator to see wind energy become the top source of electricity, surpassing both coal and natural gas.[69] The SPP, which covers some of the windiest states in the central plains corridor, has a robust transmission system and relies on accurate forecasting, a diverse mix of generators and an efficient wholesale market to manage high shares of variable renewable energy.[70] (→ *See Systems Integration chapter.*)

Despite the many advances across the United States, developers continued to report challenges related to raising tax equity[ii] for projects already in development due to economic uncertainty, limited tax equity supply and tight lending standards.[71] New projects increasingly are facing challenges related to project siting and resource availability, as well as grid congestion.[72] Many of the best areas for wind power projects in some states, such as California, have already been developed or have established prohibitions on new development, while grid congestion and related transmission upgrade costs have led to the cancellation of several wind (and solar) power projects – including many that had already secured PPAs – in nearly every region of the country.[73]

i The PTC gives wind energy generators a tax credit of roughly USD 0.02 per kilowatt-hour for electricity fed into the grid. Starting in 2021, the credit was scheduled to decline steadily and to end in 2025. In light of delays and supply chain issues caused by the pandemic, the commissioning deadline for projects that began construction in 2016 and 2017 was extended by one year; in December 2020, the PTC was legally extended for a further year at 60% of the full credit rate.

ii Essentially, trading the monetary value of the federal PTC (the future stream of tax credits to be received upon project completion) for upfront capital in order to develop a project.

Canada had a relatively slow year in 2020 (adding less than 0.2 GW), and most of the remaining installations in the Americas were in Latin America and the Caribbean.[74] Even as the region was hard-hit economically by the pandemic, a record 4.7 GW of new capacity came online, with Brazil ranking third globally for additions and eighth for total capacity.[75] Wind power has become the region's fastest growing power source, with around 33.9 GW of wind power capacity operating across at least 26 countries at year's end.[76]

Brazil added 2.3 GW, three times the country's 2019 installations, for a total of 17.7 GW.[77] The significant increase was thanks to capacity deployed through local PPAs, driven by wind energy's competitive prices in Brazil.[78] The government cancelled auctions in 2020 due to the pandemic but rescheduled them for 2021.[79] Wind energy accounted for 9.7% (56.5 TWh) of the country's total 2020 electricity generation.[80]

Argentina (1 GW) and Chile (0.7 GW) followed Brazil in the region, both with record years.[81] Mexico (0.6 MW), Panama (66 MW) and Peru (38 MW) also added capacity.[82] After two years of ranking among the world's top 10 installers, Mexico's market declined 45% in 2020 due to policy and regulatory changes undertaken since a new federal administration took office in late 2018 – including the cancellation in 2019 of government-led electricity auctions.[83] The changes have eroded the competitiveness of electricity from wind energy and other renewable sources, creating significant uncertainty for potential private investors and developers.[84] Social acceptance issues and limited grid connection availability also have hampered Mexico's wind energy development.[85] PPAs for corporate procurement in Mexico nearly dried up in 2020, whereas Brazil signed a record 1 GW of corporate renewable energy PPAs that year.[86]

Europe added 13.8 GW of new wind power capacity in 2020 (down nearly 7% relative to 2019), of which 21% is operating offshore, bringing the region's total to nearly 210.4 GW.[87] Onshore additions were below expectations due largely to commissioning delays resulting from COVID-19-related supply chain disruptions and restrictions on the movement of people and goods, as well as continued permitting delays in some countries (particularly Germany).[88] As in other regions, the diversity and number of investors has declined in recent years with the phase-out of FITs.[89] Even so, 2020 was Europe's third biggest year for new installations, after 2017 and 2019.[90]

Outside of the EU, annual additions were up the most in Norway and the Russian Federation, both with record installations. Norway added 1.5 GW of capacity onshore, for an onshore total of nearly 4 GW.[91] Europe's largest wind farm (1 GW Fosen) was completed in Norway, despite the country's low power prices and protests over the project's potential impacts on local reindeer herders.[92] The Russian Federation increased its capacity more than four-fold (adding 0.7 GW), as capacity awarded in a 2018 auction began to come online, for a year-end total of 0.9 GW.[93] Although the Russian Federation remained the world's only major economy just beginning to develop a domestic wind market and industry, the awarded capacity (3.3 GW in total) should continue to come online through 2024.[94]

In the United Kingdom, which just a year prior was the top installer in Europe and the third largest globally, additions fell 75% in 2020 to 0.6 GW, most of it added offshore, for a cumulative total of 24.2 GW.[95] After five years with no public support for onshore wind (or solar) power, the UK government announced in 2020 that the technology will again be allowed to participate in the Contracts for Difference scheme[i].[96] Wind generation rose 18% relative to 2019 due to increased capacity and even more so to favourable wind conditions, particularly offshore, where output increased 26% and exceeded onshore generation for the first time.[97] During the year, more than 100 wind farms across the United Kingdom were participating in a flexibility market trial, enabling them to provide balancing services; industry governance codes require new UK wind farms to provide "power available" signals[ii].[98]

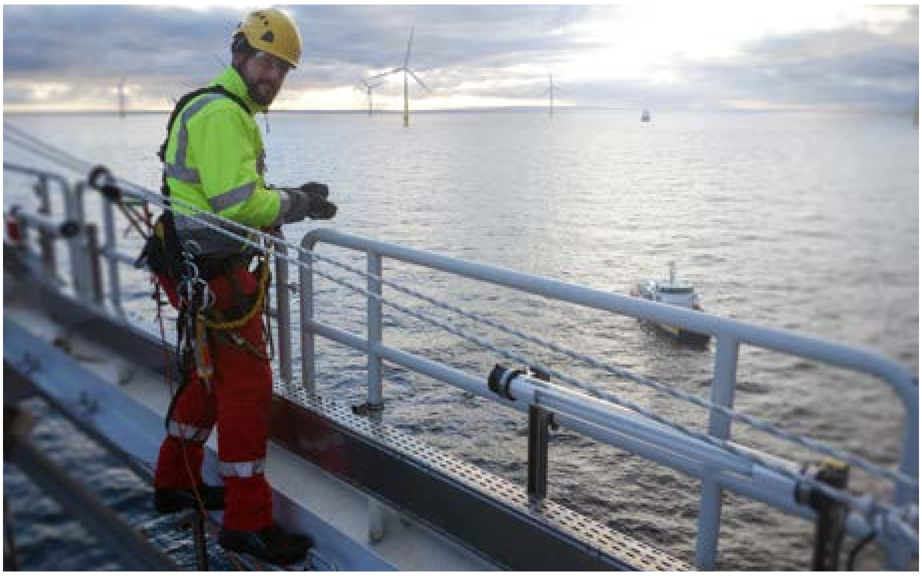
Most new capacity in Europe was installed in the EU-27, which brought online nearly 10.8 GW (8.4 GW onshore and 2.4 GW offshore), or net additions of 10.4 GW (accounting for decommissioning).[99] Across the 27 Member States, 16 added capacity during 2020, down from 18[iii] in 2019.[100] Annual additions were slightly below those in 2019, with installations down in all but a handful of countries.[101] The EU ended the year with a total of 179.3 GW[iv], including 164.7 GW onshore and 14.6 offshore.[102]

i The Contracts for Difference (CfD) is the UK government's primary mechanism for supporting renewable electricity generation. Developers that win contracts at auction are paid the difference between the strike price (which reflects the cost of investing in the particular technology) and the reference price (a measure of the average market price for electricity).

ii A power available signal is a live data feed available to engineers in the control room of the UK's National Grid ESO. The data provide engineers with the potential maximum power output of a generator (in this case a wind farm) at any given time, enabling control systems to calculate each generator's response and reserve capability; this in turn allows the generator to compete with other generators to provide real-time response and reserve services. See endnote 98 for this section.

iii This figure excludes the United Kingdom for the sake of comparison.

iv Note that the EU cumulative data are lower than those reported for end-2019 because they no longer include the United Kingdom, which ended 2020 with around 24.2 GW (13.7 GW onshore and 10.4 GW offshore).



The community structure of the Dutch Zeewolde project helped to **increase social acceptance,** easing permitting and reducing risk for potential financers.

The EU's annual wind power market was again fairly concentrated, with the top five countries – the Netherlands (added 2 GW), Spain (1.7 GW), Germany (nearly 1.7 GW), France (1.3 GW) and Sweden (1 GW) – accounting for 70% of the total.[103] Although it was not among the top countries, Poland also saw a substantial jump over 2019 with 0.7 GW installed (up from 0.05 GW), helping to balance the decline in other countries.[104] The leading countries[i] for cumulative capacity at year's end were Germany, Spain, France, Italy and Sweden.[105]

The Netherlands was the top installer in Europe and ranked fourth globally, adding nearly 2 GW (up from 0.3 GW in 2019) for a cumulative total of 6.8 GW.[106] Most of the new capacity was offshore, with the country's largest offshore project fully commissioned in December.[107] Onshore in mid-2020, a cooperative of 200 local residents, farmers and other investors closed turbine supply contracts and financing for a repowering project near Amsterdam.[108] Once completed in 2021-2022, the 0.3 GW Zeewolde project is expected to be the largest onshore wind farm in the Netherlands and the largest community-owned wind power project in Europe.[109] The community structure helped increase social acceptance of the project, easing permitting and reducing risk for potential financers.[110] The Dutch government aims to increase community ownership from only a small fraction of wind power capacity in 2020 to 50% of new wind (and solar) projects by 2030.[111]

Spain ranked second in the region and fifth globally for new capacity, adding more than 1.7 GW for a total of 27.4 GW.[112] While down from the 2.2 GW brought online in 2019, and below the government's target (set in 2020) of 2.2 GW per year to 2030, it is a significant increase over annual installations during the years 2009 through 2018.[113] In late 2020, Spain approved an order that regulates a new auction mechanism for wind and other renewable power capacity for the 2020-2025 period.[114] Wind energy accounted for 21.9% of Spain's electricity generation in 2020.[115]

Germany placed third in the EU (and all of Europe) and sixth globally for new capacity, but total additions were the country's lowest in a decade.[116] Germany added almost 1.7 GW (1.4 GW net) for a total of 62.6 GW (54.9 GW onshore and 7.7 GW offshore).[117] Offshore installations (0.2 GW) were down 80% relative to 2019; onshore additions increased nearly 33% after two years of decline following Germany's shift from a feed-in policy to tenders, but were at their second-lowest level since 2010.[118] Even so, wind output was up 4% and wind energy accounted for 23.6% (131 TWh) of national gross electricity consumption during 2020, exceeding brown coal (lignite) for the second consecutive year.[119]

In recent years, most of Germany's auctions for onshore capacity have been undersubscribed (including six of seven in 2020), and annual deployment has fallen significantly. Factors behind the drop include restrictive siting legislation in some states, complex planning procedures and a decline in local proponents as the number of local investors has fallen and projects increasingly are planned by a relatively limited number of participants (mostly larger-scale developers); these developments together have resulted in a lack of permitted projects eligible to compete in the tendering process.[120] As of mid-2020, the onshore wind permitting process took more than two years, compared to the historical average of 10 months.[121] Uncertainty about possible changes to setback distancing rules also has reduced investments in new onshore capacity; in mid-2020, the federal government gave states the final authority on distancing rules[ii],[122] Germany's New Renewable Energy Sources Act (EEG 2021), passed at the end of 2020, set a new target for a total of 71 GW of wind power onshore (and 20 GW offshore) by 2030.[123]

For the EU and the United Kingdom combined, wind energy generated an estimated 458 TWh in 2020 (up from 417 TWh in 2019) and met around 16.4% of total electricity demand (13.4% with onshore and 3% with offshore wind).[124] The 1.9 percentage point share increase relative to 2019 resulted from additional capacity, windy conditions early in the year and a drop in electricity demand due to COVID-related restrictions.[125]

i If the United Kingdom were still an EU member, the country would rank third in the EU for total capacity, and the top five list would remain unchanged from 2019.

ii New federal provisions allow states to set minimum distances between turbines and residential areas at 1,000 metres. See endnote 122 for this section.

In the **South Pacific**, Australia continued to account for the majority of new installations, while New Zealand added capacity (0.1 GW) for the first time since 2015.[126] For the second consecutive year, Australia saw records for both installations and output, with 1.1 GW brought online at 10 new wind farms for a total approaching 7.4 GW (all onshore).[127] Renewable capacity under corporate PPAs also achieved a new capacity record, with wind power accounting for 41% (the rest being solar PV) of the 1.3 GW contracted in 2020.[128] Community engagement also is playing a growing role in Australia, with the industry increasingly recognising the importance of benefit sharing with the local community for successful project development.[129]

Wind power again was Australia's largest renewable source of electricity, producing 22.6 TWh (up 16% over 2019), or 9.9% of the country's total generation.[130] Among the individual states, the highest local shares of generation occurred in Victoria (29.7%), South Australia (25.9%) and New South Wales (20.4%).[131] The rapid increase in the number and capacity of large wind (and solar) power projects and their output continued to challenge the grid, with ongoing connection and transmission issues; several state governments announced renewable energy zones that are expected to ease pressure on the grid.[132] (→ *See Solar PV section in this chapter.*)

Africa and the Middle East combined installed over 0.8 GW of wind power capacity, nearly the same amount as in 2019, despite the pandemic's impact on supply chains and project installation.[133]South Africa accounted for nearly 63% of these additions with more than 0.5 GW added, followed by Senegal (0.1 GW), which fully commissioned its first commercial wind farm, and Morocco (nearly 0.1 GW), where several additional projects were under construction.[134] Jordan, Iran, Egypt and Tanzania also added capacity, with Tanzania completing its first commercial wind project.[135] At year's end, 13 countries in Africa and 5 in the Middle East had a total of 7.3 GW of wind power capacity (all onshore), with most of it in South Africa (2.5 GW), Egypt (1.5 GW) and Morocco (1.3 GW).[136]

Countries in the region are installing wind (and solar) power to diversify their energy mix, lower per unit electricity costs while meeting rising demand, reduce reliance on imported electricity and fuels, and free up more of their own oil and gas for export.[137] For example, to eliminate its heavy reliance on imported electricity from Ethiopia, Djibouti was planning its first utility-scale wind project (59 MW) in 2020, and Ghana was planning for 1 GW of wind capacity to reduce reliance on fossil fuels and hydropower, which has seen output decline with reduced river flows.[138] However, both Africa and the Middle East continued to face challenges to further wind power deployment, including uncertain or unsupportive policy and power market frameworks, bottlenecks in transmission infrastructure and off-taker risk.[139]

In the **offshore wind power** segment, five countries in Europe and two in Asia, as well as the United States, connected nearly 6.1 GW in 2020, increasing cumulative global offshore capacity to more than 35.3 GW.[140] Wind turbines operating offshore accounted for 6.5% of all newly installed global wind power capacity in 2020 (down from 10% in 2019) and represented 4.7% of total capacity at year's end (down from 5% in 2019).[141] China led the sector for the second year running, accounting for just over half of new installations, and Europe installed most of the rest.[142]

China added a record 3.1 GW of offshore capacity, raising the total 44% to around 10 GW.[143] More capacity might have been commissioned in 2020, but progress was stalled by bottlenecks including supply chain issues and a lack of offshore turbine installation vessels.[144] Developers rushed to finalise projects before the end of 2021, when the national FIT for offshore wind power is scheduled to end.[145] Jiangsu, Fujian and Guangdong together were home to more than 80% of China's offshore capacity in operation at the end of 2020.[146] These and other coastal provinces have set offshore wind capacity targets totalling nearly 60 GW of capacity by 2030.[147]

Elsewhere in Asia, the Republic of Korea added 60 MW of offshore wind power capacity; Japan launched its first offshore wind auctions, including one for a floating wind farm; and Chinese Taipei had three projects under construction offshore with a total capacity of 0.7 GW.[148] The Republic of Korea aims for 12 GW of offshore capacity by 2030, and in December 2020 Japan released a vision document that calls for 10 GW of offshore capacity by 2030 and 30-45 GW by 2040.[149]

In July 2020, a PPA was signed for the entire output of a 0.9 GW wind project (the world's largest-ever renewable energy PPA at the time) off the west coast of Chinese Taipei that is due to begin construction in 2025.[150] To date, relatively few corporate deals have been signed globally for offshore wind energy, but corporate interest is increasing due to the large scale of generation, high capacity factors, fairly uniform generation profile and falling costs.[151] Six new offshore PPAs also were signed in Europe, for projects in Belgium, Germany and the United Kingdom, following the first six in 2018-19.[152] PPAs have become an increasingly important means for developers to guarantee revenue over the long term, especially in the case of exposure to wholesale market price (as with "zero-subsidy" bids at auction).[153]

Europe remained home to most of the world's offshore capacity. The region added 2.9 GW in 2020 (down 20% from 2019) in nine completed wind farms, bringing the regional total to 25 GW.[154] The Netherlands more than doubled its offshore capacity (adding 1.5 GW) and accounted for more than half of Europe's installations; it was followed by Belgium (0.7 GW), which had a record year, the United Kingdom (0.5 GW), Germany (0.2 GW) and Portugal (nearly 17 MW).[155] UK installations were the lowest since 2016, not because of faltering commitment but because of

a gap between government contracting rounds, and foundations were installed to prepare sites for enormous future wind farms.[156]

Germany saw its lowest numbers in nearly a decade, with no new offshore wind power projects under construction at year's end as all projects planned under tenders had been installed. However, under a new offshore wind energy law that entered into force in December 2020, Germany is set to increase offshore tender volumes significantly.[157] Portugal's additions of two floating turbines completed the Windfloat Atlantic wind farm.[158] Europe's total floating capacity reached 62 MW, and the pipeline for floating wind projects in the region for the next decade exceeds 7 GW.[159]

At year's end, five countries continued to host nearly all of Europe's offshore capacity: the United Kingdom (42%), Germany (31%), the Netherlands (10%), Belgium (9%) and Denmark (7%).[160] The year brought a record EUR 26.3 billion (USD 32.3 billion) of financing for 7.1 GW of future capacity (including transmission infrastructure) off the coasts of the United Kingdom, Germany and France; this is up from EUR 6 billion (USD 7.37 billion) in 2019.[161] In 2020, several countries increased their future targets for offshore wind power capacity, including the United Kingdom (boosted its 2030 target from 30 GW to 40 GW) and Germany (increased its 2030 target from 15 GW to 20 GW).[162] As of early 2021, total government commitments for offshore wind power by 2030 reached 111 GW.[163]

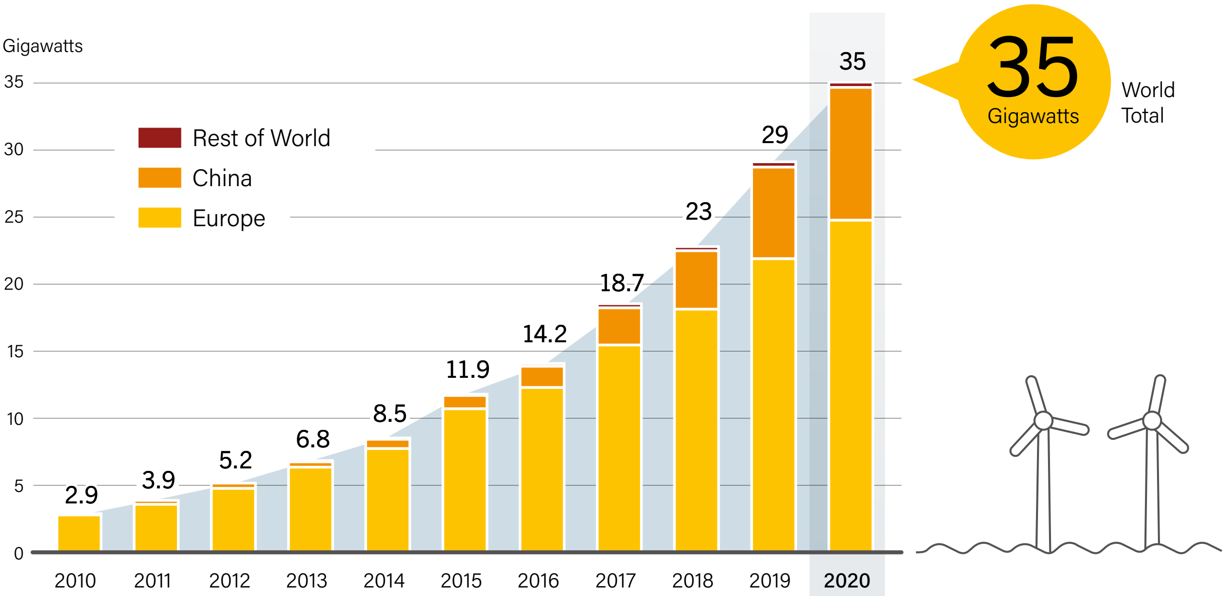
Targets also were increased in the United States, with six eastern states aiming to bring online a combined 28.1 GW of offshore wind power capacity by the 2030-2035 period.[164] By early 2020, state procurement commitments totalled 28.9 GW, and another 55.9 GW was in interconnection queues by mid-year.[165] Actual installations remained low, however. The country's first project installed in federal waters, a 12 MW pilot[i] off the coast of Virginia, was completed during 2020, bringing total US offshore capacity to 42 MW.[166]

Other US developments in 2020 included: New York state issued a second solicitation for 2.5 GW; Rhode Island announced a request for proposals for 0.6 GW; Massachusetts approved contracts for the 0.8 GW Mayflower Wind project; the Icebreaker project on Lake Erie moved forward after years of permitting battles; and Louisiana began investigating the potential for offshore wind in the Gulf of Mexico to create jobs and reduce greenhouse gas emissions.[167] In early 2021, the 0.8 GW Vineyard Wind project (Massachusetts) was granted final federal approval.[168]

By the end of 2020, 18 countries (12 in Europe, 5 in Asia and 1 in North America) had offshore wind capacity in operation, unchanged from 2019.[169] The United Kingdom maintained its lead for total capacity (10.4 GW), followed by China (10 GW), which overtook Germany (7.7 GW), the Netherlands (2.6 GW) and Belgium (2.3 GW), both of which overtook Denmark (1.7 GW) in 2020.[170] Europe was home to around 70% of global offshore capacity (down from 75% in 2019 and 79% in 2018), with Asia (mostly China) accounting for nearly all the rest.[171] (→ *See Figure 36.*) Around the world, an additional 82 GW of offshore capacity was under construction, had been approved through regulatory processes or had reached financial close.[172] Global capital expenditures committed to offshore wind power surpassed investments in offshore oil and gas for the first time in 2020.[173]

i This proof-of-concept project was a step towards development of a 2.6 GW project in the same area, scheduled to be brought online in phases between 2024 and 2026.

FIGURE 36.
Wind Power Offshore Global Capacity by Region, 2010-2020



Note: Totals above 20 GW are rounded to nearest GW. Rest of World includes the rest of Asia as well as North America.
Source: See endnote 171 for this section.

The pandemic added to existing challenges, but several developments fed hope for the year to come.

The **decommissioning** of wind turbines that had reached the end of their service life, or were ripe for refurbishment on economic grounds, totalled an estimated 0.5 GW in 2020, across 10 countries.[174] In Europe, seven countries decommissioned almost 0.4 GW of capacity, all of it onshore, led by Germany (222 MW), Austria (64 MW) and Denmark (62 MW), with smaller amounts in Belgium, France, Luxembourg and the United Kingdom.[175] The United States decommissioned around 74 MW of capacity, with the remainder removed from operation in Japan and the Republic of Korea.[176] Decommissioning does not necessarily mean the end of a project, but can pave the way for repowering with more advanced and efficient technology; some of the decommissioned projects were repowered. (→ *See Industry section below.*)

WIND POWER INDUSTRY

Even as the global market expanded and several countries had a strong year, the global wind industry continued to face perennial challenges that were exacerbated by the pandemic. Nonetheless, a number of developments fed hope for the year to come, including: remedial policy adjustments in several countries, ongoing technology development and innovations, growing attention to climate change mitigation and wind energy's potential role, and increasing interest among industry actors and governments in advancing floating wind technologies and green hydrogen.

Particularly early in the pandemic, the wind industry was affected by restrictions on movement of labourers and supplies.[177] Turbine assembly generally requires components produced in numerous countries around the globe, and lockdowns disrupted supply chains.[178] Restrictions also slowed project permitting and development (particularly onshore), which was especially challenging for developers racing to complete projects before support policies changed or expired at year's end, or before fixed commissioning deadlines.[179] Short-term declines in electricity demand and prices led asset owners to reduce operation and maintenance (O&M) budgets; these downward trends also adversely affected demand for turbines and new projects and curtailed access to financing for onshore wind, which slowed the signing of PPAs and investment in new onshore projects.[180] The result was reduced margins for turbine manufacturers (suppliers of both machines and, increasingly, O&M).[181]

These troubles all added to existing challenges, including: the lack of grid access and unreliable grid systems; poorly designed tenders in some countries; and the lack of available land with good wind resources.[182] Permitting delays also have been prevalent, due in some cases to local opposition as the number of participants declines and the size of developers and the scale of projects increase; in 2020, delays worsened as government staff was reassigned to pandemic-related matters.[183] In another ongoing challenge, downward pressure on bid prices in some markets is affecting manufacturers and developers, even as a lack of investment and competition in other markets has driven bid prices up.[184]

In several countries, governments responded by extending deadlines to account for pandemic-related delays.[185] By the end of 2020, new policy commitments had helped stimulate record investments in new projects.[186] The year saw new entrants (including fossil fuel companies) to the wind power sector, and wind turbine manufacturers and developers expanded further into new sectors.[187] The industry continued to better integrate wind energy into existing electricity grids and to improve technologies to increase output and further reduce the cost of energy.[188]

By one estimate, from the second half of 2019 to the same period in 2020, the global benchmark **levelised cost of energy**[i] (LCOE) from new wind power projects fell 17% onshore (to an average USD 41 per MWh) and 1% offshore (USD 79 per MWh).[189] Cost reductions are the result of several factors, including more powerful and efficient turbines that can capture more wind and economies of scale with larger projects, which reduce per unit costs of installation, operation and maintenance.[190]

Auctioned capacity in 2020 was down 26.5% relative to 2019 but reached the second highest level on record, with a global total of 35 GW[ii] (including 33.7 GW onshore).[191] Activity plummeted early in the year, due mainly to pandemic-related postponements in some key markets, but increased over the second half of 2020 relative to the same period in 2019.[192] China accounted for two-thirds of the total wind power capacity auctioned and awarded, with most of this for onshore projects to be built without direct government support.[193] Thirteen other countries or regions held wind-specific or renewable energy auctions, including several in Europe as well as Ecuador, India and the US state of New Jersey.[194]

Results[iii] from auctions vary widely depending on local conditions and costs, project scale and other factors.[195] For example, Europe's winning onshore bids during 2020 were in the range of EUR 42.4 to EUR 69.2 (USD 52 to USD 85) per MWh, compared with EUR 21 to EUR 67 (USD 25.8 to USD 82.3) per MWh in 2019.[196] While declining costs and fierce competition in auctions and tenders have driven down average bid prices in many markets, bids have been stable or even rising in others. Relative to earlier auctions, prices for onshore wind power in 2020 were down significantly in France and Greece.[197] In contrast, prices were up in Italy, where all three auctions for solar PV and wind power were undersubscribed, due in part to permitting challenges.[198]

i Note that energy costs vary widely according to wind resource, project and turbine size, regulatory and fiscal framework, the cost of capital, land and labour, exchange rates and other local influences.

ii Unless noted otherwise, mentions of auctions and tenders as support mechanisms presume wind technology-specific tenders or those specific to renewables in general. Technology-neutral tenders (open to non-renewables) do not constitute a support mechanism, although such tenders can and do draw successful bids from renewable energy developers.

iii Note that bid levels do not necessarily equate with costs. Bid levels differ from market to market due to varying auction designs, policies and risks, among other factors.

In Germany, winning bid levels for onshore capacity were fairly stable through the year, but remained higher than at auctions in 2017 and early 2018, and above the statutory tariffs under the country's previous Renewable Energy Act.[199]

In India, several wind tenders in recent years resulted in relatively low levels of competition, as policy, regulatory and market uncertainty have shifted the sector towards developers with greater risk-taking capacity.[200] The inconsistent regulatory environment and lack of suitable sites in most Indian states for wind power project development have contributed to the rise in wind tariffs since 2017 and helped to increase the relative attractiveness of solar PV.[201]

In the offshore sector, the Netherlands held its third tender for which the winning project (due online by 2023) will receive only the wholesale price of electricity and will pay an annual rent for seabed rights.[202] The winning consortium of Shell and Eneco plans to build a 759 MW project that will include floating solar PV and battery storage, and to use the electricity generated to produce hydrogen.[203] Offshore wind tenders also were held in the US state of New Jersey (bid price pending as of early 2021) and France, where the winner of a tender for 1 GW off the coast of Normandy is expected to be announced in 2022.[204]

In some countries where auctions are putting growing price pressure on markets, **direct PPAs** are becoming increasingly important.[205] In Brazil, for example, returns to developers can be higher through PPAs than in national electricity auctions.[206]

PPA prices trended upwards in Europe through most of 2020 but generally declined in the fourth quarter.[207] In the United States, prices under PPAs for onshore wind power capacity rose throughout 2020, with steeper increases starting in the second quarter; the pandemic was among the factors driving up prices, in addition to grid connection delays, permitting challenges and the fact that the windiest sites with easy grid access have already been developed.[208] This increase followed a steady decline in US average PPA prices since 2009.[209] In the offshore segment, in early 2020 developers signed PPAs with six utilities in the US state of Massachusetts for electricity from the 0.8 GW Mayflower Wind project, due for commissioning in 2025; the levelised price over 20 years was USD 58.47 per MWh[i] (13% below the levelised price of the relatively nearby Vineyard Wind project in 2018), setting a new benchmark for US offshore wind.[210]

The wind industry has seen more than 100 **turbine suppliers** over the years, with a peak of 63 suppliers reporting installations during 2013; the number has declined rapidly since 2015, with 33 in 2019, but might have climbed slightly in 2020, due to the rush of installations in China.[211] The six leading manufacturers captured 75% of the capacity installed in 2020 (up from 64% in 2017).[212]

The top six turbine suppliers in 2020 were Vestas (Denmark), GE Renewable Energy (GE, US), Goldwind, Envision (both China), Siemens Gamesa (Spain) and Mingyang (China), together accounting for more than 63 GW of installations.[213] Vestas stayed on top for the fifth consecutive year, GE delivered record global volumes and benefited from a strong home market – as did Goldwind (which also suppled more than 1 GW of turbines for overseas markets for the first time), Envision and Mingyang – and Siemens Gamesa dropped from third in 2019 to fifth in 2020, but led the offshore market.[214] Chinese manufacturers took 10 of the top 15 places, thanks to the dramatic increase in China's onshore installations; the role of most Chinese firms beyond the domestic market remains limited.[215]

Senvion (Germany) and Suzlon (India), both among the top 10 in 2017, and Germany's Enercon (eighth in 2019), all continued to struggle due to declining sales in their home markets.[216] Even top manufacturers suffered losses for the year, closed factories and laid off workers, despite selling more turbines (by capacity), as the highly competitive market combined with pandemic-related costs and delays to further squeeze profit margins.[217] Both Vestas and GE reported that their orders for new turbines had fallen slightly relative to 2019.[218] Legal battles among manufacturers escalated in 2020 and into 2021 over intellectual property as they sought to maintain or gain control over key markets.[219]

To further diversify their portfolios in key markets, wind power developers and turbine manufacturers continued expanding into new sectors during 2020.[220] Ørsted (Denmark), the largest

In some countries where auctions put growing price pressure on markets, **direct PPAs** are becoming increasingly important.

MARKET AND INDUSTRY TRENDS

i The combined price for electricity and renewable energy credits under the Mayflower Wind project will come to USD 77.76 per MWh on a nominal levelised basis for the two phases of the project. See American Clean Power Association, *ACP Market Report – Fourth Quarter 2020* (Washington, DC: 2021), p. 16, https://cleanpower.org/resources/american-clean-power-market-reportq4-2020.

offshore wind developer and operator, took the final investment decision in late 2020 to develop a large solar PV project in the US state of Texas under a long-term PPA, bringing the company's solar portfolio to 1.1 GW under construction.[221] Chinese turbine manufacturers are turning to solar PV and other avenues to diversify their business as national subsidies are phased out. Mingyang, for example, has developed a solar and financing lease business, while Goldwind has expanded into water treatment, and Envision acquired Automotive Energy Supply Corporation (Japan) to move into energy storage and batteries.[222]

Manufacturers also focused on **technology innovation**, building largely on existing concepts.[223] The fact that nearly all major wind power markets are auction driven (including new, emerging markets) has pressured the industry to continuously reduce costs and achieve the lowest possible levelised cost of energy.[224] One ensuing trend in recent years has been a move to turbines with lower specific power (the ratio of capacity to rotor swept area). This results in less energy production per square metre of rotor area but offers several benefits that help reduce the LCOE, including lower generator costs and savings on other components, as well as higher capacity factor and reduced variability of output, which lowers balancing costs and can increase the value of the turbine's generation to the grid system.[225]

Turbines for use onshore and offshore continued to get **larger and taller** during 2020, enabling them to capture more energy from the wind to make wind-generated electricity economical in more locations.[226] Onshore turbines in the 5 to 6-plus MW range were introduced by GE, Nordex (Germany), Siemens Gamesa, and Vestas, and Mingyang launched a 6.25 MW machine.[227] Several companies also launched new smaller machines for low-wind sites, including those targeted to wind conditions in specific markets.[228] Goldwind was working on new turbines for low- and medium-wind speeds (both onshore and offshore) and new hybrid tower concepts to further reduce the LCOE as China's FITs come to an end.[229]

Taller turbine towers and longer blades have affected everything from design to manufacture, transport and installation (and related costs).[230] To address the challenges associated with transporting taller towers, Nordex launched a facility in Spain (the company's 12th such factory) based on a mobile concept that enables concrete towers to be produced and assembled locally, reducing logistics costs as well as transport distances. The facility can be dismantled and reassembled in new locations.[231] GE announced a partnership with a robotics firm and a building manufacturer to develop 3-D printed concrete bases for on-site production of turbine towers. The process should allow for larger bases and thus taller hub heights to capture stronger winds, while also reducing transport-related costs and challenges.[232]

Larger, taller wind turbines are able to capture more energy, making wind-generated electricity **economical** in more locations.

The world's then-longest blade – LM Wind Power's 107 metre blade – was certified for use in November 2020.[233] The move towards ever-longer blades for use onshore and offshore has affected supply chain strategies, including the increasing outsourcing of production.[234] Even so, the number of blade suppliers declined by about one-third from 2016 to 2020 as small- and medium-sized manufacturers were unable to compete on R&D investment, costs and global presence.[235] In 2020, both GE and Siemens Gamesa closed blade manufacturing facilities to cut costs and because of the facilities' inability to handle larger blades and the falling demand for the smaller blades they produced.[236]

In 2020, the average size of turbines delivered to market was 2% larger than in 2019 (2.76 MW), at 2.81 MW (2.7 MW onshore and 6.0 MW offshore).[237] In late November, the last of 77 MHI Vestas[i] 9.5 MW turbines – the largest turbines installed thus far – was installed at a site off the Dutch coast.[238] Just one of these turbines has nearly as much power capacity as the combined total of the first two offshore wind farms, off the coast of Denmark.[239]

Turbines are set to get only larger as manufacturers race to build the biggest and most powerful units, especially for offshore use. In 2020, GE increased the power rating of its Haliade-X prototype to 13 MW, and later boosted it to 14 MW for use in the UK's Dogger Bank wind farm, with installation set to begin in 2025.[240] Siemens Gamesa released a 14 MW turbine that can be boosted to 15 MW and should be commercially available starting in 2024.[241] By mid-2020, several Chinese manufacturers had entered the fray, with Dongfang commissioning a 10 MW prototype and Mingyang announcing an 11 MW hybrid drive (the world's largest), which it expects will be commercially available in 2022.[242] Not to be left behind, Vestas became the first to launch a 15 MW turbine (upgradable to 17 MW) in early 2021.[243]

i Note that Vestas acquired Mitsubishi Heavy Industry's (MHI) shares in MHI Vestas in late 2020, and the company was integrated back into Vestas. See endnote 238 for this section.

Offshore developers are taking advantage of larger turbines as soon as they become available, with several orders placed for these mega-turbines during 2020.[244] Larger, higher-efficiency turbines mean that fewer turbines, foundations, converters, cables, less labour and other resources are required for the same output, translating into faster project development, reduced risk, lower grid-connection and O&M costs, and overall greater yield, all particularly important for the offshore sector.[245]

Floating turbines offer the potential to expand the areas where offshore wind energy is viable and economically attractive because they can be placed where winds are strongest and most consistent, rather than where the sea-floor topography is suitable.[246] Costs are about double those of fixed bottom turbines but continue to fall as technologies advance, and the sector is ready for full commercialisation.[247] In late 2020, an MHI Vestas (now Vestas) 9.5 MW turbine became the largest yet installed for use in a floating project, off the coast of Scotland.[248]

Throughout 2020, several major wind power developers – including Enel (Italy), Equinor (Norway), Ørsted, RWE (Germany) and Vattenfall (Sweden) – unveiled plans to produce hydrogen or methane with wind energy.[249] In addition, Siemens Gamesa and spin-off Siemens Energy were developing an offshore turbine with a fully integrated electrolyser to produce hydrogen directly.[250] Several **oil and gas companies** also announced plans or launched partnerships to develop hydrogen projects linked to offshore wind power.[251]

As offshore wind power has advanced (and particularly floating technologies), major oil companies have begun investing large and growing amounts of money into the sector, which is one of the areas (in addition to geothermal) where the skill and knowledge transfer from oil to renewable energy is most clear.[252] As of early 2021, oil majors accounted for only 5% of offshore capacity in operation, but from early 2019 to March 2021 they won about half of offshore wind power tenders awarded outside of China.[253] European oil majors[i] have a combined target of at least 125 GW of renewables capacity by 2030, with much of this being offshore wind power.[254]

Among developments in 2020, Total (France) made its first major investments in offshore wind power, acquiring stakes in projects in UK waters and announcing plans to develop a 2.3 GW floating project off the Republic of Korea, and Eni (Italy) also entered the UK market, acquiring 20% of the UK Dogger Bank project.[255] Both Equinor (Norway), a pioneer in floating wind technology, and Neoenergia (Spain) were looking at the possibility of developing offshore wind projects in Brazil, and Equinor and BP (UK) partnered to develop offshore wind capacity in the United States.[256] Shell (Netherlands) is partnering on several offshore projects, and (along with German utility Innogy) is a major backer of the Steisdal TetraSpar, a new floating foundation that promises easier assembly and installation, and thus lower costs.[257] Also, Australian oil and gas explorer Pilot Energy announced plans to undertake a feasibility study into a 1.1 GW project off the coast of Western Australia as part of its effort to diversify beyond fossil fuels.[258]

Several Asian and European utility companies have begun moving into offshore wind power technology and project development, especially in the floating sector.[259] In 2020, two of India's largest fossil fuel and electricity companies partnered to develop renewable energy projects, including offshore wind.[260]

Offshore wind is not without its **challenges**. There are concerns that the offshore sector is growing so quickly – in the number of projects and the scale of turbines – that it will outpace the number, size and ability of installation vessels to transport and lift large components.[261] As of late 2020, only four vessels were capable of handling the next generation of offshore turbines, such as GE's Haliade-X.[262] In addition, new offshore markets still face challenges that Europe and China have addressed, including developing supply chains, a trained workforce and associated infrastructure such as ports, rail links and grid infrastructure.[263] The United States, for example, had no offshore wind factories as of 2020; however, at least six states were competing during

i Excludes Shell, which did not have a stated target as of early 2021.

the year to host them, announcing plans to build manufacturing facilities and to transform ports and marine terminals into hubs for an offshore wind industry, and some states announced plans to start training workers.[264]

Around the world, and particularly onshore, major manufacturers are focused increasingly on the **repowering**[i] segment.[265] Historically, repowering has involved the replacement of old turbines with fewer, larger, taller, and more efficient and reliable machines at the same site, but increasingly operators are switching even relatively new machines for larger and upgraded turbines (including software improvements) or are replacing specific components (partial repowering).[266] Bigger blades, new rotors and improved mechanics all can boost efficiency and provide better monitoring of wind speed and direction, increasing output by 10% or more, and without the challenges of interconnection and permitting hurdles.[267]

In the United States, project owners partially repowered 2.9 GW at existing projects in 2020, slightly below 2019 levels but 130% above 2018 levels.[268] Repowering in the country was driven by the looming expiration of the federal PTC[ii] at year's end (later extended in December) and by the significant technology improvements of recent years.[269] Repowering increased somewhat in Europe (345 MW) through projects in Germany (339 MW) and smaller amounts in Greece, Luxembourg and the United Kingdom.[270] Repowering in China has been limited to date.[271]

As the earliest fleets of wind turbines reach retirement age, and components are replaced, concerns are increasing about what to do with turbines and components at the **end of their life**. Although most of a turbine can be used on another wind farm or recycled, blades are made of complex composite materials that are difficult and expensive to recycle.[272] Efforts have focused on repurposing old blades (e.g., as sound barriers) or developing solutions for recycling and reusing their composite materials, and on developing blades with entirely different materials.[273]

Related developments in 2020 and early 2021 included: GE signed a contract with Veolia North America to use decommissioned blades as raw material in place of coal, sand and clay for cement production; the DecomBlades consortium (Denmark) launched to find sustainable recycling solutions for composite materials in blades; a consortium of 10 companies and technical centres launched the Zero wastE Blade ReseArch (ZEBRA) project in Europe to develop the world's first fully recyclable blade of thermoplastic resin; and US researchers validated the structural integrity of thermoplastic composite blades, determining that they could be more efficient and robust, manufactured on site, and the material could be melted and reused.[274]

An increasing number of manufacturers also are focused on making wind turbines sustainable in their production as well as at end of life, and trying to do so in a way that is cost effective in order to remain competitive.[275] After achieving its 2019 goal to become carbon-neutral in early 2020, Siemens Gamesa turned its attention to its international supply chain.[276] Also in 2020, Vestas (which achieved 100% renewable electricity in 2013) joined RE100 and set a target to become carbon neutral by 2030 through its own corporate actions; Vestas also announced plans to eliminate non-recyclable waste from manufacturing, operating and decommissioning of its wind turbines by 2040.[277] Early in 2021, Envision committed to achieving carbon neutrality for its operations by 2022 and for its value chain by 2028.[278]

→ *See Box 7 for developments in the small-scale wind power sector.*[279] *Also see Sidebar 6 on the following pages for a summary of the main renewable energy technologies and their characteristics and costs.*[280]

An increasing number of manufacturers are focused on
making wind turbines sustainable
in production as well as at end of life.

i Repowering refers to the process of replacing turbines within an existing wind farm with newer turbines. If the majority of components (including foundation) are replaced, a project is considered repowering; replacement of only specific components is consider partial repowering. See endnote 265 for this section.

ii Repowering a project enables owners to reset the clock on 10 years' worth of US federal tax credits, encouraging the replacement of parts of existing turbines well ahead of the end of their original life expectancies. Looming expiration of the tax credit drove increased activity. See endnote 269 for this section.

BOX 7. Small-scale Wind Power

Small-scale[i] (up to 100 kW) wind turbines are used for a variety of on- and off-grid applications, including defence, rural electrification, water pumping and desalination, battery charging, telecommunications and to displace diesel in remote locations. The annual global market continued to shrink in 2019 (latest data available) in response to onerous local permitting and planning laws, inconsistent policy support as well as unfavourable policy changes (e.g., introduction of market caps, removal of incentives), and ongoing competition from relatively low-cost solar PV.

By one estimate, 42.5 MW of new small-scale wind power capacity was installed in six countries during 2019, down from an estimated 47 MW in 2018 and 114 MW in 2017. Due to a lack of data, these estimates do not include off-grid systems even in large markets, or installations in additional countries. At the end of 2019, more than 1 million small-scale turbines (totalling at least 1.7 GW) were estimated to be in operation worldwide.

China continued to be the largest market with an estimated 23 MW installed in 2019, down from 30.7 MW in 2018. Japan added 17 MW, followed distantly by the United States with 1.4 MW, a 7% annual reduction that continued the country's downwards trend in small-scale turbines; much of the new US capacity was for retrofit projects. Other important markets included Germany (0.5 MW), the United Kingdom (0.4 MW) and Denmark (0.2 MW).

Markets declined during 2019 in all of these countries except Japan, where installations were up nearly 32% over the previous year. By June 2020, Japan had more than 5,000 projects (108 MW) approved under a new FIT system, and only a small portion of these was already in operation.

In response to shrinking domestic markets, the number of producers of small-scale wind turbines in China and the United States has declined sharply in recent years, with manufacturers relying heavily on export markets, which also have been in decline. US-manufactured exports, for example, fell below 0.5 MW in 2019, down from 2015 (21.4 MW), as key export markets largely dried up due to reduced or discontinued feed-in tariff programmes. US domestic sales rose slightly in 2019 (from 1.1 MW in 2018 to 1.2 MW in 2019) as imports fell; but domestic small-scale turbine sales were well below their annual totals early in the decade.

At least in the United States, however, things were looking up in 2019 and early 2020 with evidence that a 2018 extension of the federal investment tax credit for small-scale wind power, combined with public research and development (R&D) funding to improve competitiveness, could enable small and distributed wind power to turn the corner in the country. US R&D efforts also were under way to make wind power technology a plug-and-play component in hybrid systems and microgrids, among other options.

Italy, which has been an important market in past years, also received a boost from a new FIT incentive that was enacted in mid-2019. Following a decline in total capacity due to decommissioning (8.2 MW in 2018 and 2.6 MW in 2019), an estimated 8 MW of new small-scale wind power capacity was installed in the first half of 2020.

Elsewhere, the small-scale wind sector is seeing the emergence of several start-up companies, including Diffuse Energy (Australia) and Alpha 311 Ltd (UK), which manufactures vertical-axis turbines that are attached to existing light posts located near roads or rail lines. New uses for small-scale turbines under consideration or development include mining, small microgrids and data centres.

i Small-scale wind systems generally are considered to include turbines that produce enough power for a single home, farm or small business (keeping in mind that consumption levels vary considerably across countries). The International Electrotechnical Commission sets a limit at around 50 kW, and the World Wind Energy Association and the American Wind Energy Association as well as the US government define "small scale" as up to 100 kW, which is the range also used in the GSR; however, size varies according to the needs and/or laws of a country or state/province, and there is no globally recognised definition or size limit.

Source: See endnote 279 for this section.

SIDEBAR 6. Renewable Electricity Generation Costs in 2020

Renewable power costs continued to decline in 2020, keeping with trends from the past decade. The mature technologies such as hydropower, bio-power and geothermal, typically are dispatchable and low-cost power sources, and are competitive in regions where unexploited resources exist. However, the decade was notable for the rapid improvements in the competitiveness of solar and wind power technologies.

The levelised cost of electricity (LCOE)[i] of utility-scale solar PV fell 85% between 2010 and 2020, from USD 0.381 per kWh to USD 0.057 per kWh. (→ *See Figure 37.*) Over the decade, utility-scale solar PV became competitive with the lowest-cost new fossil fuel-fired capacity[ii]. Cost declines were driven primarily by falling module prices and reductions in balance-of-system[iii] costs, which tumbled between 2010 and 2020 as module efficiency improved and manufacturing was scaled up and optimised. As a result, the total installed cost of utility-scale solar PV fell 81% over the decade.

The LCOE of onshore wind power fell 54% between 2010 and 2020, from USD 0.089 per kWh to USD 0.041 per kWh. The total installed cost of newly commissioned onshore wind projects fell from USD 1,970 per kW to USD 1,355 per kW during the decade.

Cost reductions for onshore wind were driven by declining turbine prices and by reductions in balance-of-plant costs and operation and maintenance costs. At the same time, costs have been reduced through continued improvements in wind turbine technology (e.g., larger turbines, higher hub heights and larger swept blade areas), wind farm siting and reliability that have led to an increase in average capacity factors, with the global weighted average rising from 27% in 2010 to 36% in 2020[iv].

For offshore wind, the LCOE of newly commissioned projects fell 48% from USD 0.162 per kWh in 2010 to USD 0.084 per kWh in 2020. Annual values for the global weighted average total installed costs, capacity factors and LCOE are relatively volatile given the small number of projects added in some years[v]. From 2010 to 2020, total installed costs fell around 32%, while capacity factors increased from 38% in 2010 to 42% in 2019, before dropping back to 40% in 2020. The drop in the global weighted average capacity factor in 2020 was driven by new plants being commissioned mainly in China, where offshore wind farms still predominantly use smaller offshore wind turbine designs and are in areas with lower-quality wind resources (e.g., inter-tidal or near shore).

i All references to LCOE and total installed costs in this sidebar are global weighted averages. Note also that costs are very location- and project-specific, and cost ranges can be substantial; the LCOEs presented here should be considered in the context of the country- and region-specific project cost ranges outlined in International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2020* (Abu Dhabi: 2021), which provides further details on the LCOE methodology.

ii The fossil fuel-fired power generation cost range varies by country and fuel, but overall is estimated at between USD 0.055 per kWh and USD 0.148 per kWh. The lower bound represents new coal-fired plants in China.

iii Balance-of-system and balance-of-plant costs encompass the full project costs, including labour, hardware, permitting, grid interconnection, etc.

iv The global weighted average capacity factor for newly commissioned onshore wind projects in 2020 reported here is uncertain given that the geographic distribution of new capacity connected to the grid in China in 2020 was not available when the analysis was undertaken.

v The growth in new markets in recent years, both within Europe (where offshore wind's first markets developed) and globally, have made year-on-year cost comparisons difficult.

The LCOE of concentrating solar thermal power (CSP) fell 68% from USD 0.340 per kWh to USD 0.108 per kWh between 2010 and 2020. These costs declined into the middle of the range of the cost of new capacity from fossil fuels despite only several projects being commissioned in recent years. Similar to solar PV, the decline in the cost of electricity from CSP has been driven by reductions in total installed costs. Yet, technology improvements that have spurred improved economics of thermal energy storage also have played a role in increasing capacity factors.

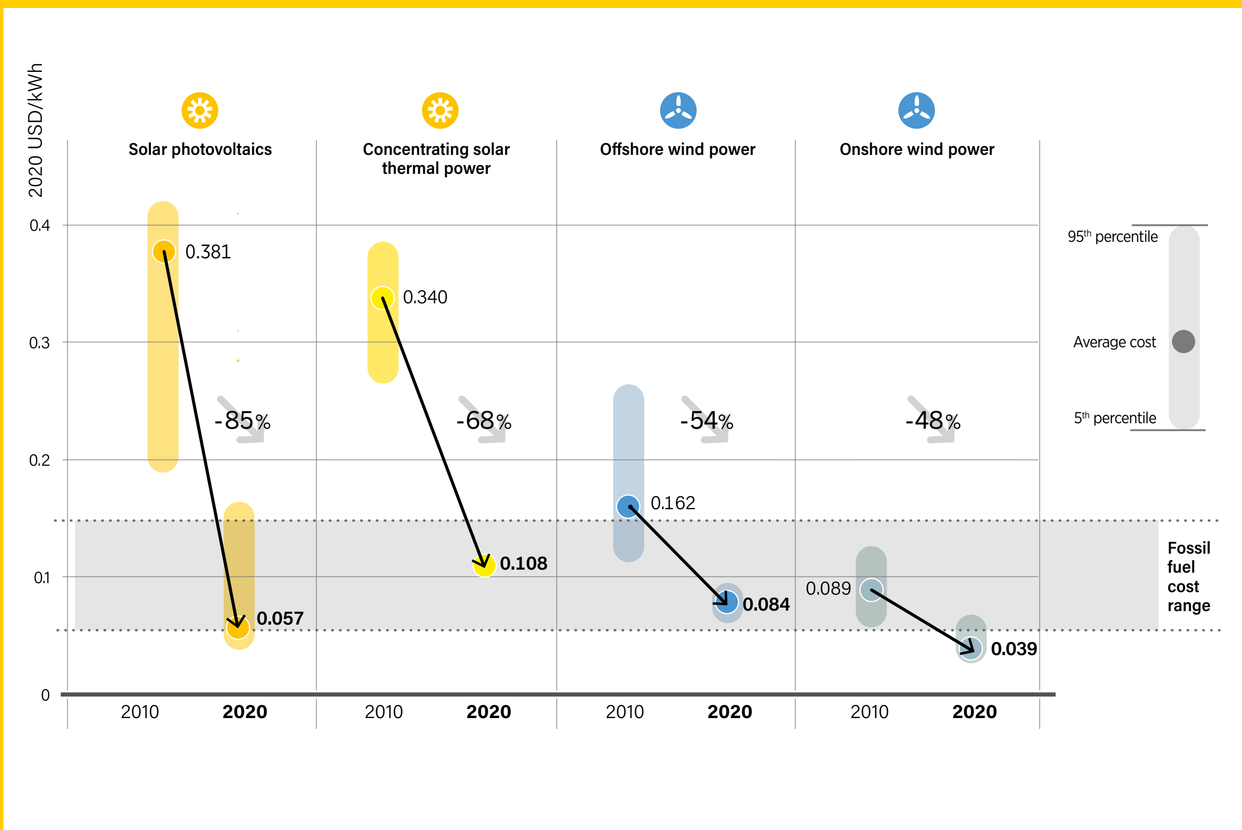
For bio-power, geothermal and hydropower, the installed costs and capacity factors tend to be project specific. This, coupled with different cost structures in different markets, results in considerable year-to-year variability in global weighted average values, particularly when deployment is relatively thin and the share of different countries or regions in new deployment varies significantly.

Between 2010 and 2020, the LCOE of bio-power projects was volatile. By the end of the decade, it had remained at around the same level as in 2010 at USD 0.076 per kWh – still at the lower end of the cost of electricity from new fossil fuel-fired projects.

For the same period, the LCOE of hydropower rose 16%, from USD 0.038 per kWh to USD 0.044 per kWh. This was still lower than the cheapest new fossil fuel-fired electricity option, despite the 10% year-on-year increase in costs in 2020.

The global weighted average LCOE of geothermal has ranged between USD 0.071 per kWh and USD 0.075 per kWh since 2016. The LCOE of newly commissioned plants ended up at the lower end of this range in 2020 at USD 0.071 per kWh, having declined 4% year-on-year.

FIGURE 37.
Global Levelised Costs of Electricity from Newly Commissioned Utility-scale Renewable Power Generation Technologies, 2010 and 2020



Source: IRENA. See endnote 280 for this chapter.

Oorja – a company working at the intersection between agriculture and clean energy – finances and installs distributed solar energy systems for farming purposes.

04

04 DISTRIBUTED RENEWABLES FOR ENERGY ACCESS

KEY FACTS

- By the end of 2019, 90% of the global population had access to electricity, although **one-third still had to cook with polluting fuels**. Only 4% of people living in rural sub-Saharan Africa had access to clean cooking solutions.
- Sales of off-grid solar systems fell 22% in 2020, as **businesses were affected by the effects of the COVID-19 pandemic** such as lockdowns, supply chain issues and economic downturn. Sales improved in the second half of the year.
- Financing for off-grid solar companies increased slightly by around 1%, with a much larger **shift from equity finance to debt** and grant funding.
- While many mini-grid projects were delayed, in several countries new **solar mini-grids were commissioned specifically to power healthcare facilities** as an emergency response to COVID-19.
- Overall, clean cooking continues to attract only a fraction of the estimated funding needed to achieve universal access; however, 25 clean cooking companies were able to raise USD 70 million in 2019, a **63% increase** compared to the 32 companies that raised USD 43 million in 2018.

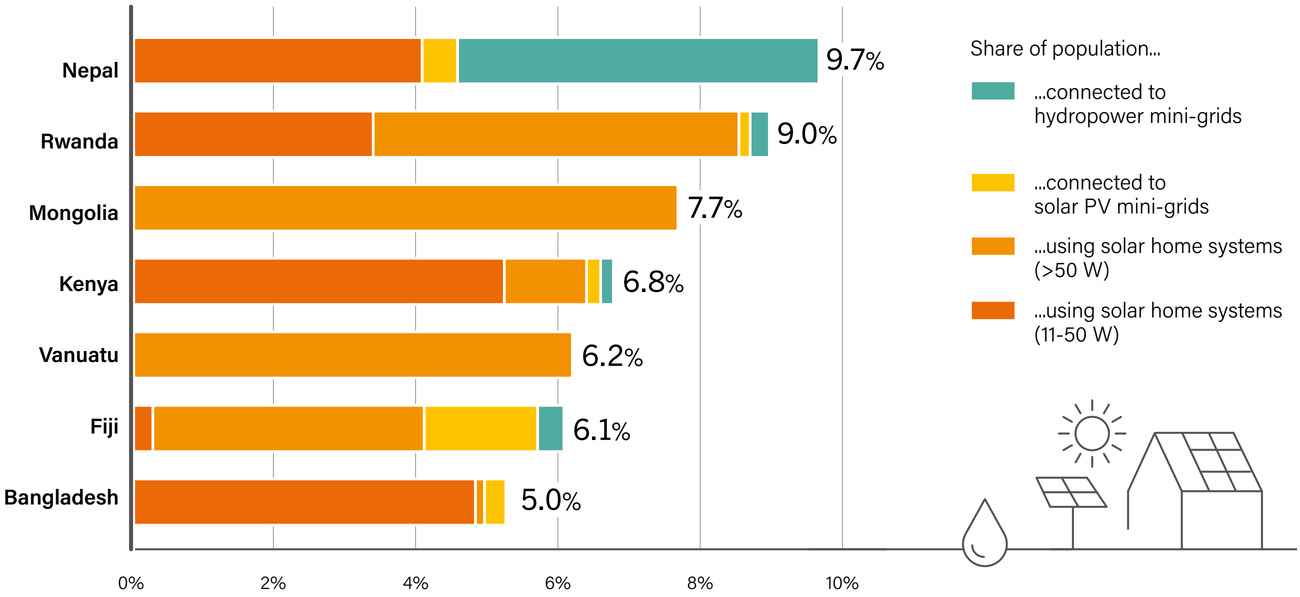
INTRODUCTION

Distributed renewables for energy access[i] (DREA) play an increasingly important role in delivering energy access in developing countries, providing electricity to between 5% and 10% of the population in several countries.[1] (→ *See Figure 38.*) These systems deliver a wide range of services, including electricity for lighting, appliances, productive uses, cooling, irrigation and water pumping, as well as energy for cooking and heating.

Renewables-based electric power systems have proven valuable in rural and peri-urban communities that are difficult or costly to reach through grid electrification programmes. Distributed renewables can provide affordable electricity access that can be scaled up over time, powering not only households but also businesses and community services, such as health care and education. In recent years, solar photovoltaics (PV) has become the technology of choice for off-grid electricity access, but many other renewable access solutions are in place (for example, mini-grids based on mini-hydropower or small wind turbines to power households).

i See Sidebar 9 in GSR 2014 for more on the definition and conceptualisation of DREA. Note that since 2018 the GSR has used the terminology "distributed renewables for energy access" to distinguish from "distributed renewable energy" (DRE) that has no link to providing energy access.

FIGURE 38.
Top 7 Countries with the Highest Electricity Access Rate from Distributed Renewable Energy Solutions, 2019



Note: Data in figure include solar home systems and mini-grids but exclude solar lights.
Source: See endnote 1 for this chapter.

Providing **clean cooking**[i] remains the biggest energy access challenge and has seen the least progress in recent years. Many people in the developing world have little choice than to cook using traditional biomass systems, such as indoor open fires or inefficient cook stoves. This results in high levels of household air pollution with serious health impacts that fall disproportionately on women.[2] Clean cooking solutions exist but are not always available or affordable.[3] In off-grid settings, renewables such as biogas and improved biomass cook stoves can play a role,

whereas in urban areas, electricity, liquefied petroleum gas (LPG) and ethanol are most frequently used. While a switch to LPG has improved health outcomes in many countries, clean cooking ultimately needs to align with decarbonisation objectives.[4]

Cooling is a critical aspect of the provision of modern energy services. Without access to sustainable cooling[ii], labour productivity often remains low, agricultural produce goes to waste, and health care is compromised (for example, vaccine storage is not possible).[5] In the rural areas of many developing countries, lack of electricity access is the main reason for the lack of cooling, whereas in urban areas the key factors are a poor standard of housing and the intermittency of electricity supply.[6] Distributed renewables can enable the use of cooling, especially when combined with efficient appliances.

The coronavirus pandemic has led to renewed focus on the importance of energy access. Evidence has emerged about the links between long-term exposure to particulate matter from air pollution and the risk of mortality from COVID-19.[7] As the crisis has progressed, the challenges of health care and vaccine roll-out in the absence of reliable access to electricity have become increasingly clear.[8] (→ *See Box 8.*) Renewables-based energy systems have been highlighted as offering solutions to these energy access problems, as well as providing economic opportunities during the recovery phase.[9]

i As per the guidelines of the World Health Organisation for indoor air quality linked to household fuel combustion, access to clean cooking facilities means access to (and primary use of) modern fuels and technologies, including natural gas, liquefied petroleum gas (LPG), electricity and biogas, or improved biomass cook stoves that have considerably lower emissions and higher efficiencies than traditional three-stone fires for cooking.

ii Sustainable cooling includes efficient fans, air conditioners, refrigerators and other cold storage, ideally run on renewable electricity. In addition, it covers measures to reduce the need for cooling through insulation, shading, reflectivity or ventilation.

BOX 8. Energy Access, Health and COVID-19

A lack of access to modern energy services has implications for health and the provision of medical services. Cooking with polluting fuels has been linked to 4 million premature deaths from illnesses such as chronic obstructive pulmonary disease, and people with these diseases also are at higher risk of severe cases of COVID-19. At the same time, a lack of electricity access greatly restricts the available treatment options for COVID-19 and other diseases. Crucial equipment such as ventilators and oxygen generators require constant electricity to function, but 60% of healthcare facilities in 46 middle- and low-income countries lack a reliable power supply. In rural areas of sub-Saharan Africa, there is often no electricity at all.

Reliable electricity is essential for vaccine storage, and all of the COVID-19 vaccines that are approved or under development require refrigeration, some as low as minus 70 degrees Celsius. Solar-powered vaccine refrigerators have been available since the 1980s but often fail due to short battery lifetimes or lack of regular maintenance. The global vaccine alliance GAVI has been investing in solar direct-drive refrigerators, which can store vaccines at constant temperatures using ice banks instead of batteries. These refrigerators have already been transformative in remote and under-immunised areas. While they are not able to operate at the very low temperatures that some COVID-19 vaccines require, they are suitable for vaccines that only need to be stored at ordinary fridge temperatures. Cold storage during transport is also crucial, and innovations such as cool boxes with solar-powered batteries can provide a solution for transport to remote locations.

In response to the COVID-19 pandemic, many donor programmes have allocated funds to support the electrification of health services. For examples, Power Africa, funded by the US Agency for International Development (USAID), redirected programme funds to provide USD 2.6 million in grants to off-grid companies for electrification of rural and peri-urban health clinics.

Source: See endnote 8 for this chapter.

OVERVIEW OF ENERGY ACCESS

Globally, billions of people continue to lack access to modern energy services. The biggest deficit is in clean cooking, with a third of the world's population, or 2.6 billion people, still relying on polluting fuels (mostly traditional use of biomass) in 2019.[10] The trend for electricity access has been more positive, with 90% of people globally having access to electricity in 2019, up from 80% in 2010.[11] However, modelling data for 2020 suggest that this trend may have reversed due to the pandemic; in Africa, 2% fewer people had access to electricity in 2020.[12]

Progress in **clean cooking** remains slow and is focused on relatively few countries. Although more than 1 billion people gained access to clean cooking between 2010 and 2018, most of this improvement was in Asia.[13] In China and India, more than 450 million people achieved clean cooking access, but these two countries still account for nearly half of the global population without access.[14] Many countries in Latin America and the Caribbean have high rates of access to clean cooking, but notable exceptions include Haiti (only 6% access), Guatemala (46%), Honduras and Nicaragua (both 55%).[15]

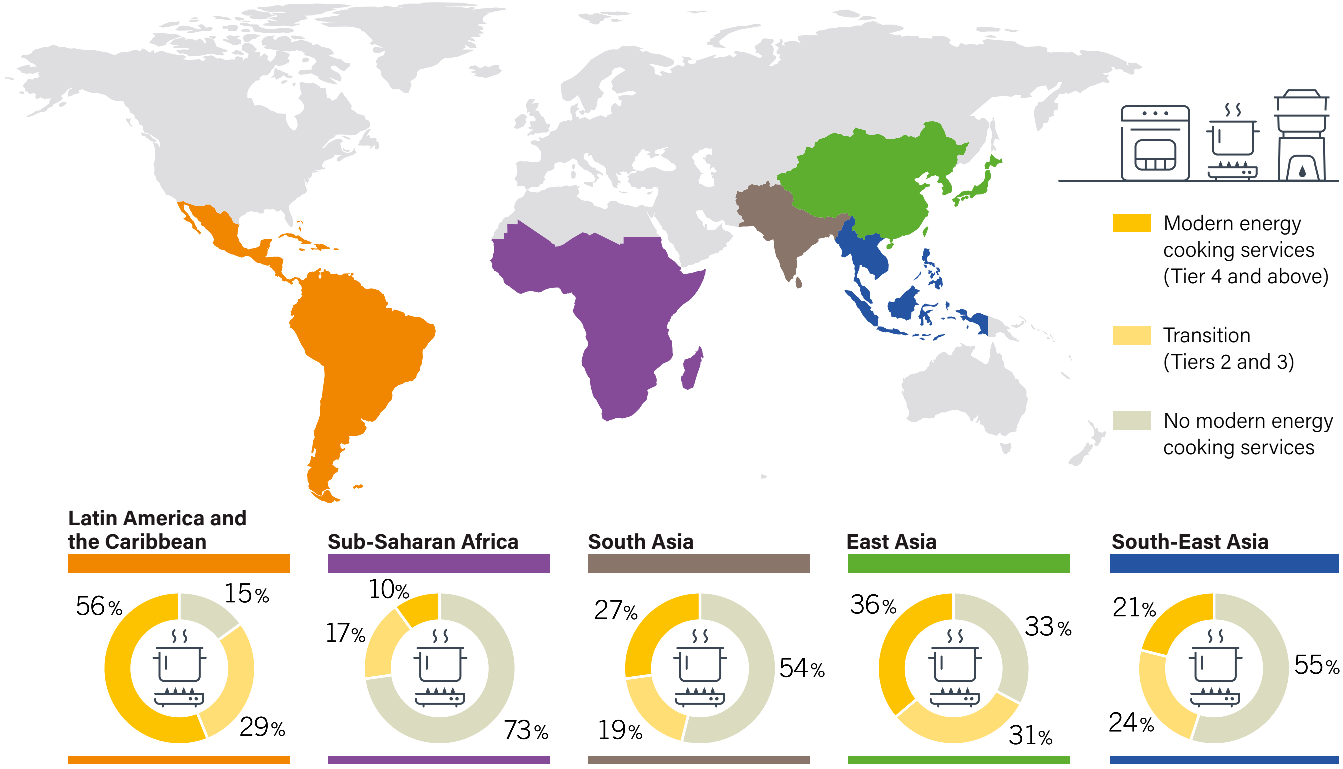
Sub-Saharan Africa continues to lag, with the number of people gaining access to clean cooking not keeping up with population growth.[16] Large differences exist between rural and urban areas: the average access rate in rural sub-Saharan Africa is only 4%, whereas in urban areas it reaches 31%.[17] Nigeria and Ethiopia have the largest populations in the region without access to clean cooking, a total of 275 million people in 2018.[18] In Ethiopia, the problem is primarily rural, whereas Nigeria has large urban and rural deficits, with only 21% of its urban population able to access clean cooking options.[19]

After seven consecutive years of improvements, the number of people **without access** to electricity in Africa was estimated to have increased in 2020.

The assessment of clean cooking progress is constrained by data limitations.[20] In September 2020, new data on the state of access to modern energy cooking services provided a more granular assessment than was available previously.[21] These data suggest an even higher deficit in access, with an estimated 4 billion people out of a sample of 5.3 billion people across 71 countries lacking access to modern energy cooking services in 2020.[22] Only 12% of rural households had access to such services, compared to 38% in urban areas.[23] Sub-Saharan Africa had the smallest share of the population with access, at 10%, whereas Latin America and the Caribbean and East Asia had the highest shares, at 56% and 36% respectively.[24] (→ *See Figure 39.*)

The **electricity access** deficit has improved for some years, with the number of people lacking access decreasing from 801 million in 2018 to 759 million in 2019.[25] However, large variations persist among and within regions. Sub-Saharan Africa lags the most, accounting for three-quarters (570 million) of people globally without electricity access.[26] Although access in urban areas of sub-Saharan Africa reached 78% by 2019, access in rural areas was only 25%.[27] In some African countries – such as Chad, Congo and Djibouti – rural electricity access rates are as low as 1%.[28]

FIGURE 39.
Population with Access to Modern Energy Cooking Services, by Region, 2020



Note: Data based on a 71-country sample of 5.3 billion people representing 90% of lower- and lower-middle-income countries. Modern energy cooking services refers to a household context that has met the standards of Tier 4 or higher across all six measurement attributes of the Multi-Tier Framework (MTF). The MTF for cooking includes six attributes: exposure, efficiency, convenience, safety, affordability and fuel availability. To measure progress, each attribute has six tiers, ranging from 0 to 5.

Source: ESMAP. See endnote 24 for this chapter.

In developing Asia, urban electricity access rates were 99% in 2019, with rural areas close behind at 94%.[29] The access rate in Cambodia increased the most, from 23% in 2010 to 75% in 2019.[30] India and Indonesia also made big improvements, with their rates rising from 67% (Indonesia) and 68% (India) in 2010 to near-universal access in 2019.[31] The People's Democratic Republic of Korea was the only country in the region with access rates below 50% (reaching only 26% in 2019).[32]

Central and South America reached very high average electricity access rates (97%) in 2019.[33] Haiti again was an exception, with only 39% access overall and a mere 12% in rural areas.[34] Bolivia, Honduras and Panama had rural access rates below 80%.[35]

In the Middle East, Yemen remained the only country with a significant electricity access deficit (53%) in 2019.[36]

In many countries, renewables (both on-grid and off-grid) have played an important role in enabling greater electricity access, especially in rural areas.[37] However, in several countries the recent successes have been based mostly on grid expansion using fossil fuels. Indonesia's move to universal energy access was accompanied by a 155% increase in coal consumption, whereas renewables have increased very little and contributed only 16% of national electricity generation in 2019, up slightly since 2010.[38] In India, electricity access rose from 68% to almost 100% during this period, while coal's share of electricity generation increased from 67% to 71%.[39] Bangladesh's electricity access improvement (from 46% to 83%) was accompanied by large increases in natural gas and oil generation.[40]

In Cambodia, on the other hand, hydropower has played a major role in the country's improved energy access. Electricity access jumped from 23% in 2010 to 75% in 2019, while at the same time hydropower generation increased from 32 gigawatt-hours (GWh) to 4,370 GWh.[41] Ethiopia's more than doubling in electricity access since 2010 also is based mostly on hydropower (with some additional wind generation in recent years), whereas in Kenya geothermal has played a big role.[42] Electricity access in Kenya increased from 18% in 2010 to 85% in 2019, and renewable energy generation doubled over the same period, with its share increasing from 69% to 82%.[43]

Although much of this renewables-focused expansion has been driven by larger-scale, grid-connected systems, distributed renewables increasingly play a role in providing electricity access. In 2019, solar home systems[i] supplied electricity to nearly 8 million people in Bangladesh, 4.4 million people in India and 3.4 million people in Kenya.[44]

Despite overall progress in electricity access, the trend is currently measured based on household consumption levels, which masks the ongoing lack of sufficient electricity for other activities, such as productive uses that can allow people to get out of poverty.[45] In addition, unreliable connections remain a significant problem. Across Africa, only two-thirds of people connected to the grid have electricity most of the time.[46]

Worldwide, the **provision of cooling** is affected by low, unreliable or unaffordable electricity supply. In 2021, more than 1 billion people – two-thirds of them in urban areas – were considered at "high risk" because of no access to electricity, low incomes, and other factors, with a lack of cooling threatening their health and safety.[47] In Asia, the highest risk populations are predominantly the urban poor, whereas in sub-Saharan Africa the rural poor are affected most.[48] This reflects both different population dynamics as well as varying levels of electricity access.[49]

Between 2020 and 2021, the number of people in rural areas at high risk from a lack of cooling is estimated to have increased faster than those at risk in urban areas, primarily due to the poverty impact of the COVID-19 pandemic.[50] India, Indonesia, Nigeria, Bangladesh and Pakistan were among the top 10 countries for both rural and urban poor at risk.[51] India saw the fastest rise (13%) in people at risk in rural areas, affecting an additional 14 million people.[52] China and India accounted for 36% of the growth in poor urban settings, with an additional 6.8 million people at risk.[53] In rural areas, distributed renewables can provide cooling needs, from simple fans connected to solar home systems to sophisticated refrigeration units based on solar PV.

TECHNOLOGIES AND MARKETS

Renewables-based systems have enabled greater energy access in many countries and often represent the most cost-effective solution, especially when solar systems are used to provide electricity in low-density rural areas.[54] For access to clean cooking, renewable options such as improved biomass stoves, biogas, ethanol and solar cookers already make a contribution, and renewables-enabled electric cooking has begun to play a role as well.

Renewables deployment for energy access has grown strongly in recent years, although the COVID-19 pandemic had an impact in 2020.[55] As lockdowns spread across countries, energy access companies initially struggled to maintain operations, and the resulting economic crisis affected people's ability to make payments for their existing power supply or to purchase new systems.[56] In August 2020, of 600 energy access companies surveyed in 44 countries, 70% reported significant disruptions from the pandemic, with 30% having to either pause all activity or cease operations entirely.[57] in several countries, however, the off-grid sector was recognised as providing essential services and was allowed some degree of continued operation.[58] Investment also picked up later in the year, and some sectors such as off-grid solar proved surprisingly resilient.[59]

CLEAN COOKING

The global clean cooking market is dominated by **liquefied petroleum gas**, with almost 2 billion people cooking with LPG.[60] In the 71 countries with a clean cooking deficit in 2019, 37% of people overall used LPG as a cooking fuel; however, LPG shares exceeded 70% in urban areas of South Asia, South-East Asia and Latin America and the Caribbean.[61] Electricity also was used increasingly for cooking, with its share more than doubling from 4% in 2010 to 10% in 2019.[62]

Renewables-based clean cooking solutions include improved biomass cook stoves and more efficient fuels (for example, pellets and briquettes), biogas, ethanol, solar cookers and electric cooking linked to renewables-based electricity such as solar or hydropower mini-grids. These options are being promoted mostly through national and donor-funded programmes and tend to involve some form of performance-based incentive or

A lack of access to cooling threatens the **health and safety** of at least 1 billion people worldwide.

i Solar home systems are off-grid solar systems, rated at 11 watts (W) and above, that can be used for lighting and to power small electrical appliances.

subsidy.[63] Even where clean cooking solutions are prevalent, households commonly practice "fuel stacking" and continue to use some traditional cooking methods, often to meet socio-cultural expectations.[64]

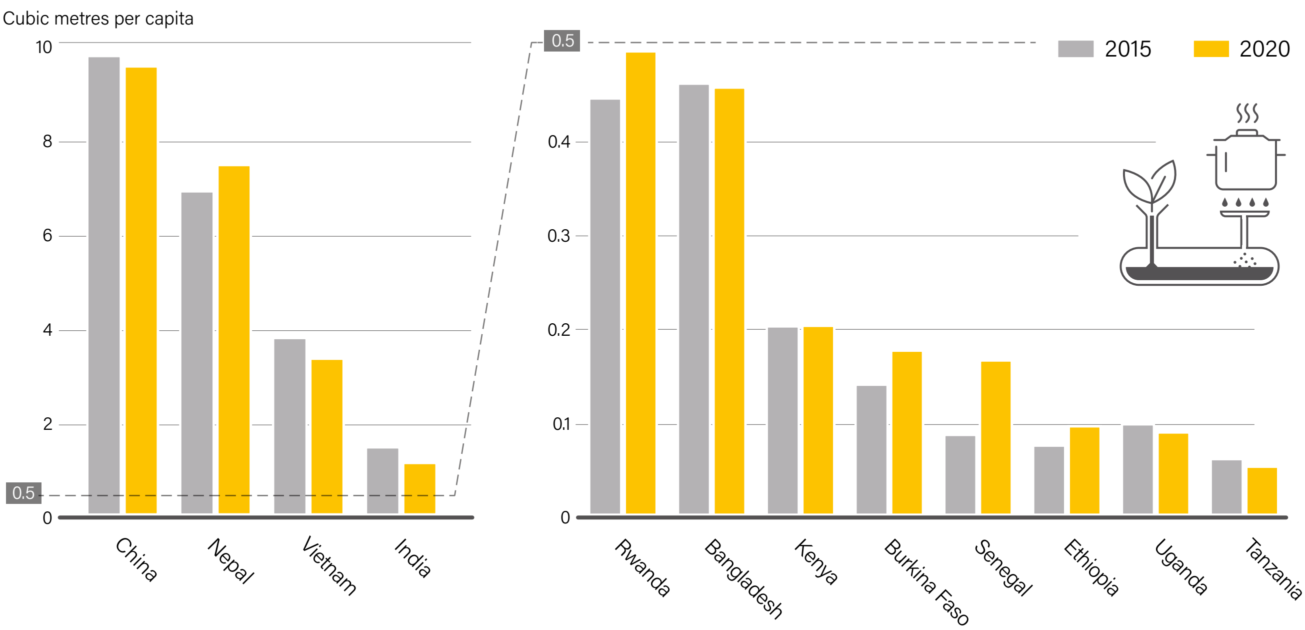
With traditional uses of biomass still dominant in cooking in most of the developing world, **improved biomass cook stoves**[i] have been a focus of donor, non-governmental and government programmes for several decades.[65] Of the many types of improved cook stoves, very few meet World Health Organization guidelines for emissions.[66] However, no comprehensive data are available on distribution of the stoves, and data for 2020 are particularly scarce.

Recent programmes include the Bangladesh Improved Cookstove Programme, initiated jointly by Bangladesh's Infrastructure Development Company Limited (IDCOL) and the World Bank in 2013; by the end of 2020, the programme had distributed 2.4 million improved cook stoves, with a target of 5 million by the end of 2023.[67] On a smaller scale, in Kenya, the Results-Based Finance programme of the Energising Development (EnDev) multi-donor partnership delivered around 80,000 improved biomass and ethanol cook stoves (as well as 21,000 LPG stoves) between 2016 and 2019, reaching half a million people.[68] A new phase starting in January 2020 aimed to deliver 40,000 additional highly performing cook stoves by March 2021.[69]

Biogas can be a solution in areas where agricultural residues, animal or human wastes are locally available.[70] An estimated 125 million people use biogas for cooking globally, a figure that has been broadly constant over the last decade.[71] Most people cooking with biogas live in Asia (99.7%), with the bulk of the production per capita occurring in China, Nepal, Vietnam, India and Bangladesh.[72] (→ *See Figure 40.*)

i An improved cook stove is a biomass stove that is more efficient and emits less emissions than a traditional stove or three-stone fire. An array of diverse technologies exist, which vary considerably in terms of efficiency and emissions.

FIGURE 40.
Per Capita Production of Biogas for Cooking, Selected Countries, 2015 and 2020



Source: IRENA. See endnote 72 for this chapter.

While most of the 125 million people who cook with biogas live in Asia, African biogas production has increased 28% in the last five years.

In Africa, production remains small but increased 28% between 2015 and 2020.[73] This occurred mostly in Rwanda, Senegal and the five countries covered by the Africa Biogas Partnership Programme (Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda). More than 38,000 biogas digesters were installed during Phase II of the programme, implemented by Hivos and SNV between 2014 and 2019 with funding from EnDev and the Netherlands Directorate-General for International Cooperation.[74] Although well below the targeted 100,000 installations, the programme was successful in establishing markets for private sector biogas companies.[75] Funding was approved for a follow-up biogas programme funded by the Dutch government through EnDev, expected to start during 2021.[76]

Electric cooking is already cost effective for many people connected to national grids or off-grid small-scale hydropower, and battery-supported electric cooking linked to solar-hybrid mini-grids is expected to become cost effective by 2025.[77] To achieve this, the focus has been on linking renewables-based solutions to efficient cooking appliances such as electric pressure cookers (which greatly reduce the cost of electric cooking compared to traditional electric hotplates) and on reducing the demand on the system during peak times.[78] However, high upfront equipment costs remain a challenge, which could be addressed by "Pay-As-You-Go" (PAYGo) providers adding these cookers to the services they offer.[79]

The electric cooking market is in the early stages of development, especially for the direct current appliances required for off-grid settings.[80] In 2020, the Global LEAP Awards launched the first-ever competition for highly energy-efficient electric pressure cookers suitable for use in both off-grid and weak-grid settings.[81]

Solar cookers (such as parabolic cookers and solar ovens) offer another clean cooking solution. Globally, more than 4 million solar cookers had been distributed by early 2021, providing clean cooking solutions to an estimated 14.3 million people.[82]

DISTRIBUTED RENEWABLES FOR ELECTRICITY ACCESS

Pico solar[i] and **solar home systems** have played a growing role in the provision of energy access, with more than 180 million units sold over the last decade.[83] Apart from bringing electricity to the homes of over 100 million people, these units allow some 2.6 million people to run a business.[84] During the COVID-19 pandemic, many countries officially designated off-grid solar companies as "essential services", enabling them to operate at least partly during lockdowns.[85]

The global market for off-grid solar systems grew a record 13% in 2019, the highest increase of the preceding five-year period.[86] Similar, if not higher, expansion had been expected by the industry in 2020, but the pandemic led to a significant slowdown.[87] Sales of affiliated[ii] systems fell 22% compared to 2019, with cash sales (especially of solar lanterns) experiencing the biggest reductions (30%), while PAYGo sales declined only 1.7%.[88] The business operations of off-grid solar companies were disrupted because of lockdown measures that restricted the movement of goods and sales staff, as well as supply chain issues.[89] While businesses were affected mainly during the early months of the crisis, two-thirds of off-grid companies still reported lower sales in the second half of 2020 compared to 2019.[90]

Around 6.6 million affiliated off-grid lighting products were sold during 2020.[91] Portable solar lanterns (up to 3 W) accounted for 64% of this, with another 18% of sales for larger light systems of up to 10 W.[92] In addition, 1.2 million solar home systems were sold, with all but 49,000 systems having an output smaller than 100 W.[93] Appliance sales linked to off-grid solar products also decreased, with a total of 946,000 appliances sold in 2020 compared to almost 1.2 million in 2020.[94] Television sales proved more resilient than fan sales, with decreases of 3% and 31%

i Pico solar systems/products refer to off-grid systems rated up to 10 W, used primarily for basic lighting and mobile phone charging.

ii Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process.

respectively.[95] Solar water pump sales plunged more than 60%, although this was due at least in part to bulk procurement in 2019, which did not happen in 2020.[96]

Regionally, the biggest reduction in off-grid solar product sales in 2020 occurred in South Asia, with a 51% drop compared to 2019.[97] East Africa, which remained by far the largest market, saw a dip of 10% (mostly in cash sales), whereas sales in Central Africa and West Africa increased despite the pandemic, up 22% and 9% respectively.[98] West Africa experienced a small reduction (3.6%) in cash sales, but PAYGo sales increased 23%, while in Central Africa both segments increased (up 8% for cash sales and 71% for PAYGo sales).[99] (→ See Figure 41.)

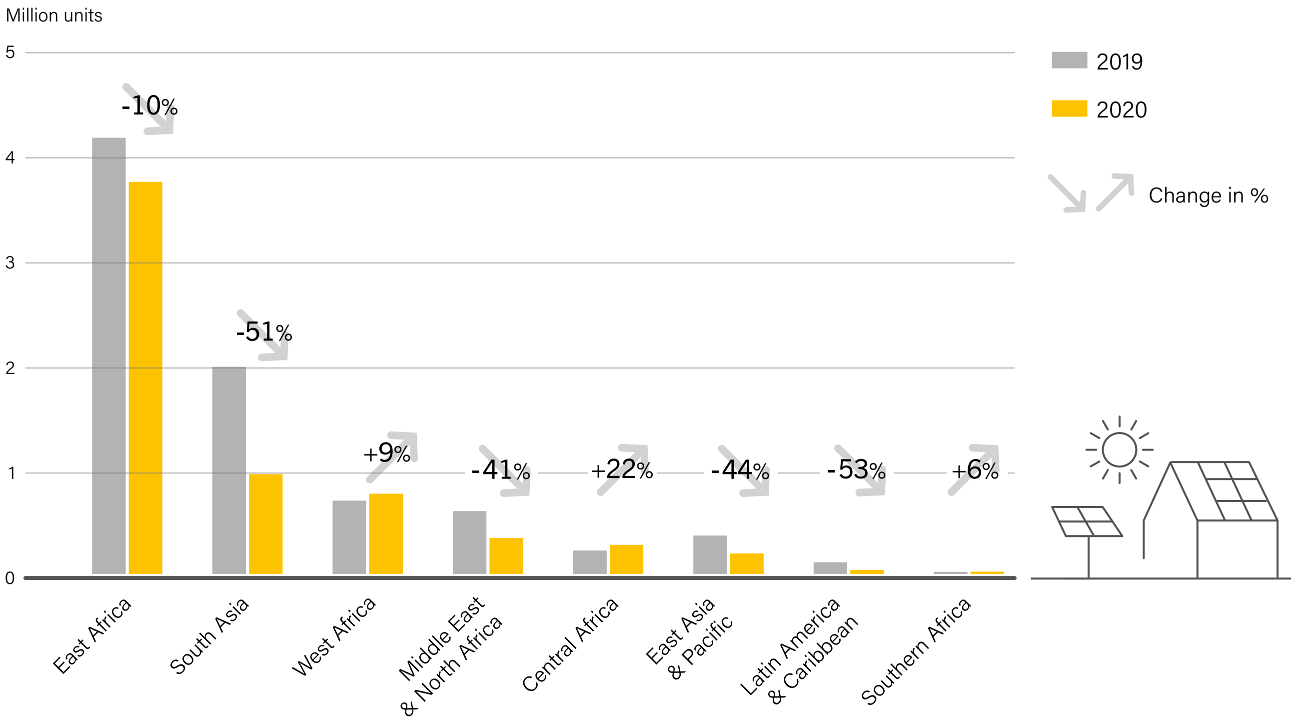
Kenya, India, Ethiopia, Uganda and Nigeria were the top five off-grid solar markets globally by sales volumes.[100] The largest reductions occurred in India, where sales dropped 54% in 2020 (the country had already experienced a 31% reduction in 2019).[101] In Ethiopia, where off-grid solar sales had more than doubled in 2019 to just over 1 million products, sales dropped 40% in 2020.[102] Nigeria was the only one of the top five markets where sales increased in 2020, although by less than 1% (compared to a 5% increase in 2019).[103]

In addition to stand-alone solar systems, **renewables-based mini-grids** are recognised increasingly as an important facilitator of energy access.[104] Of the identified 5,544 mini-grids operating in energy access settings in March 2020 (with a total capacity of 2.37 GW), 87% were renewables-based.[105] Solar PV has been the fastest growing mini-grid technology, incorporated into 55% of mini-grids in 2019 compared to only 10% in 2009.[106] (→ *See Figure 42.*)

Mini-grid development used to be driven by utilities and non-governmental organisations (NGOs), but in recent years private developers also have entered the space.[107] In 12 sub-Saharan African countries with high electricity access deficits, renewables-based mini-grid connections installed by private developers increased from just 2,000 in 2016 to more than 41,000 in 2019, mostly in East Africa.[108] Over 200,000 people, as well as businesses, schools and health facilities, have been connected through these mini-grids.[109] The rapid growth has been linked to policy and regulatory changes, as well as to donor programmes that have provided incentives to developers.[110]

While most mini-grid developers are small-scale companies or start-ups, some are beginning to reach scale; in late 2020, Husk Power became the first company globally to install 100 community mini-grids, which also serve 5,000 business customers.[111] In recent years, large and international corporations such as EDF, Enel, ENGIE, Iberdrola, Shell and Tokyo Electric also have joined the mini-grid market, generally by taking over or investing in smaller

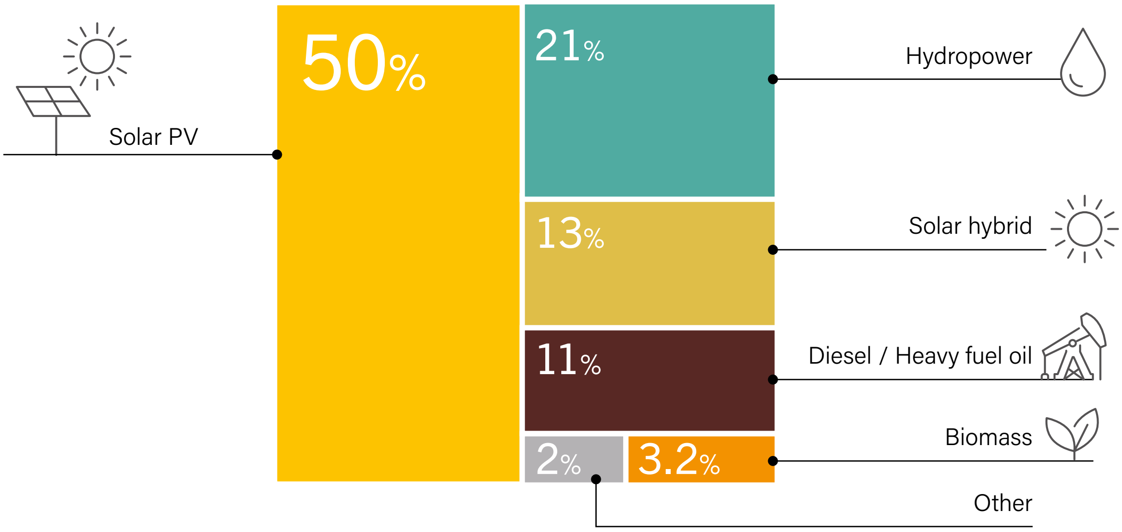
FIGURE 41.
Sales Volumes of Affiliated Off-Grid Solar Systems, Selected Regions, 2019 and 2020



Note: Affiliated products are those sold by companies that are connected to any of the partner organisations involved in the semi-annual GOGLA sales data reporting process, including GOGLA members and companies selling products that meet Lighting Global Quality Standards.

Source: GOGLA. See endnote 99 for this chapter.

FIGURE 42.
Shares of Installed Mini-Grids by Technology, March 2020



Note: Figure refers to currently operational (functioning) mini-grids in energy access settings. Solar hybrid mini-grids combine solar PV with other power sources such has hydropower or wind power but most frequently with diesel generators. Where totals do not add up, the difference is due to rounding.
Source: Mini-Grids Partnership. See endnote 106 for this chapter.

companies.[112] Although private sector interest in mini-grids has grown, most developers have relied on public funding such as grants or results-based financing from donors, although some form of subsidy is also common for grid-based electricity.[113]

In Africa, the COVID-19 pandemic impacted the mini-grid sector more than the rest of the solar industry in 2020 due to complex logistics and difficulty accessing remote areas.[114] Many projects under development or being tendered were slowed or put on hold.[115] However, some progress occurred. Nigeria, which has one of the largest mini-grid support programmes under its National Electrification Project, aims to electrify 300,000 households and 30,000 local enterprises through private sector-driven solar-hybrid mini-grids by 2023.[116] With funding from the World Bank and the African Development Bank, it offers minimum subsidy tenders and performance-based grants.[117] In 2020, Nigeria's Rural Electrification Authority (REA) commissioned several installations under the project, including two solar hybrid mini-grids with a combined capacity of 135 kW developed by Renewvia Energy and a 234 kW solar hybrid mini-grid installed by local developer GVE Projects Limited that will power nearly 2,000 households.[118]

Nigeria's REA also developed several solar mini-grids for use at hospitals and other healthcare facilities as an emergency response to COVID-19.[119] Health facilities were a focus of several other donor-driven mini-grid initiatives as well. Power Africa, funded by USAID, redirected USD 4.1 million in grants to off-grid companies in 2020 for rural and peri-urban health clinic electrification, including through mini-grids.[120] In Lesotho, OnePower together with SustainSolar aim to supply seven containerised solar mini-grids under Power Africa to electrify several clinics.[121] Recent mini-grid activity has occurred in several countries of francophone West Africa. Benin in 2020 selected 11 companies to construct solar mini-grids serving 128 localities under its Off-Grid Clean Energy Facility.[122] In early 2021, Togo's Rural Electrification and Renewable Energy Agency announced the first 129 localities to be electrified by its mini-grid programme, and Senegal's Rural Electrification Agency launched a tender for the electrification of 117 villages through solar mini-grids.[123]

In East Africa, Kenya has been the most active mini-grid market with almost 200 sites in operation in 2019.[124] Renewvia Energy commissioned another three solar mini grids in 2020, with a total capacity of 87.6 kW in Kenya's Turkana and Marsabit counties, serving two communities and a refugee camp in an electrification project supported through the EnDev RBF facility.[125] Meanwhile Kenya Power launched a tendering process in early 2021 to hybridise 23 older diesel mini-grids, mostly with solar.[126] In Central Africa, a 1.3 MW solar-hybrid mini-grid installed by Nuru in the city of Goma, in the Democratic Republic of Congo, was put into service in February 2020.[127]

In Asia, Bangladesh's 170 kW BREL solar mini-grid project came online in early 2020, financed by IDCOL as part of its solar mini-grids initiative for islands and other remote areas.[128] This brought the total under this initiative to 27 projects, with a combined capacity of 5.6 MW.[129] In the Americas, in late 2020, the national Rural Electrification Program (PERMER) in Argentina's remote Rio Negro province repowered two mini-grids (22 kW and 40 kW), which previously ran on LPG, with solar PV and wind power as well as storage; this increased electricity access for 100 families from 16 to 24 hours.[130]

BUSINESS MODEL INNOVATIONS

In most developing countries, grid-based electricity access is the domain of state-owned electric utilities. In contrast, off-grid renewables are much more reliant on the private sector and on innovative business models. Business models vary greatly among off-grid renewables providers. Over the last decade, PAYGo systems have enabled energy access for millions of off-grid consumers, mostly through solar home systems, although PAYGo also has made inroads into productive uses such as solar water pumping and even clean cooking. PAYGo companies typically provide either a "lease-to-own" or a "usage-based" payment model.[131]

In 2020, 84% of affiliated solar home systems were sold on a PAYGo basis.[132] Traditionally, many PAYGo companies providing solar home systems focused on basic services such as lighting and phone charging, or possibly a small television. Increasingly, companies have expanded their offerings to bigger systems that power a broader range of appliances, such as fans and refrigerators, as well as bundling in other services.

For example, the product range of M-Kopa, which operates in Kenya, Nigeria and Uganda, includes three sizes of solar home systems, solar fridges for small businesses and smartphones. For customers who have made reliable payments on a PAYGo product, the company also offers services such as clean biomass cook stoves, entertainment packages and even financial services such as loans (for example, for hospital stays).[133] Bboxx (UK) also has branched out into home entertainment and joined forces in 2020 with the French media company Canal+ to sell televisions and decoders with its solar home systems in Togo and the Democratic Republic of the Congo.[134]

While many companies have offered higher-value services for better-off customer segments, affordability remains a major problem for many communities, especially in more-remote rural areas with high levels of poverty. In August 2020, Bboxx launched a new product (bPower20) – a package of 20 W solar panels and new improved batteries – targeted specifically at low-income rural households; with it, the company aims to reach a wider segment of the global market.[135] The initial target markets are the Democratic Republic of the Congo, Kenya, Rwanda and Togo, but Bboxx aims to expand into further markets in 2021.[136]

Pico solar and solar home systems remain the most common renewables-based electricity access solutions using PAYGo models, with 2.2 million affiliated systems sold worldwide in 2020.[137] In Rwanda, a new pilot PAYGo solution was launched in October 2020 when ENGIE Energy Access teamed up with OffGridBox to deploy containerised solar PAYGo.[138] This supplies clean drinking water, electricity for recharging and Wi-Fi from solar-powered containers equipped with electricity storage, water purification systems and a WI-FI hotspot.[139] Customers get a battery, LED (light-emitting diode) lights, phone chargers and a water canister and pay a small fee for recharging and refilling from the system.[140]

Beyond households, a number of PAYGo solutions exist in agriculture, particularly for solar irrigation. SunCulture, which already offered solar irrigation kits on a "pay-as-you-grow" basis in Kenya, announced a new partnership in December 2020 with Bboxx and EDF to bring solar irrigation to 5,000 farmers in Togo using the PAYGo model.[141] The government of Togo will provide a subsidy to halve the costs of the systems to make them more affordable for farmers.[142]

PAYGo also has advanced in the clean cooking sector, for example for ethanol, a renewable cooking fuel that is relatively easy to distribute.[143] The traditional model has been centralised bottling and bulk distribution, but in 2019 KOKO Networks launched a new **decentralised distribution model** with the fuel infrastructure company Vivo Energy in Nairobi, Kenya.[144] Customers pay digitally for the fuel, which is then dispensed by 700 ethanol vending machines (Koko Points) in corner shops across the city.[145] KOKO Networks also sells its own ethanol stoves, and by August 2020 it was serving 50,000 households.[146] In June 2020, the company was rewarded a results-based finance project for a further 250,000 connections under the Dutch SDG 7 programme.[147]

Most clean cooking PAYGo is dominated by small LPG start-ups – such as KopaGas and PayGo Energy – but in July 2020 ENGIE Africa, a major player, announced a new partnership with the PAYGo gas company PayGas in South Africa to support two new LPG refilling stations that can service 4,000 homes.[148] PayGas plans to scale its operations to other African countries.[149]

Similar to the solar irrigation sector, public funding is often needed to support private sector business models that operate in the clean cooking sector. To drive further innovation in clean cooking, in 2020 the Clean Cooking Alliance launched the Cooking Industry Catalyst, which aims to demonstrate new viable and scalable business models.[150]

Business models for mini-grids for rural electrification vary, with different combinations and approaches to ownership and operation, service delivery and billing. Many mini-grids are owned by national utilities, whereas others are under private, community or hybrid ownership.[151] There is no proven business model that works everywhere, and as of late 2020 no private mini-grid company was profitable.[152] In general, revenues per customer remain low, and low consumption is a systemic problem.[153] Expanding consumption is critical to the success of mini-grid business models, with many companies focusing on developing productive uses, which also are increasingly supported through donor funding.

In 2020, the Energy and Environment Partnership Trust Fund (EEP Africa) approved funding to support several innovative mini-grid business models that include productive uses. In Rwanda, EEP is supporting East African Power in developing a hydropower plant and mini-grid that will service not only households but also community buildings and an agricultural centre of excellence, as well as a women's aquaculture business to improve socio-economic development.[154] In Uganda, ENGIE Equatorial is receiving EEP support to deploy four solar-hybrid mini-grids, with an industrial park as an anchor client.[155] The project also includes an incubation programme that enables local women entrepreneurs to access asset financing for productive use appliances.[156]

Some companies involve communities to identify needs and how to grow demand. Miowna SA, a joint venture of PowerGen and Sunkofa Energy, won a competitive tender run by the Benin Off-Grid Clean Energy Facility in 2020 to electrify 40 villages in the country.[157] Miowna worked with communities and other local stakeholders to identify innovative value propositions through productive uses that will help increase local incomes and make the mini-grids viable.[158]

More than
2 million solar products
were sold on a pay-as-you-go basis in 2020.

FINANCING FOR RENEWABLES-BASED ENERGY ACCESS

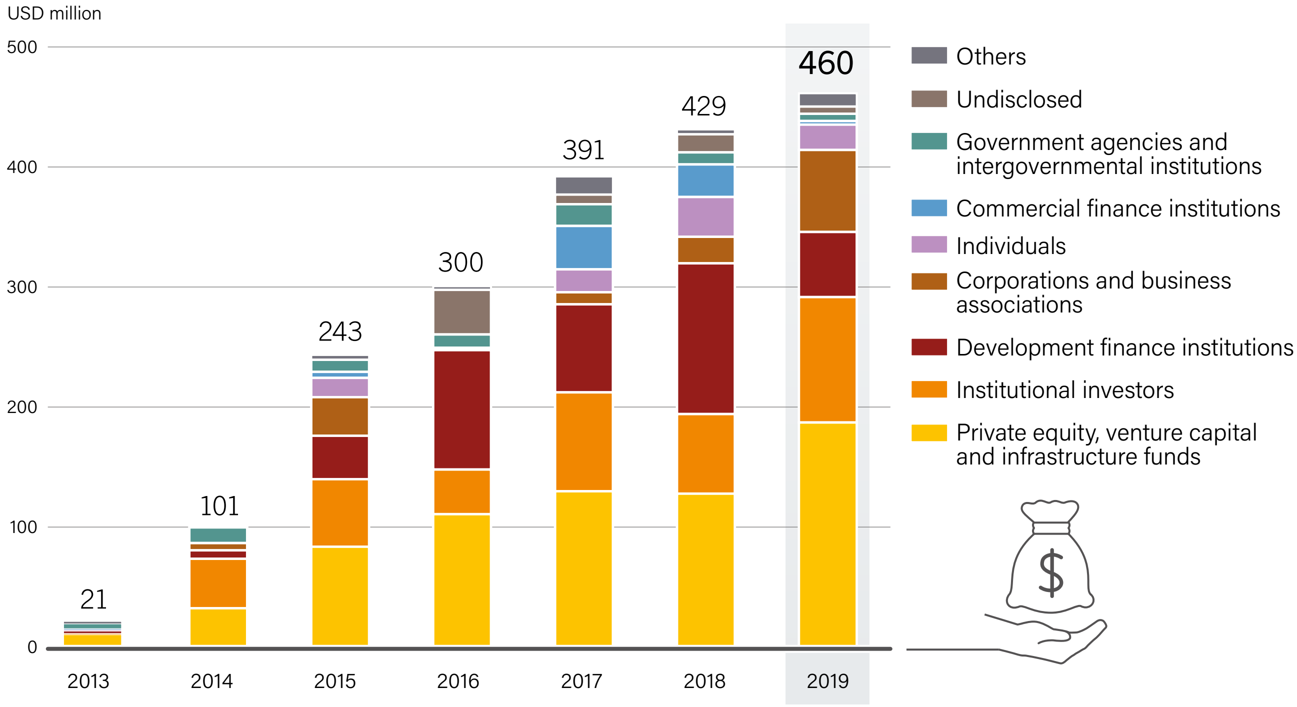
With less than a decade left before 2030, even prior to the COVID-19 pandemic the total investment in energy access was far below what has been estimated as needed to achieve SDG 7.[159] The energy access finance that was available mostly bypassed the countries with the greatest access deficit, and very little of the already small amount of finance was dedicated specifically to renewables-based energy access systems.[160]

Clean cooking suffers from the largest investment gap overall and remains well below the estimated annual USD 4.5 billion required to achieve universal access by 2030.[161] However, positive developments have occurred, with overall finance for clean cooking tripling from USD 48 million in 2017 to USD 131 million in 2018 (most recent data available).[162] Most clean cooking funding comes from the public sector, with international donor and development finance institutions providing two-thirds of financing in 2018, nearly half of it as grants.[163] The public sector is also very active in the delivery of the funded activities, with 44% of the funding passing through public channels (compared to only 14% for electricity access).[164] Private finance plays a relatively small role, with just under one-quarter of funding in 2018, while carbon markets provided another 16%.[165]

Finance for electricity access in the 20 countries with the highest access deficit increased 25% between 2017 and 2018 to reach USD 43.6 billion.[166] In some countries, more than 95% of electricity finance went to grid-connected renewables, mini-grids and off-grid solutions; however, these accounted for only 14% of the total energy access funding in 2018, and, overall, renewables-based systems received only around 1.5% of the total.[167]

Unlike in clean cooking, private investment has been a key driver of off-grid electricity access, accounting for 78% of funding in 2019.[168] While public financing halved compared to the previous year, major increases in funding occurred from several types of private investors. Private equity, venture capital, infrastructure fund and institutional investors increased their off-grid funding from USD 193 million in 2018 to USD 290 million in 2019, while corporations more than tripled their investment during this period, from USD 22 million to USD 68 million.[169] The latter focused mostly on East Africa and South-East Asia.[170] (→ *See Figure 43.*)

FIGURE 43.
Annual Commitments to Off-Grid Renewable Energy, by Type of Investor, 2013-2019



Source: IRENA and CPI. See endnote 170 for this chapter.

The COVID-19 pandemic affected finance flows to the energy access sector, particularly mini-grids.[171] Some attempts have been made to help companies struggling with these effects. The Energy Access Relief Fund was established with the aim of raising USD 100 million to provide unsecured, low-cost, subsidised loans, with funding from donors including the Green Climate Fund.[172] In late 2020, the African Development Bank launched the USD 50 million COVID-19 Off-Grid Recovery Platform to provide relief and recovery capital to energy access businesses.[173] Additionally, the Shine Campaign made available grants of between USD 3,000 and USD 10,000 to smaller players.[174]

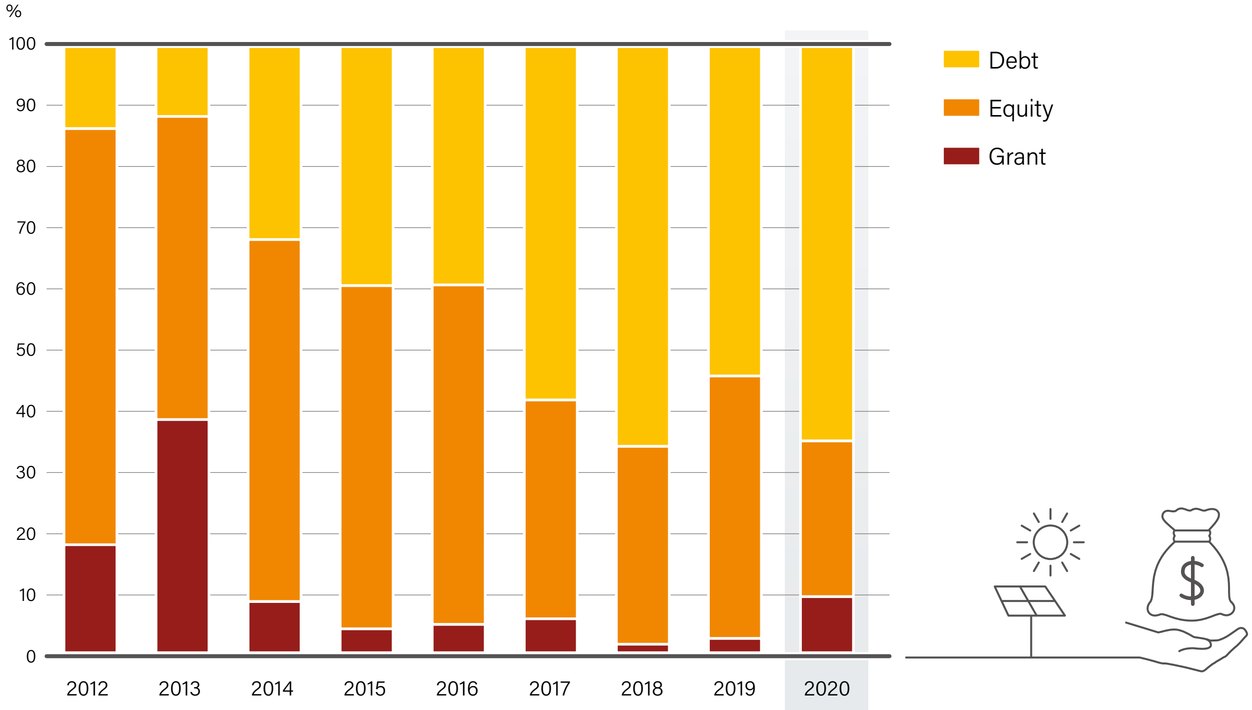
CLEAN COOKING SECTOR FINANCING

In 2019, 25 clean cooking companies were able to raise USD 70 million, a 63% increase compared to the 32 companies that raised USD 43 million in 2018.[175] Around three-quarters of the funding went to companies offering renewables-based solutions, with biomass stoves and biogas accounting for 25% and 19% respectively of the capital raised.[176]

In 2020 and early 2021, several renewables-focused clean cooking companies managed to raise new capital. Improved cook stove manufacturer BURN (Kenya) partnered with the crowdfunding platform Bettervest (Germany) in an attempt to raise more than EUR 1 million (USD 1.2 million) in working capital.[177] Bettervest also raised over EUR 300,000 (USD 360,000) for Kenyan biomass briquette company Sanergy in early 2021.[178] One of the companies involved in the African Biogas Partnership

Investment in the **largest clean cooking companies** increased 63% in 2019.

FIGURE 44.
Shares of Off-Grid Solar Financing, by Type of Funding, 2012-2020



Note: The data cover financing for off-grid solar such as solar home systems, solar lanterns and solar-powered appliances (e.g., water pumps) but exclude solar mini-grids.
Source: GOGLA. See endnote 186 for this chapter.

Programme, Sistema.bio, received a USD 1.35 million loan facility from the Dutch Development Bank FMO in late 2020 to scale up its operations in Kenya.[179] In addition, Connected Energy, which offers a smart meter specifically for biogas systems, attracted USD 1.25 million in funding.[180]

Although sales revenues provided 80% of the total revenues of clean cooking companies in 2019, this was being supplemented by grants and results-based finance, as well as carbon offset revenues.[181] The latter experienced a five-fold increase between 2018 and 2019 to USD 5.2 million, with almost all of the carbon offset funding going to biomass stove manufacturers.[182]

OFF-GRID ELECTRICITY ACCESS SECTOR FINANCING

The COVID-19 pandemic impacted financing for off-grid companies in 2020, but not to the extent that was initially feared. In the case of off-grid solar, the overall volume of funding for affiliated companies was up slightly at USD 316 million compared to USD 312 million in 2019.[183] The main impact has been a reduction in equity funding of 46%, due mainly to problems in carrying out on-the-ground diligence, which made it difficult to complete equity transactions.[184] Most of this reduction was due to strategic corporate deals falling from USD 76 million in 2019 to USD 8.5 million in 2020.[185] The reduction in equity funding was compensated by an increase in both debt and grant funding, mostly from governments and development finance institutions.[186] (→ *See Figure 44.*)

Much of the 2020 off-grid solar funding flowed to Africa. Lumos received USD 35 million in financing from the US International Development Finance Corporation to further expand in Nigeria.[187] Bboxx secured a USD 4 million loan from the Off-Grid Energy Access Fund of the Energy Inclusion Facility to expand in the Democratic Republic of the Congo.[188] Oolu closed a USD 8.5 million Series B investment round involving several impact investors to further develop its operations in West Africa.[189] UpOwa signed a EUR 3 million (USD 3.6 million) debt facility with EDFI ElectriFI to enable expansion in Cameroon.[190] Easy Solar, which operates in Sierra Leone and Liberia, announced a USD 5 million round of funding including a USD 3 million Series A Equity led by global impact investor Acumen and Dutch development FMO, in addition to a USD 2 million debt facility from investment platform Trine.[191] Fenix International, a subsidiary of ENGIE, secured a USD 12.5 million loan from the European Investment Bank to support the deployment of 240,000 solar home systems in Uganda.[192]

Energy+, a less well-established Malian-owned and managed off-grid solar company, secured USD 1 million through a combination of debt, equity and grant financing from Venturebuilder, Cordaid and the US African Development Foundation.[193] Easy Solar, together with Altech of the Democratic Republic of the Congo and Deevabits of Kenya, also received unspecified loans from the newly established Sima Angaza Distributor Finance Fund, which aims to provide capital for the last-mile distribution sector.[194] In addition to the finance provided to companies focused on household solar systems, solar-powered irrigation supplier SunCulture closed a Series A investment round of USD 14 million in late 2020; investors included Energy Access Ventures, Électricité de France, Acumen Capital Partners and Dream Project Incubators.[195]

Crowdfunding continued to play an important role for off-grid solar companies. In the first half of 2020, crowdfunding transactions were mostly refinancing of earlier loans.[196] For example, the initial response of UK crowdfunding platform Energise Africa to the pandemic focused on refinancing the existing debt of seven companies, raising just over GBP 1.5 million (USD 2.0 million).[197] By late 2020, the platform had not only resumed its normal lending activities but also launched its first funding campaigns both for solar projects in the small and medium-sized enterprise sector and outside of Africa, raising a total of GBP 1.9 million (USD 2.6 million) for Candi Solar to provide solar energy to such enterprises in South Africa and India.[198]

While funding for the off-grid solar sector has held up during the COVID crisis, funding for the mini-grid sector dropped by almost a third, with the biggest reduction occurring in equity finance.[199] However, by late 2020 some activity had resumed, with, for example, Dutch development bank FMO investing USD 5 million in Husk Power in October 2020.[200] Winch Energy in early 2021 mobilised USD 16 million for 49 mini-grids in Sierra Leone and Uganda through NEoT Off-grid Africa, a platform developed by Électricité de France, Mitsubishi and Meridiam.[201] The funding includes some grants through development aid from Germany, the European Union (EU) and the United Kingdom.[202] Also in early 2021, Nigerian start-up Havenhill Synergy obtained USD 4.6 million local currency funding for 22 solar mini-grids from the Chapel Hill Denham Nigeria Infrastructure Debt Fund.[203]

Funding in 2020 was not just limited to companies supplying renewables equipment but also those providing enabling services. For example, Angaza, which sells software for solar PAYGo solutions, raised USD 13.5 million from East African energy impact fund KawiSafi Ventures and Total Carbon Neutrality Ventures, the venture capital arm of energy company Total (France).[204] Total was also one of several investors providing USD 12 million Series A financing to SparkMeter, a provider of grid management services to hard-to-reach communities.[205] Acumen invested an unspecified amount in Solaris Offgrid, a social enterprise providing PAYGo software.[206]

A new innovative financing instrument was launched in early 2021 by South Pole and Positive.Capital Partners with the support of several foundations.[207] The D-REC Initiative will provide funding for renewables-based energy access projects by selling third-party-certified renewable energy certificates to companies interested in going beyond their corporate renewables commitments.[208]

The Green Climate Fund committed
USD 300 million
to renewables-based energy access projects in 2020.

PUBLIC FUNDING AND INITIATIVES

While the private sector has been driving much of electricity access funding, development finance institutions (DFIs), bilateral donors and other funders such as philanthropic foundations continue to commit funding to energy access. This funding takes various forms including grants, results-based finance, guarantees, loans and other debt facilities and can be used to support governments, development partners such as NGOs, or private sector companies in implementing energy access programmes.

Off-grid energy access funding by DFIs has consistently lagged behind funding for on-grid electrification.[209] In 2019, DFIs committed an estimated USD 1 billion – around 12% of their total energy funding commitments – to off-grid electricity access.[210] DFI funding for clean cooking, meanwhile, totalled only USD 78 million in 2018, even though the lack of access to clean cooking affects many more people than the lack of electricity access.[211] In 2020, most of the significant new energy access commitments from DFIs were again focused on electricity access, with a few exceptions as set out below.

The World Bank approved USD 150 million in financing to improve access to modern energy for households, enterprises and public institutions in Rwanda, both on- and off-grid.[212] Although the majority of the funding will go to electricity access, the project includes the Bank's largest clean cooking commitment in Africa, and the first project co-financed by the recently launched Clean Cooking Fund (CCF).[213] The CCF will provide USD 20 million for clean cooking, with USD 10 million as grants and USD 10 million as loans.[214] The project targets 2.15 million people, leveraging an additional USD 30 million in public and private sector investments.[215]

In Burundi, the World Bank agreed to provide USD 100 million in grants for the Solar Energy in Local Communities programme (SOLEIL), which will double the rate of electricity access in the country, with a focus on rural areas.[216] The World Bank also approved USD 52.9 million in financing for the Lesotho Renewable Energy and Energy Access Project, aimed at expanding electricity access in remote areas of the country.[217] In Haiti, the World Bank approved USD 6.9 million additional financing for the Haiti:

Renewable Energy for All project, specifically to provide renewable energy solutions for at least four priority healthcare facilities involved in the response to COVID-19.[218]

The African Development Bank (AfDB) made its first significant investment in clean cooking in late 2020 with a USD 5 million commitment to the SPARK+ Africa Fund, with another USD 10 million for the Fund coming from the European Commission.[219] SPARK+ Africa, which targets total investment of USD 50-70 million, is a new impact investment fund launched by Enabling Qapital and the Clean Cooking Alliance to provide debt and equity financing to enterprises that manufacture, distribute and finance clean cooking solutions across sub-Saharan Africa.[220]

The AfDB, jointly with the European Commission, KfW, the Clean Technology Fund, Norfund and other investors, also committed a total of USD 160 million to the first close of the Facility for Energy Inclusion, a fund to improve electricity access across Africa through small-scale renewable energy and mini-grid projects.[221] To further support mini-grids, the AfDB approved a USD 7 million grant from the Sustainable Energy Fund for Africa (SEFA) for technical assistance.[222]

The European Union provided a EUR 62 million (USD 76 million) de-risking guarantee to COFIDES, the Spanish development finance institution, and AECID, the Spanish development agency, for their renewable energy support programme for rural sub-Saharan Africa.[223] The guarantee will help generate a total investment of more than EUR 800 million (USD 983 million) and is expected to provide electricity to at least 180,000 new people in rural areas.[224] A EUR 62 million (USD 76 million) guarantee agreement with France's Agence Française de Développement in partnership with Italy's Cassa Depositi e Prestiti is expected to provide electricity access to another more than 1 million people.[225]

Sweden's Beyond the Grid Fund for Africa (BGFA) expanded to Uganda, with initial funding of EUR 11.8 million (USD 14.5 million) for a six-year programme.[226] The Fund now operates in five countries, with total funding of EUR 59 million (USD 73 million).[227] Sweden's SIDA together with the Nordic Environment Finance Corporation announced in September 2020 the allocation of SEK 5 million (USD 0.6 million) for a new Scaling of Clean Cooking Solutions programme in Zambia. The aim is to accelerate the use of higher-tier cooking solutions.[228]

Climate finance has become a significant funding source for energy access, and the Green Climate Fund (GCF) approved three projects in 2020 for just over USD 300 million.[229] Although the GCF provided funding in 2019 for clean cooking projects in Bangladesh, Kenya and Senegal, in 2020 the main energy access projects were focused on mini-grids. They included: a USD 45.7 million project to develop 22 community-scale solar plus battery storage micro-grids in southern Haiti to provide an alternative to diesel generators; a USD 235.5 million project in Senegal to mobilise private sector participation in solar-powered mini-grids for 1,000 remote villages; and USD 21.4 million to kickstart a renewable energy market in rural Afghanistan and lay the groundwork for developing a mini-grid sector (including three solar mini-grids).[230] In addition, the GCF approved USD 60 million for equity and co-financing of the Energy Access Relief Fund, open to both electricity and clean cooking enterprises.[231]

PHILANTHROPIC AND INNOVATION FUNDING

Significant announcements in **philanthropic funding** in 2020 included the Rockefeller Foundation committing USD 1 billion over a three-year period to catalyse a green recovery from COVID-19, building on Rockefeller's existing work on mini-grids.[232] A key focal area is scaling distributed renewable energy across developing countries, in addition to equitable access to COVID-19 tests and vaccines.[233]

The IKEA Foundation, jointly with UK Aid, launched the Powering Renewable Energy Opportunities (PREO) programme in June 2020 to support productive use of energy projects in rural areas, with a focus on grants of up to EUR 300,000 (USD 368,473) for action learning and supply chain innovation.[234] The aim is to deliver a project portfolio of EUR 20 million (USD 24.6 million).[235]

Several foundations (Rockefeller Foundation, Shell Foundation and Good Energies) supported Sustainable Energy for All (SEforALL) in establishing the Universal Energy Facility to provide results-based finance. Other donors and partners include UK Aid, Power Africa, Carbon Trust and the Africa Minigrid Developers Association. In the first phase, USD 6 million in grant payments are available for mini-grid projects in Benin, Madagascar and Sierra Leone to deliver around 14,000 electricity connections.[236]

While renewables-based energy access solutions are already well developed and commercially available for many applications, funding also has been allocated to support **research and innovation**. In 2020, the Fair Cooling Fund, administered by Ashden and launched in November with USD 580,000 in funding from the philanthropic collaborative K-CEP, awarded grants of between USD 40,000 and USD 100,000 to seven innovators for the development of sustainable cooling options, including in off-grid areas.[237] Engineers Without Borders USA awarded seven grants in May 2020 of between USD 30,000 and USD 50,000 for its Chill Challenge to catalyse innovative solutions for off-grid refrigeration; projects included innovative solar chilling refrigeration and an icemaker powered by farm waste.[238]

To support innovation in clean cooking, the UK Aid-funded modern energy cooking services (MECS) programme awarded a total of GBP 826,000 (more than USD 1 million) to 14 community-scale pilots and market assessments to advance efficient electric cooking.[239] Renewables-focused pilots include funding for PowerCorner Zambia, which will explore powering rural electric cooking with solar mini-grids.[240]

NATIONAL POLICY DEVELOPMENTS

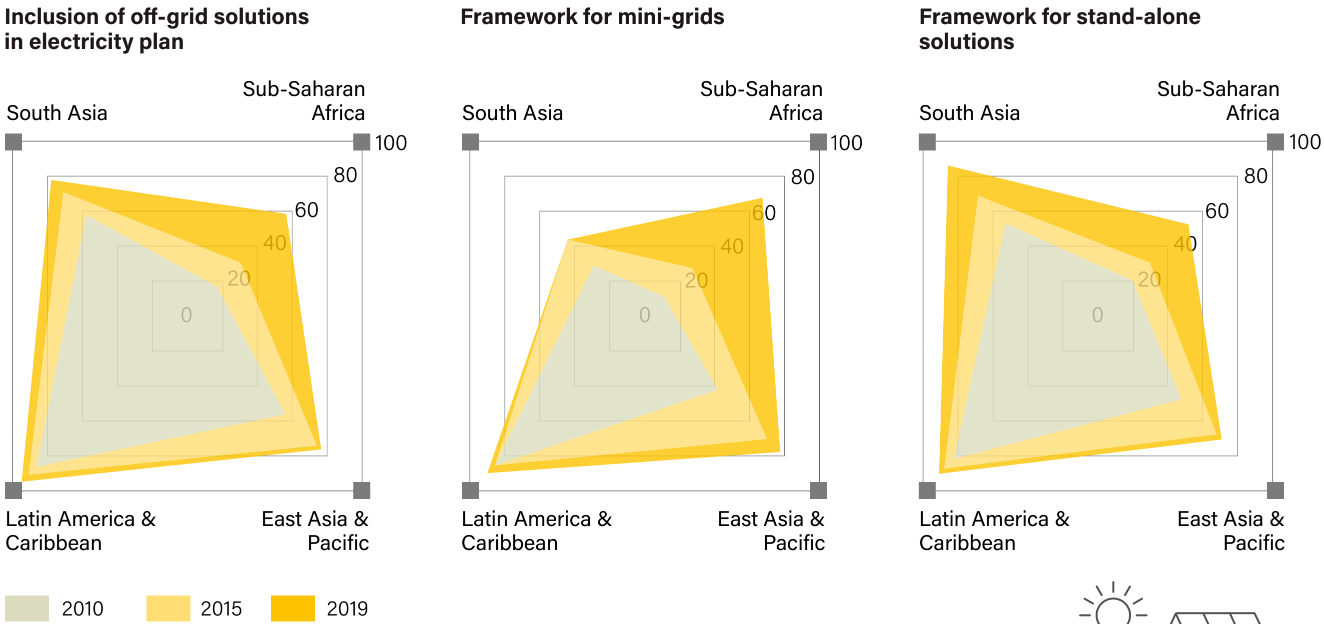
The scale-up of renewables-based systems for energy access requires conducive policy, regulatory and fiscal environments. This means national targets and plans that include off-grid renewables, combined with a variety of specific measures to support renewables – such as fiscal incentives (for example, lower VAT rates, import duty exemptions) and subsidies, quality standards for solar systems and cook stoves, and tariff regulations for mini-grids.[241] (→ *See Tables 7 and 8.*)

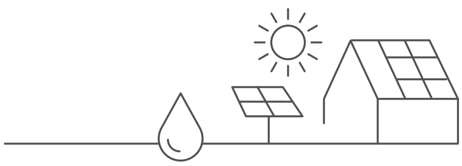
While many countries had electricity access targets in 2020, out of 64 selected countries with electricity access deficits, just under half had renewables-focused energy access targets.[242] (→ *See Table 7.*) Several countries also have included off-grid renewables targets for electricity access in their Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement.[243] Some countries have adopted new off-grid energy access targets linked to economic recovery plans in response to the COVID-19 pandemic. For example, Nigeria announced that it would support 5 million new solar home systems or mini-grid connections serving up to 25 million customers under the Solar Power Naija Initiative.[244] As part of the Nigerian Economic Stability Plan, the initiative also aims to create up to 250,000 jobs in the energy sector.[245]

Over the last decade, policy frameworks benefiting renewables for electricity access have made major advances, especially in sub-Saharan Africa where most countries had few relevant policies in 2010 or even as recently as 2015.[246] By 2019, policies such as the inclusion of off-grid solutions in electricity planning, regulatory and fiscal frameworks to promote mini-grids and stand-alone renewables had been implemented in many more countries.[247] (→ *See Figure 45.*)

Developments in 2020 include the Ethiopian Energy Authority's new directive to establish procedures for mini-grid licencing and tariff regulations.[248] Benin and Mali introduced VAT and import duty exemptions for solar.[249] Kenya, on the other hand, removed a VAT exemption for solar and wind power, including batteries, in

FIGURE 45.
Key Improvements in RISE Indicators, Selected Regions, 2010, 2015 and 2019





Note: RISE (Regulatory Indicators for Sustainable Energy) provides a set of indicators to help compare national policy and regulatory frameworks for sustainable energy. Indicators in the Figure assess average countries' policy and regulatory support for access to electricity across selected regions. RISE classifies countries into strong performers in the top third of the 0-100 score range, middle third performers, and weaker performers in the bottom third.

Source: ESMAP. See endnote 247 for this chapter.

its 2020 Finance Bill (although there were suggestions that this removal would be repealed in 2021).[250]

Solar irrigation received support in India, where the Kusum Yojana scheme offers farmers a 60% subsidy for installing solar pumps.[251] Togo announced that it would provide 50% subsidies for solar water pumps.[252]

Several donor programmes aim to further support off-grid renewables policy development, especially to improve the regulatory environment for mini-grids. In 2020, the Global Environment Facility, with the United Nations Development Programme as the lead agency, launched its new Africa Mini-grids Programme.[253] The programme focuses on policy de-risking to reduce costs and will initially support 11 African countries in addressing the key risks and underlying barriers holding back investment.[254]

Clean cooking tends to receive less attention from policy makers, as half of the population without access to clean cooking lives in countries that lack advanced policy frameworks (such as plans, standards and financial incentives) for clean cooking.[255] However, some countries have implemented these type of policy measures during the last decade, especially in Latin America, the Caribbean and South Asia.[256] In Africa, Benin, Kenya, Nigeria and Tanzania also have been catching up.[257] Clean cooking policies generally do not focus on renewables but support clean cooking solutions more broadly.

Several countries have covered clean cooking in their NDCs to address the significant climate impacts of deforestation from inefficient biomass cooking.[258] (→ *See Table 8.*) For example, the Nepalese government included new clean cooking targets in its second NDC submitted in December 2020.[259] In addition to 500,000 additional improved cook stoves and 200,000 household biogas systems, the NDC aims for 25% of households to cook with electricity by 2030, in tandem with targets to increase electricity generation from renewables.[260] To support a shift to electric cooking, the government decided in 2020 to waive the 15% customs duty for induction stoves and to introduce a 20% discount on electricity bills for induction stove users.[261]

India has supported major growth in clean cooking with LPG and in 2020 expanded the Pradhan Mantri Ujjwala Yojana scheme to provide subsidised LPG connections to 10 million additional poor households.[262] As part of the country's March 2020 COVID relief package, up to three free-of-cost LPG refills were provided to scheme recipients.[263] By contrast, in Kenya fiscal responses to the pandemic resulted in clean cook stoves and fuels losing the VAT exemption in place since 2016.[264] This was denounced by the clean cooking industry as a major setback in a country that had strongly supported growth in the sector.[265]

Half of the population without access to clean cooking lives in countries that
lack policy frameworks
for this.

TABLE 7.
Distributed Renewables Policies for Electricity Access, Selected Countries, 2020

Country	National Plans and Targets				Regulatory Policies		Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/ strategy	Administrative and legal provisions (connection codes, tariff, licencing, etc.)	Tendering, call for proposals or competitive process	Quality/ Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa									
▲ **Angola**	●		●	●	●	●	●	●	
Benin	●				●	○	●	●	★
Botswana						●			
▲ **Burkina Faso**	●		●	●	●	●		●	●
Burundi					●			★	●
Cameroon		●	●		●		●	●	●
Central African Republic					●		●	●	
▲ **Chad**									●
Comoros									●
▲ **Congo, Democratic Republic of the**	★		●		●				●
Congo, Republic of the									
Côte d'Ivoire	●		●	●	●	●			●
Djibouti			●		●				
Equatorial Guinea									
Eritrea			●				●		
Eswatini		●							
▲ **Ethiopia**	●		●	●	★	●	★	●	●
Gabon									
Gambia	●		●		●				
Ghana	●	●	●		●	●	●	●	●
Guinea									●
Guinea-Bissau	●								
▲ **Kenya**	●		●		●	●	●	●	□
Lesotho									
Liberia	●		●		●			●	●
▲ **Madagascar**	●		●	●	●	●	●	●	●
▲ **Malawi**	●		●	●	●		●	●	●
Mali	●		●	●	●			●	★
Mauritania		●	●	●	●		●	●	●
▲ **Mozambique**	●		●	●	●			●	●
Namibia	●				●			●	
▲ **Niger**	●	●	●		●		●		●
▲ **Nigeria**	●	●	●	●	●	○	●	●	
Rwanda	●	★	●	●	●	●	●	★	●
São Tomé and Príncipe		●							
Senegal	●	★	●		●	○		●	★
Sierra Leone	●		●	●	●	●	●	●	●
Somalia		●					●	●	
South Africa			●	●	●		●	●	●
South Sudan	●								
▲ **Sudan**	●	●	●					●	
▲ **Tanzania**			●	●	●		●	●	●
Togo	●		●			○	●	★	●
▲ **Uganda**	●	●	●		●		★	●	●
Zambia			●	●	●	●	●	●	●
Zimbabwe		●		●	●		●	●	●
Asia									
▲ **Bangladesh**		★	●	●	●	●	●	●	●
Cambodia		●		●	●		●	●	
▲ **India**	●		●	●	●	○	●	●	●
▲ **Korea, Democratic People's Republic**									
Mongolia	●				●				
▲ **Myanmar**	●	●	●		●	●	●	●	●
Nepal	●	★		●	●	●	●	●	●
▲ **Pakistan**		●					●		●
Philippines			●		●			●	

Note: Please see key on the next page.

TABLE 7.
Distributed Renewables Policies for Electricity Access, Selected Countries, 2020 (continued)

Country	National Plans and Targets				Regulatory Policies		Non-Regulatory Policies		
	Distributed renewables for energy access targets	Distributed renewables for energy access in INDC or NDC	Integration of distributed renewables in energy access plan/strategy	Grid arrival plan/strategy	Administrative and legal provi-sions (connection codes, tariff, licencing, etc.)	Tendering, call for proposals or competitive process	Quality/ Technical frameworks and standards	Public financing (loans, grants, subsidies, guarantees, etc.)	Fiscal incentives (import duty, VAT, etc.)
Central and South America									
Guatemala			●						●
Haiti									
Honduras									●
Panama		★							
Middle East									
Syria									
▲ **Yemen**	●	●	●					●	

Note: The list includes only countries that have an electrification rate below 95% according to the IEA World Energy Outlook 2020 Electricity Access Database (except for India and the Philippines). The top 20 access-deficit countries are the 20 countries with the highest electricity access-deficit populations. These are Angola, Bangladesh, Burkina Faso, Chad, the Democratic Republic of the Congo, Ethiopia, India, Kenya, the Democratic People's Republic of Korea, Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, Pakistan, Sudan, Tanzania, Uganda and Yemen.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions towards reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 241 for this chapter.

● Existing national policy or tender framework (could include sub-national)
★ New (one or more policies of this type)
○ National tender held in 2020
☐ Removed
▲ Top 20 access-deficit countries

TABLE 8.
Distributed Renewables Policies for Clean Cooking Access, Selected Countries, 2020

Country	National Plans and Targets			Regulatory Policies		Non-Regulatory Policies		
	Clean cooking targets	Clean cooking in INDC or NDC	Integration of clean cooking in energy access plan/ strategy	Administrative and legal provisions	Tendering, call for proposals or competitive process	Quality/ Technical frameworks and standards	Public financing (loans, grants, subsidies, etc.)	Fiscal incentives (import duty, VAT, etc.)
Africa								
▲ **Ethiopia**	●	●	●			●		
▲ **Ghana**			★			●		
▲ **Kenya**	●		●			●		☐
Rwanda	●	●	●			●		●
▲ **Uganda**	●	●	●					●
Asia								
▲ **Bangladesh**	●	●	●			●		●
▲ **China**	●	●	●					
▲ **India**	●	●	●				★	
▲ **Nepal**	●	★	●			●	●	★
Central and South America								
Guatemala		●	●					

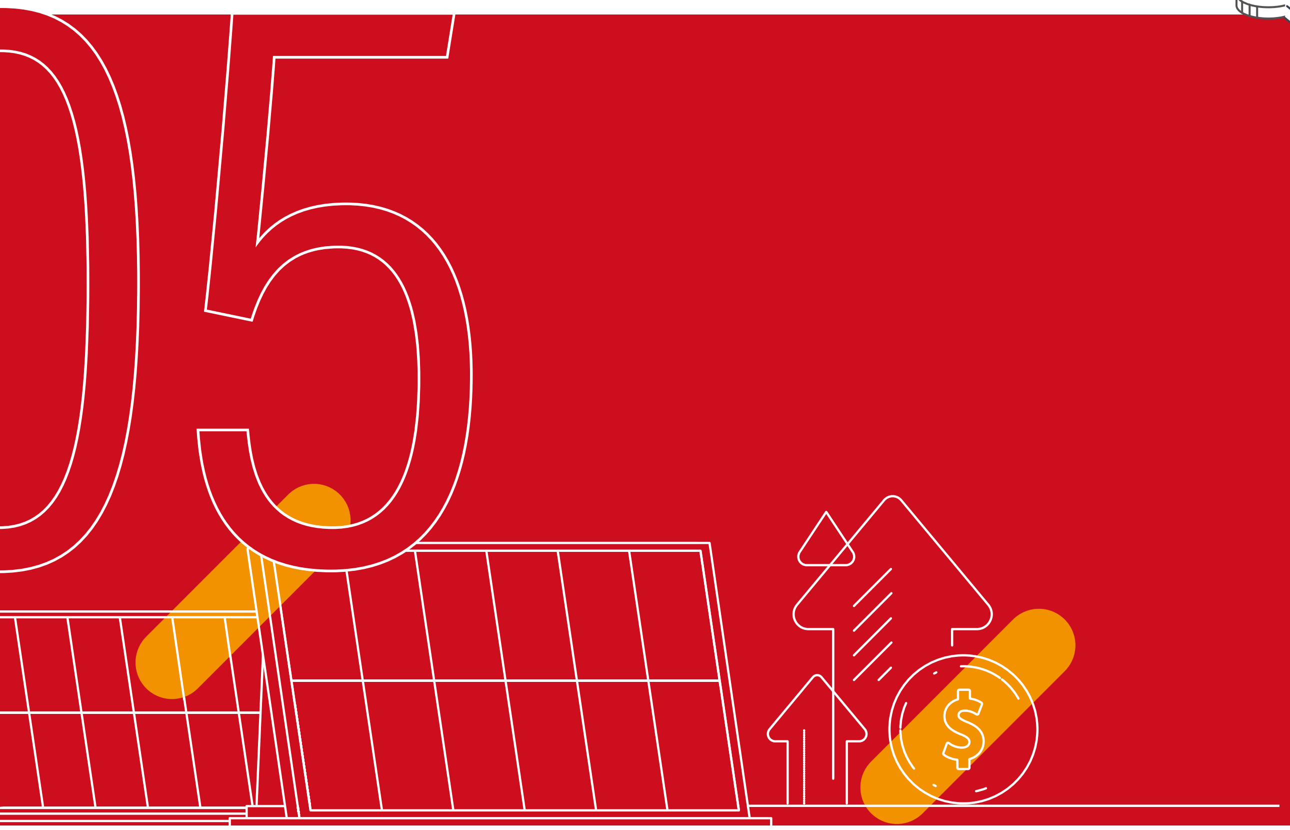
Note: The top 20 access-deficit countries are the 20 countries with the highest clean cooking access-deficit populations. These are Afghanistan, Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, Ghana, India, Indonesia, Kenya, the Democratic People's Republic of Korea, Madagascar, Mozambique, Myanmar, Nigeria, Pakistan, Philippines, Sudan, Uganda, Tanzania and Vietnam.

INDC and NDC refers to countries' (Intended) Nationally Determined Contributions towards reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change; VAT = value-added tax.

Source: See endnote 241 for this chapter.

● Existing national policy or tender framework (could include sub-national)
★ New (one or more policies of this type)
○ National tender held in 2020
☐ Removed
▲ Top 20 access-deficit countries

In 2020, Banco do Brasil committed to expanding renewables in its energy matrix up to 90% by 2024 and inaugurated its first solar power plant in March.



05 INVESTMENT FLOWS

KEY FACTS

- Global investment in new renewable energy capacity totalled **USD 303.5 billion in 2020**, up 2% from 2019.
- **Developing and emerging economies surpassed developed countries** in renewable energy capacity investment for the sixth year running, although by a smaller margin than in previous years, reaching USD 153.4 billion.
- Recovery packages from January 2020 to April 2021 allocated at least USD 53.1 billion in direct support for renewable energy, **nearly six times less** than for fossil fuels.
- Renewable energy projects represented nearly **60% of all climate finance** during 2017 and 2018, averaging USD 337 billion.
- The divestment movement continued its upward trend in 2020, with more than 1,300 institutional investors and institutions worth **nearly USD 15 trillion committing to divesting** partially or fully from fossil fuel-related assets.

INVESTMENT IN RENEWABLE ENERGY CAPACITY

Global investment in new renewable energy capacity (excluding large hydropower)[i] withstood the economic crisis triggered by the COVID-19 pandemic and totalled USD 303.5 billion[ii] in 2020.[1] This 2% increase over 2019 marks a significant rebound, particularly during the second half of the year.[2] With lockdowns and mobility restrictions affecting the entire renewables production and construction chain in the first half of 2020, new renewable capacity was expected to fall 10% for the year.[3] In the first quarter of 2020, final investment decisions[iii] on solar and wind projects dropped to their 2017 levels (USD 10 billion for solar and USD 23 billion for wind).[4]

However, government recovery packages increased the flow of renewable energy finance.[5] (→ *See Sidebar 3 in Policy Landscape chapter, and Figure 5 in Global Overview chapter.*) Private initiatives also contributed to the resilience of renewables, with continued development aimed at boosting investor interest in renewable energy – including through climate-related financial disclosure, green standards and taxonomies, and (to a certain extent) divestment campaigns. (→ *See Feature chapter.*)

i Renewable energy includes onshore and offshore wind, large- and small-scale solar, biofuels, biomass and waste, marine, geothermal and small hydropower.

ii These estimates are for capacity investment and exclude capital invested in companies and money spent on research, development and manufacturing.

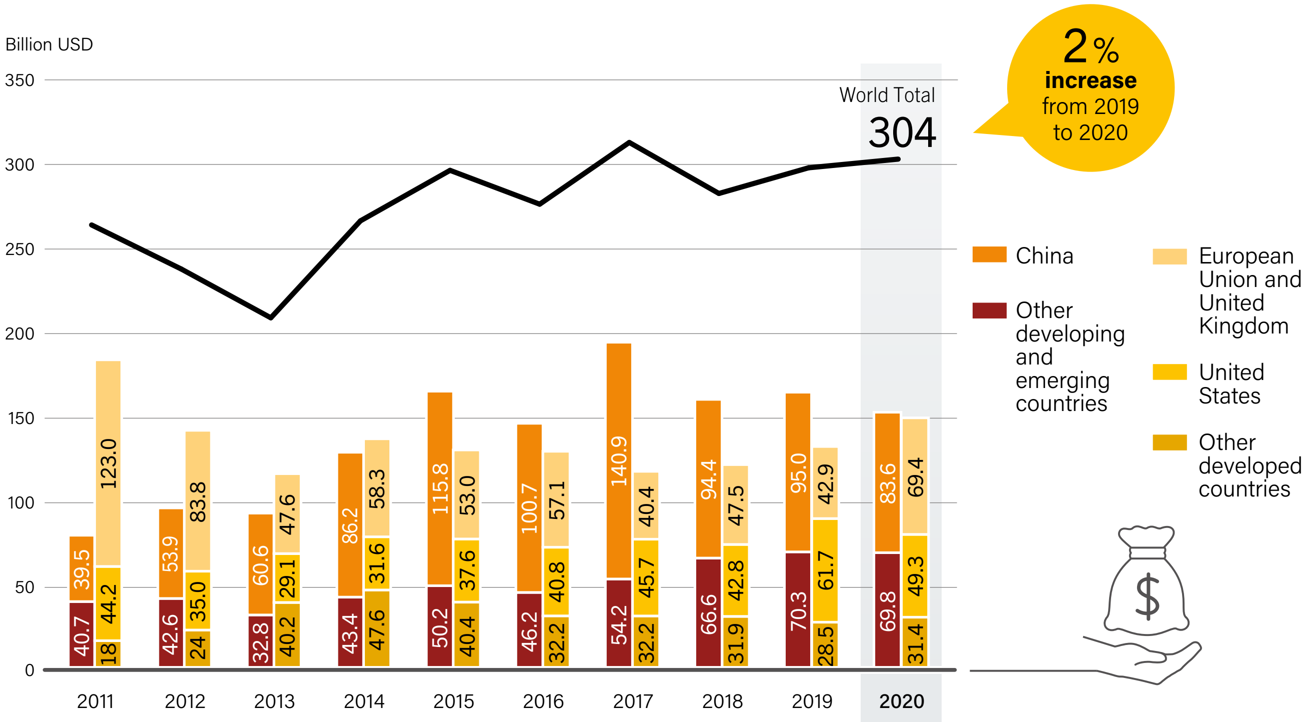
iii The final investment decision marks the point in the capital project planning process when the decision to make major financial commitments is taken. At that point, major equipment orders are placed and engineering, procurement and construction contracts are signed.

INVESTMENT BY ECONOMY

For the sixth consecutive year, renewable energy capacity investments by developing and emerging countries (excluding hydropower projects larger than 50 megawatts, MW) exceeded those of developed countries, although by a smaller margin than in previous years, accounting for 50.5% of the 2020 total.[6] (→ *See Figure 46.*) Investments for the year rose 13% in developed countries and fell 7% in developing and emerging countries.[7]

The drop in developing countries was due mainly to declining capacity investment in China (down 12%), India (down 36%) and developing countries in the Americas (down 33%).[8] Investment also fell in Sub-Saharan Africa (down 14%), further diminishing the low investment in new renewable capacity in the region (USD 2.8 billion).[9] In contrast, investment growth continued for the seventh consecutive year in developing countries outside of those areas, including in Brazil (up 23%), the Middle East and North Africa (up 22%), and Asia and Oceania (up 13%).[10] (→ *See Figure 47*).

FIGURE 46.
Global Investment in Renewable Power Capacity in Developed, Emerging and Developing Countries, 2010-2020



Note: Figure includes utility-scale renewable energy and small-scale solar projects and excludes large hydropower projects of more than 50 MW.
Source: BloombergNEF. See endnote 6 for this chapter.

Renewable energy **capacity investments** in developing and emerging countries exceeded those in developed countries.

Although capacity investment in China fell 12% compared to 2019, the country continued to lead in overall renewable energy capacity investment, accounting for 27.5% of the global total.[11] The European Union (EU) was next, with 22.9%, followed by Asia-Oceania (16.9%, excluding China and India) and the United States (16.2%).[12] Africa and the Middle East accounted for 4.5%, non-EU Europe for 4.1%, the Americas (excluding Brazil and the United States) for 3%, Brazil for 2.9% and India for 2%.[13]

Overall capacity investment in China totalled USD 83.6 billion in 2020.[14] Around 65.5% of these investments were in the wind sector (onshore and offshore), followed by solar PV (30%), biomass and waste (4.2%) and small hydropower (0.5%).[15] In parallel, China's foreign investments in solar PV, wind power and hydropower represented for the first time more than half of the country's total overseas energy investments under the Belt and Road Initiative – China's main international co-operation and economic strategy – increasing from 38% in 2019 to 57% in 2020.[16] This was due mainly to the steady decline in coal investments since 2015 (although they resurged in 2020) and to the sharp decrease in natural gas investment, which represented only 2.4% of the total 2020 investment, compared with 23.7% in 2019.[17] The majority of renewable energy investment was in hydropower (35%), while solar and wind represented 23%.[18]

Qatar and Oman received 100% of the renewable energy investments from China in 2020.[19] However, most of the power plants financed[i] during the year by foreign direct investment from Chinese companies and China's two global policy banks[ii] were coal-fired plants (around 39% of the capacity), followed by hydropower (27%).[20] Wind and solar projects constituted a higher share of total projects than coal, gas and hydropower plants, but due to their smaller capacity they accounted for only 11% of Chinese investment overseas.[21]

After hitting a record high in 2019, US investment in renewable energy capacity fell 20% in 2020, to USD 49.3 billion.[22] Investments were mainly in solar PV (USD 31.3 billion, or 63.5% of the total) and onshore wind (USD 17.7 billion, 36%).[23] The EU was the main driver of increased renewable energy capacity investment in 2020, totalling USD 69.4 billion in 2020, led by the United Kingdom and the Netherlands (due to investments in large offshore wind projects), followed by Spain.[24]

i Chinese participation in these power plants includes foreign direct investment, mergers and acquisitions, greenfield investments and debt finance. See Global Development Policy Center, Boston University, "China's Global Power Database", http://www.bu.edu/cgp.

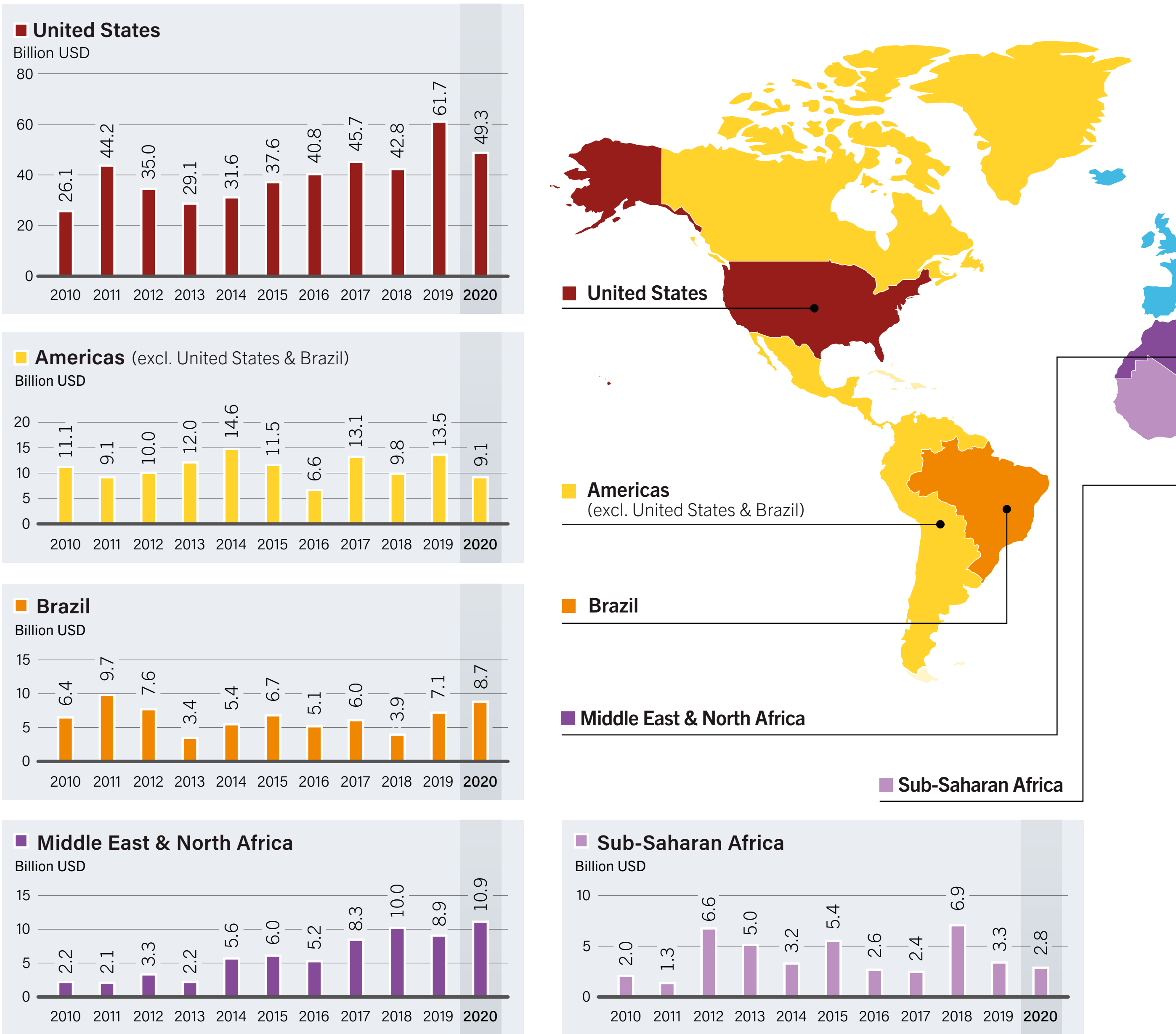
ii The China Development Bank and the Export-Import Bank of China.

INVESTMENT BY TECHNOLOGY

Solar power represented nearly half of global renewable energy capacity investment in 2020, at USD 148.6 billion.[25] It was the only renewable energy technology to increase for the year, up 12% from 2019.[26] Although wind power capacity installations grew during the year, investment

In 2020, solar power was the only renewable energy technology to experience an **increase in investments.**

FIGURE 47.
Global Investment in Renewable Energy Capacity, by Country and Region, 2010-2020



Note: Figures include utility-scale renewable energy and small-scale solar projects and exclude large hydropower projects of more than 50 MW. The regions in this chapter follow those presented in the BNEF *Energy Transition Investment 2021* report and differ from the regional definitions included elsewhere in the GSR.

Source: BloombergNEF. See endnote 10 for this chapter.

in wind power fell 6% to USD 142.7 billion, representing 47% of the total.[27] (→ *See Market and Industry chapter.*)

Biomass and waste-to-energy[i] investment was down 3% to USD 10 billion.[28] The remaining technologies continued their downward trend in 2020, with investment in small hydropower reaching USD 0.9, geothermal USD 0.7 billion and biofuels USD 0.6 billion – each dropping more than 70% since 2010.[29] (→ *See Figure 48.*)

The factors behind these trends vary by technology. Common barriers to investment in small hydropower projects include the high upfront cost, the lack of a regulatory framework encouraging deployment of the technology, and a high degree of risk and uncertainty in the different development stages.[30] For geothermal projects, high risks and expensive early-stage development (test drilling) have impeded further participation from private investors in the last two decades.[31]

i Although the energy produced from solid waste combustion is efficient, it cannot be considered entirely renewable as solid waste also contains inorganic material. Generally, around 50% of energy from municipal solid waste is classified as renewable. (→ *See Glossary.*)

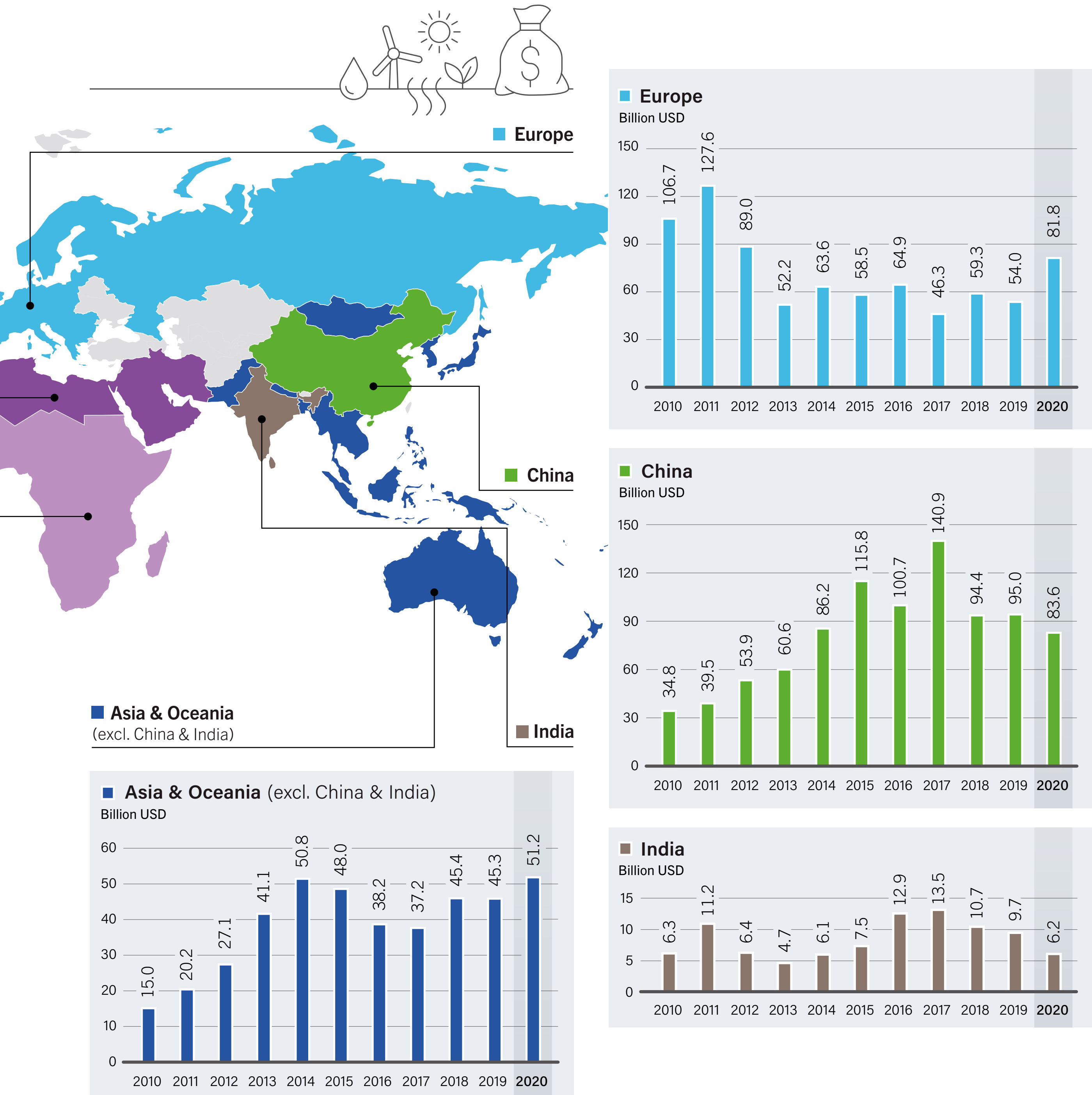
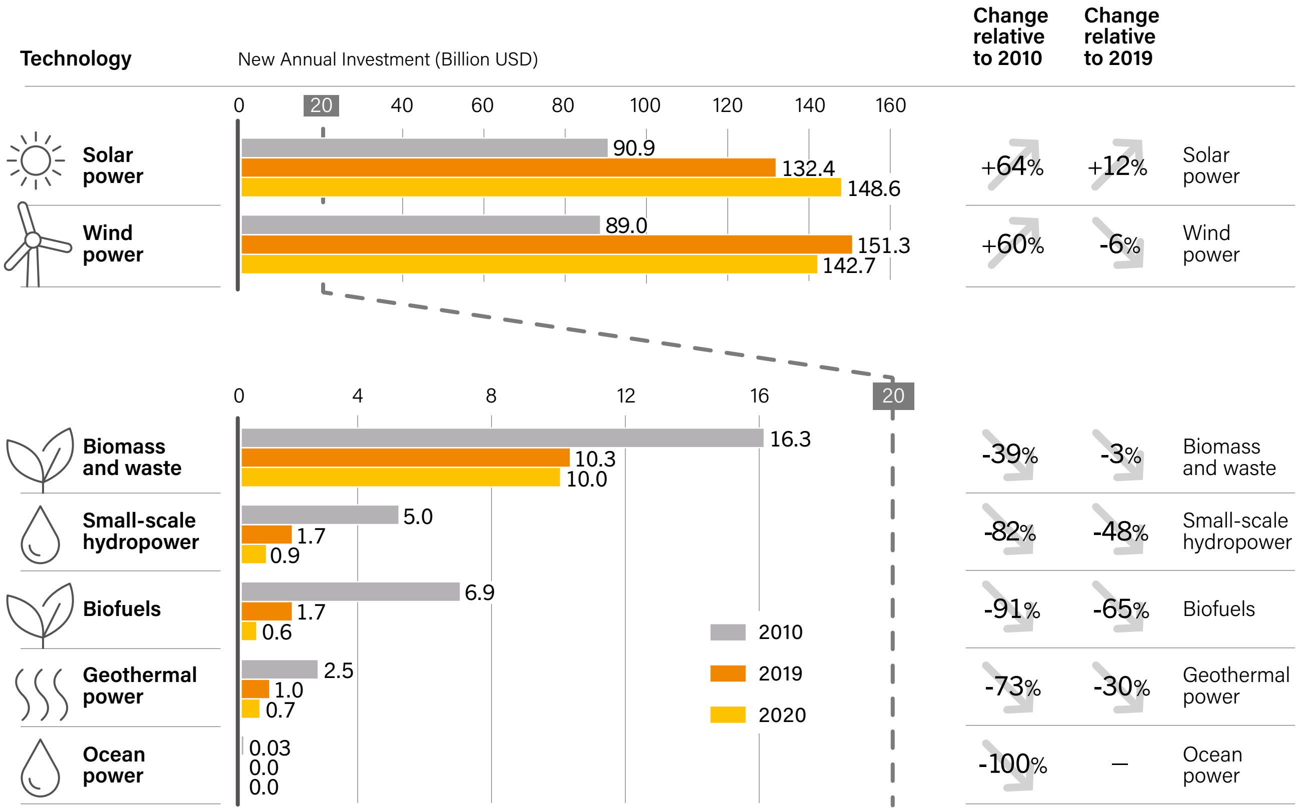


FIGURE 48.
Global Investment in Renewable Energy Capacity by Technology, 2010, 2019 and 2020



Note: Figure includes utility-scale renewable energy and small-scale solar projects and excludes large hydropower projects of more than 50 MW.
Source: BloombergNEF. See endnote 29 for this chapter.

The declining investment in first-generation biofuels started in 2007, amid growing concern about the impacts of the fuels on food security and prices and on land use (also affecting greenhouse gas emissions).[32] In contrast, investment in second-generation biofuels[i] grew starting in 2007, but the growth lasted only until 2011.[33] The main barriers to further investment in the sector include the regulatory uncertainty regarding sustainability criteria (especially in Europe), low subsidy levels, high financing costs and doubts regarding technological readiness.[34]

Marine power received no capacity investment in 2020, mainly because of technology challenges and a lack of specific policy support in the key markets.[35]

Other investments that are relevant (indirectly) to the uptake of renewables include spending on electric vehicles (EVs), heat pumps and energy storage.[36] (→ *See Systems Integration chapter.*) In 2020, investment in EVs and associated charging infrastructure was up 28% to USD 139 billion, and investment in domestic installation of energy-efficient heat pumps was up 12% to USD 50.8 billion; meanwhile, investment in batteries and other energy storage technologies (excluding pumped hydropower, compressed air and hydrogen) was unchanged from 2019, despite lower unit prices, for a total of USD 3.6 billion.[37] Hydrogen investment fell 20% in 2020, due to lower investment in fuel cell buses and commercial fuel cell vehicles, while investment in the electrolysis process rose 12.5% to USD 189 million due to the increased attractiveness of renewable hydrogen production.[38]

i Advanced biofuels, or second-generation biofuels, are made of "lignocellulosic feedstock such as corn stover, straw, wood waste, rapidly growing grasses and short-rotation trees, municipal waste, and waste oils, fats or algae, all of which have few non-energy uses, and some of which can be grown on less productive and degraded lands or in seawater (algae), thus involving a smaller impact in terms of land-use." See International Renewable Energy Agency, *Advanced Biofuels: What Holds Them Back?* (Abu Dhabi: 2019), https://irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back.

COVID-19'S IMPACT ON INVESTMENT

In addition to the resilience of renewable energy investments to the COVID-19 crisis, economic recovery packages in 2020 included significant spending to stimulate further investment in renewables, both to address climate change and to deploy specific renewable energy projects.

By September 2020, governments had announced USD 11.8 trillion in fiscal assistance in response to the pandemic-induced economic crisis, more than three times the amount spent to respond to the financial crisis of 2008.[39] While most of the funding prioritised supporting health and reducing unemployment, around 30% was allocated to sectors with an impact on the energy transition, with the aim of creating jobs and boosting economies.[40] Globally, investment in the solar PV sector in 2020 created an estimated 13 jobs per USD 1 million invested, or twice as many jobs as in the coal or gas industry.[41] Wind and hydropower projects generated as many jobs as nuclear power projects.[42]

As of April 2021, 31 governments had announced a combined USD 732.5 billion in spending to support all types of energy through new or amended policies.[43] Of this total, 42% (USD 309.9 billion) was allocated to fossil fuel-intensive sectors, 37% (USD 264.2 billion) to "clean energy"[i] and 21% (USD 152.9 billion) to other energy sources (including nuclear, first-generation biofuels, biomass and biogas, and hydrogen from unspecified sources).[44] (→ *See Figure 49.*)

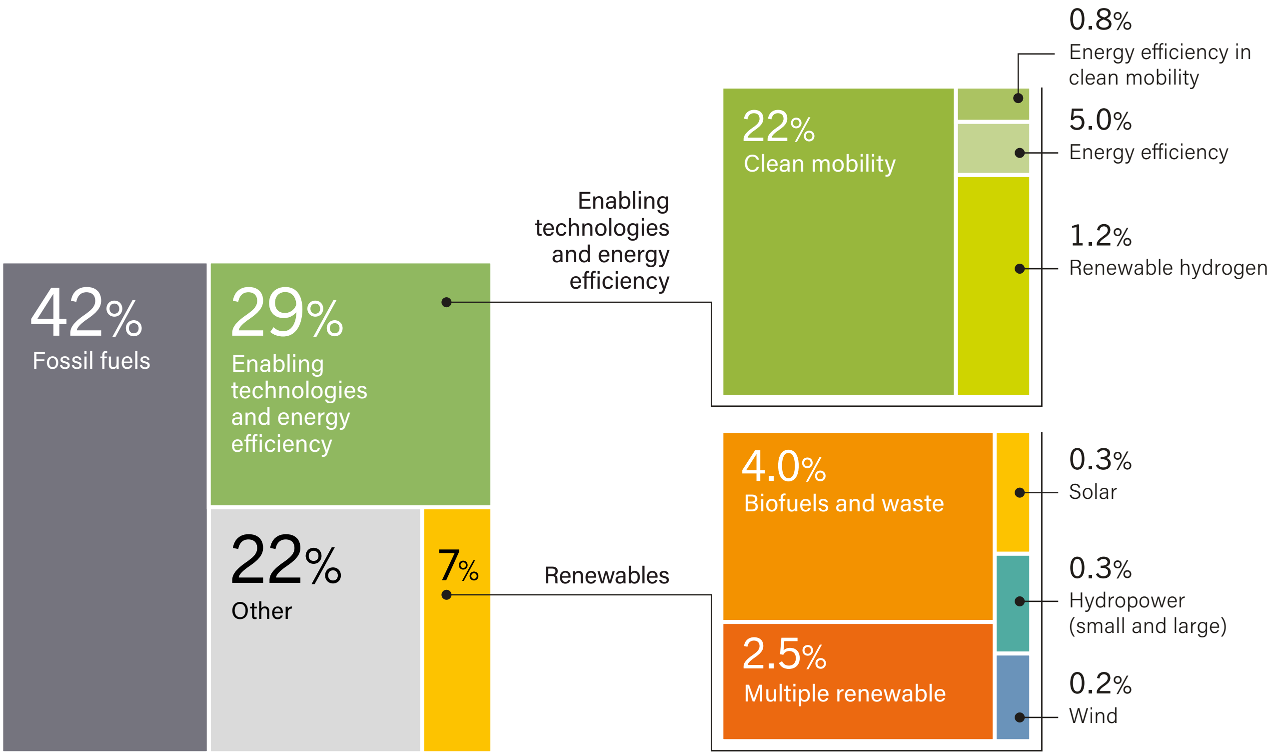
Renewable energy investments in COVID-19 recovery packages were nearly

six times less

than those for fossil fuels.

i This refers to policies supporting the production or consumption of low-carbon energy and the energy transition, including: energy efficiency and renewable energy (solar, wind, small hydropower, rain, tides and geothermal heat, large hydropower); renewable hydrogen; active transport (cycling and walking), rail, public transport and EVs (electric cars, bicycles, scooters and boats) using multiple types of energy; smart grids and technologies that better integrate renewables; hydrogen in the case of mixed, but predominantly clean, sources (e.g., as under Germany's hydrogen strategy); and biofuels, biomass and biogas with a proven minimum negative impact on the environment. For details, see EnergyPolicyTracker.org, "Methodology", https://www.energypolicytracker.org/methodology.

FIGURE 49.
Energy Investments in COVID-19 Recovery Packages of 31 Countries, January 2020 to April 2021



Note: Although the energy produced from solid waste combustion is efficient, it cannot be considered entirely renewable as solid waste also contains inorganic material. Generally, about 50% of energy from municipal solid waste is classified as renewable. (→ See Municipal solid waste in Glossary.). Multiple renewables include geothermal and ocean power. Enabling technologies include e-mobility and renewable hydrogen. The "Other" category refers to other types of energy-related policies including, among others, nuclear energy, incineration, hydrogen from unspecified sources, and multiple energy types (for example intertwined fossil fuels and clean energy). Where totals do not add up, the difference is due to rounding.

Source: EnergyPolicyTracker.org. See endnote 44 for this chapter.

Of the clean energy spending, around 20.1% (USD 53.1 billion) was allocated directly to policies to support the production or consumption of renewables (including solar and wind power, small and large hydropower, rain and tidal energy, geothermal heat, and biofuels and waste energy).[45] The amount for biofuels and waste energy covers mainly investments in India, where nearly USD 27 billion was allocated to set up 5,000 compressed biogas plants.[46] However, 67 of the 199 policies related to clean energy sources did not specify an amount, making the actual total allocation much higher.[47]

Investment in enabling technologies associated with renewable energy use (such as e-mobility and renewable hydrogen) and energy efficiency comprised an additional USD 204 billion in renewable energy-related stimulus.[48]

Regionally, the EU led in environmental investments as of April 2021, allocating 30% (around EUR 550 billion, or USD 660 billion) of its overall recovery package and its long-term 2021-2027 budget solely to climate-related projects.[49] These projects included scaling up renewable energy (mainly wind and solar), launching a European "clean hydrogen economy"[i] and developing clean mobility (including EVs).[50] However, many of the clean energy policies that could strengthen the deployment of renewables had not yet been translated into legislation, and allocation amounts had not been determined as of April 2021.[51] Within the EU, the leaders in renewable energy measures and allocations were Germany (at least USD 12.6 billion) and France (at least USD 3.9 billion).[52]

By early 2021, the United States had pledged only around USD 459.5 million to support renewable energy and USD 26.8 billion to support mobility, including EVs; this was less than 40% of the amount that was allocated to fossil fuel energy, without establishing climate targets or additional pollution reduction requirements (at least USD 72 billion).[53] The administration's proposed clean energy and sustainable infrastructure plan released in early 2021 favoured investment in renewable energy, although the US Congress still needed to pass legislation and allocate proper funding.[54]

Other economies that announced investments in renewables (as well as fossil fuels) included the Republic of Korea, which allocated USD 984 million for solar and offshore wind generation; China (at least USD 217 million in biofuels and waste and multiple renewables) and India (at least USD 30 billion, including USD 27 billion to biofuels and waste projects).[55] However, these economic recovery plans also include coal (USD 2.5 billion in the Republic of Korea, USD 1.07 billion in China and USD 15.5 billion in India).[56]

Several countries focused on electricity decarbonisation, with the Republic of Korea, France and Italy increasing their subsidies for rooftop solar PV.[57] Nigeria, Africa's largest oil and gas producer, aimed to use 10% of its stimulus funds (USD 620 million) to install solar systems for up to 5 million households.[58] Colombia allocated USD 4 billion to renewable energy and transmission projects, including wind (nine projects), solar (five), geothermal (three) and hydropower (one).[59]

With calls for a "green recovery" following the COVID recession, combined with the expectation that the new US administration would implement low-carbon measures, renewables became more attractive to investors, who increased investments in wind and solar power, batteries and EVs.[60] The decreasing cost of these technologies compared to fossil fuels also was key to their greater appeal.[61]

Several indices that track the performance of renewable energy companies surged in 2020. For example, the WilderHill New Energy Global Innovation Index (NEX)[ii] gained 142% and the S&P Global Clean Energy Index[iii] gained 138%.[62] By contrast, the NYSE Arca Oil Index and the S&P 500 Energy Index – both of which follow the performance of fossil fuel-linked companies – fell 38% and 37%, respectively.[63] The solar equipment manufacturer Enphase Energy was among the three best performers on the NEX.[64]

Overall, the stock prices of solar power manufacturers and distributors rose sharply in 2020. For example, the company SunPower tripled its value, and the Invesco solar index increased 66% between January and September.[65] However, growth in these indices must be viewed with caution as market prices fluctuate widely: the S&P Global Clean Energy Index fell 30% between early January and mid-March 2021.[66]

i The term "clean hydrogen" refers to renewable and low-carbon hydrogen in the *Hydrogen Strategy for a Climate-neutral Europe* elaborated by the European Commission. See https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

ii The WilderHill New Energy Global Innovation Index tracks the performance of around 100 companies focusing on clean energy, renewables, decarbonisation and efficiency worldwide.

iii The S&P Global Clean Energy Index is designed to measure the performance of 30 companies from around the world that are involved in clean energy-related businesses, comprising a diversified mix of clean energy production and clean energy equipment and technology companies.

DEPLOYING RENEWABLE ENERGY THROUGH CLIMATE FINANCE

Climate finance is the finance channelled to support mitigation actions that seek to reduce greenhouse gas emissions – including developing renewable energy, implementing energy efficiency and promoting sustainable transport – as well as adaptation actions that address the impacts of climate change. The renewable energy capacity investment described earlier does not include all renewables-related spending channelled through climate finance, as the latter may include, for example, finance for renewable energy companies in addition to support for new renewable energy capacity.[67]

Preliminary data indicate that in 2019, climate finance totalled between USD 608 billion and USD 622 billion, or a 6% to 8% increase over the annual average in 2017 and 2018 (USD 574 billion per year).[68] The latest breakdown of climate finance (available only for those two years and updated at year-end 2020) shows that renewable energy projects received USD 337 billion on average, representing almost 60% of all climate finance.[69]

The investment picture for developing countries is different. The 2015 Paris Agreement underscored the importance of addressing those countries' needs, setting a USD 100 billion annual target to be met jointly by developed countries by 2020.[70] Climate finance from developed to developing countries rose from USD 52.2 billion in 2013, to USD 58.6 billion in 2016, to USD 78.9 billion in 2018[i].[71] Initial data indicate that this trend continued in 2019 but did not meet the USD 100 billion annual target in 2020.[72]

During the three years between 2016 and 2018, the energy sector received the largest share of total climate finance: USD 23.8 billion per year on average, representing 34% of total climate finance mobilised by developed countries.[73] Of that total, 53% (USD 12.5 billion) supported projects targeting energy generation from renewable sources, including solar (23%), hydropower (19%), wind (15%), geothermal (5%) and biofuels (4%), with the rest (34%) from multiple sources or unspecified.[74]

For developing countries, the sources of global climate finance are divided equally between private and public, whereas for developed countries public sources constituted more than 80%.[75] Public sources mobilised by developed countries include bilateral development agencies and institutions (the annual financial commitments from developed countries to developing country governments, non-governmental organisations (NGOs) and civil society, research institutes and the private sector), multilateral development banks and climate funds, and providers of climate-related export credits[ii].[76] Export credits, which totalled USD 2.1 billion in 2018, covered mainly renewable energy projects, while the remaining USD 62.2 billion was allocated to a variety of mitigation and adaptation actions.[77]

MULTILATERAL CLIMATE FUNDS AND DEVELOPMENT BANKS

The major multilateral climate funds include, in order of investment pledged, the Green Climate Fund (GCF), the Climate Investment Funds (CIF) and the Global Environment Facility (GEF).[78] Multilateral climate funds and multilateral development banks play an important role in providing direct support to developing countries, as they are the principal interface between the public and private sectors.[79]

Replenishing these funds is important for the future of climate finance; they are central to climate funding for developing countries and determine the amount of investment in addressing climate mitigation and adaptation challenges in these countries.[80]

As of year-end 2020, the GCF had received pledges totalling USD 10.3 billion from 49 countries and regions for the 2020-2023 period, thus succeeding in its first replenishment campaign.[81] Of that total, USD 8.3 billion was secured.[82] As of October 2020, 32% of the GCF's portfolio comprised energy generation and access projects, driven mainly by private funding (USD 1,422 million, compared to USD 589 million in public funding).[83] The energy area represented half of the funding for mitigation actions, although the amount fell 40% between 2019 and 2020.[84]

60% of climate finance is directed at renewable energy projects, reaching an average of USD 337 billion during 2017 and 2018.

i Latest data available. The estimation for 2020 was expected to be ready in 2022.

ii Climate-related export credits refer to government financial support to foreign buyers to help finance the purchase of goods from national exporters, such as direct financing, guarantees, insurance or interest rate support.

As of early 2021, the GEF had invested more than USD 1.1 billion in 249 stand-alone renewable energy projects, as well as USD 277 million in 54 mixed projects with renewable energy components in 160 developing and transition countries.[85]

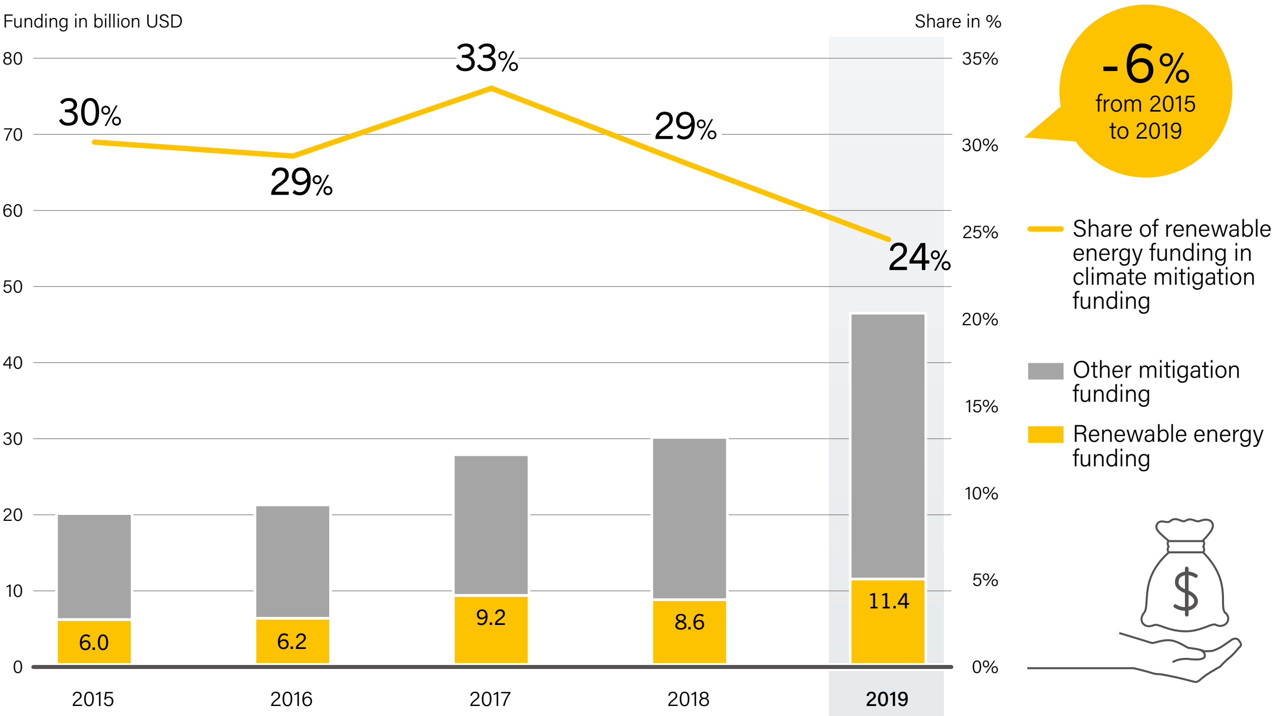
The CIF and two of its programmes, the Clean Technology Fund (CTF) and the Scaling Up Renewable Energy Program, also pledged funding for renewable energy projects (respectively, USD 5.4 billion as of early 2020, including for renewable energy deployment projects, and USD 744 million).[86] Of the CTF portfolio, 68% was allocated to renewable energy projects in reporting year (RY) 2020, resulting in installed capacity of 7.9 gigawatts (GW).[87] All CIF projects are implemented by partner multilateral development banks.[88] For example, the Renewable Energy Financing Facility in Kazakhstan, implemented by the European Bank for Reconstruction and Development, accounted for the largest share of the CTF portfolio's new capacity (21% of the RY 2020 total), with 104 MW installed.[89]

In 2019, multilateral development banks allocated USD 11.4 billion to renewable energy projects, including electricity generation, heat production and other applications, as well as measures to facilitate the integration of renewables into grids.[90] Of this total, 67% was allocated to low- and middle-income countries and 33% to high-income countries.[91] The regions that received most of the funding were the EU (30.2%), followed by Sub-Saharan Africa (16.4%), East Asia and the Pacific (9.9%), multi-regional (9.1%) and Latin America (8.8%).[92] Additional funding for renewables may have been allocated to research and development or policy support, but is tracked under other categories and thus is not included in the USD 11.4 total.[93]

Multilateral development bank investments in renewable energy projects have increased since 2014 (up 89% between 2015 and 2019).[94] However, their total investments (including non-renewable energy-specific funding) rose 132% over the same period.[95] Consequently, the share of renewable energy funding in total funding decreased during the five-year period, falling from 30% in 2015 to 24.4% in 2019.[96] (→ *See Figure 50.*)

Multilateral development banks' investments in renewable energy projects have increased since 2014, reaching USD 11.4 billion in 2020.

FIGURE 50.
Share of Renewable Energy Funding in Climate Mitigation Finance from Multilateral Development Banks, 2015-2019



Source: See endnote 96 for this chapter.

CLIMATE FINANCE INSTRUMENTS

In 2018, loans and grants made up the key public finance instruments (84% and 13%, respectively) used in the energy sector overall.[97] Guarantees and equity investments also were used but represented only a very small share (3%).[98] Loans more than doubled from USD 19.8 billion in 2013 to USD 46.3 billion in 2018, increasing their share of total public finance from 52% to 74%.[99] Grants fluctuated between USD 10 billion and USD 12 billion, and their share fell from 27% to 20%.[100]

One loan instrument in particular contributed to this trend: **green bonds**[i], which are designed to fund projects with positive environmental or climate benefits.[101] Green bonds hit record levels for a second consecutive year, up 1.1% in 2020 to reach USD 269.5 billion.[102] Rebounding in the second half of the year amid the COVID-19 crisis, the green bonds market hit a milestone, exceeding a cumulative USD 1 trillion in issuance since this mechanism was created.[103]

Investment in the energy sector represented the largest share of green bonds in 2020, at USD 93.6 billion (34.7%).[104] More than half of this (USD 55.9 billion) was allocated to renewable energy projects.[105] The share of renewable energy bonds in total green bonds issued rose for the third straight year, from 17% in 2018 to 21% in 2020.[106] The United States was the leading issuer (20% of green bonds issued), followed by China (10%), Germany (9%), France (8%), the Netherlands (8%) and Spain (7%).[107]

In developing countries, particularly least-developed countries and small-island developing states, the market for green bonds remains small, due in part to these countries' lower credit ratings or lack of appropriate institutional arrangements.[108] Innovation in the securitising[ii] green bonds, aggregating loans for small-scale low-carbon projects that, individually, are too small for the bond market, can help promote the issuance of green bonds in these countries.[109] **Green securitisation** has grown in recent years, with more than USD 25 billion of the green bonds issued in 2019 estimated to be asset-backed securities, up from USD 1.9 billion in 2015.[110]

Growth in the renewable energy sector has led to the creation of **solar asset-backed securities**, which are securities backed by consumer receivables originated by solar energy companies, and used to finance PV systems.[111] While still an emerging sector, solar asset-backed security issuance grew to over USD 2 billion in 2018, with seven active issuers.[112]

DIVESTMENT

The movement to pressure institutional investors to divest from financial assets related to fossil fuel companies has gained steam in recent years.[113] As of April 2021, more than 1,300 institutional investors and institutions worth nearly USD 15 trillion had committed to divest partially or fully from fossil fuel-related assets, up 36% from USD 11 trillion in 2019.[114] Faith organisations were the largest group of institutions divesting, accounting for almost 35% of the total number of commitments.[115] In 2020, 42 faith institutions from 14 countries announced the largest ever joint fossil fuel divestment by those institutions.[116] This commitment was echoed later by the Vatican's call for Catholics to divest from polluting industries and to shift to sustainable energy investments.[117]

Educational and philanthropic institutions accounted for another 30% of total commitments as of April 2021, while governments and pension funds represented 25% (large insurance companies and pension funds had contributed the highest share to divestments in 2019[iii]), and corporations and NGOs accounted for the remainder.[118] More than 58,000 individuals joined these institutions in the trend, divesting around USD 5.2 billion in 2020.[119]

The divestment movement focused initially on coal and expanded to include oil and natural gas. Since 2015, 135 banks and insurers with more than USD 10 billion in assets under management or loans have restricted their investments in coal (from mining to new coal-fired power plants), with 47 institutions joining in 2020 alone.[120] As of 2021, only 24 asset managers and owners with more than USD 50 billion in assets under management had done that, and more than half of those were announced in 2020.[121] The share of members from the 160 focus companies of Climate Action 100+[iv] – an investor-led initiative to address climate change – that are now planning a full phase-out of coal doubled between 2019 and 2020 (from 13% to 26%); meanwhile the share of companies with a partial phase-out plan rose from 35% to 48%, reflecting significant progress considering that those 160 companies represent over 80% of global industrial emissions.[122]

Investors have increasingly aligned their portfolios with the emission reduction goals of the Paris Agreement. Some, including the Bank of England, seek to reduce the financial risks of climate change, such as economic losses generated by extreme or chronic climate events, increased environmental regulations that negatively impact asset value, technological and demand changes, and litigation arising from inaction.[123] Global initiatives, including the Task Force on Climate-related Financial Disclosures, help the financial sector appropriately assess and price those climate-related risks and identify opportunities.[124]

i See Glossary for definition. The majority of the green bonds issued are green "use of proceeds" or asset-linked bonds. Proceeds from these bonds are earmarked for green projects but are backed by the issuer's entire balance sheet. To qualify for green bond status, they are often verified by a third party, such as the Climate Bond Standard Board, which certifies that the bond will fund projects that include benefits to the environment. See Socialfintech.org, "Capital markets and climate change: The green bond", https://socialfintech.org/capital-markets-and-climate-change-the-green-bond.

ii Securitisation is "the process whereby illiquid assets or rights are pooled and transformed into tradeable and interest-bearing financial instruments that are sold to capital market investors. These illiquid assets/claims may include bank or car loans, lease contracts, trade receivables, and insurance premiums, among others. Securitization acts not only as a means to raise cash on the capital markets, but also as a credit risk transfer tool." See Deloitte, *Securitization: Structured Finance Solutions* (Luxembourg: 2018), https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/financialservices/lu_securitization-finance-solutions.pdf.

iii Data are not available for 2020; in 2019, the total amount divested was over USD 11 trillion. See Gofossilfree.org, "Commitments", https://gofossilfree.org/divestment/commitments.

iv Climate Action 100+ is now the largest ever investor engagement initiative on climate change. The numbers of focus companies, by sector, are: 39 oil and gas companies, 31 utility companies, 26 transport companies, 26 industrial companies, 23 mining and metals companies and 14 consumer products companies. See Climate Action 100+ , "Companies", https://www.climateaction100.org/whos-involved/companies.

As of early 2021, 71 financial institutions had announced their divestment from oil and gas, particularly from oil sands extraction and Arctic drilling[i]; 36 of these institutions joined the movement in 2020 alone.[125]

A survey of institutional investors representing USD 6.9 trillion under management showed that the COVID-19 economic crisis slowed planned divestments from fossil fuels, with investors divesting 4.5%, on average, of their overall portfolio in 2020, compared to 5.7% planned in the previous year's survey.[126] Respondents now expect to divest 5.2% over the next five years and 8.6% over 10 years, down from forecasts of 14.4% and 15.6%.[127]

DOES DIVESTMENT REDUCE GLOBAL FOSSIL FUEL INVESTMENT?

Although divestment is growing, investment in fossil fuel-related companies among 35 private global banks has increased since the signing of the Paris Agreement, from USD 640 billion in 2016 to USD 736 billion in 2019.[128] This is because while some bank policies exclude financing for fossil fuel projects, they still allow lending to the corporate entity that engages in these projects.[129] Evidence also shows that other investors end up purchasing the divested stocks and that declining stock prices in fossil fuel company cannot be linked specifically to divestment.[130]

Divestment, per se, generally does not affect either the production costs of fossil fuel energy or consumers' willingness to buy.[131] Consequently, the profits of oil and gas company owners are not decreasing.[132] Furthermore, research has found that although increased oil and gas divestment pledges in a country are associated with lower capital flows to domestic oil and gas companies, this may not affect global investment, as national banks in countries with stricter exclusion policies seem to provide more funding to oil and gas companies abroad.[133]

However, some countries and some industry sectors have made progress in the sense that some companies now face new challenges in their development of fossil fuel projects.[134] In South Africa, the restrictive lending policies of two banks increased the cost of capital for fossil fuel projects.[135] Similarly, an estimated 85% of the banks in the global market have expressed unwillingness to invest in coal power plants.[136] As a result, 72% of the plants under construction outside of China have come to rely on Chinese financing.[137] As of July 2020, most public finance for coal worldwide came from China's financial institutions, which allocated USD 50 billion to 53,129 MW of installed capacity.[138]

When considering the impact on global greenhouse gas emissions, studies conclude that investment in innovative and environmentally friendly companies has a greater impact than divestment.[139]

DOES DIVESTMENT ATTRACT INVESTMENT IN RENEWABLES?

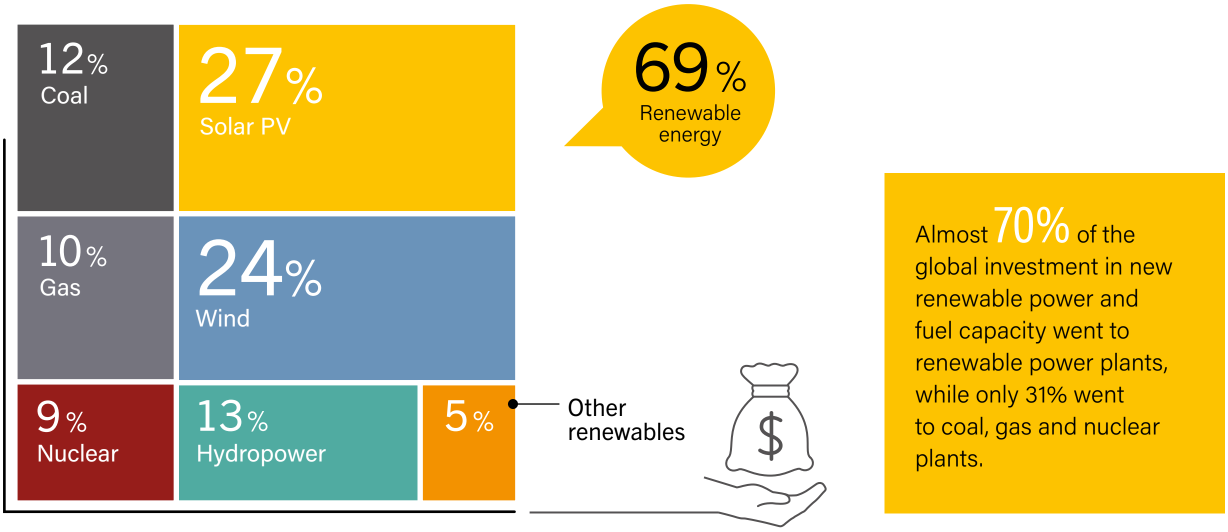
In 2020, the estimated global investment in new renewable power and fuel capacity was more than twice that in coal, natural gas or nuclear power generating plants combined.[140] Nearly 70% of the estimated global investment was allocated to renewable energy power plants, while only 31% went to coal, gas and nuclear plants.[141] (→ *See Figure 51.*) Renewable energy projects have become more appealing, particularly in light of the COVID-19 crisis. A 2020 survey of institutional investors with USD 6.9 trillion under management found that investors planned to nearly double their allocation to renewable energy infrastructure in the near term, from 4.2% in 2020 to 10.8% in 2030.[142]

However, it is hard to establish a direct link between divesting from fossil fuels and investing in renewable energy. One study

General guidance on reinvestment appears to be lacking for institutions and companies engaged in divestment.

i Oil sands extraction is among the world's most carbon-intensive, large-scale crude oil operations. Carbon emissions are reported to be 31% higher than from conventional oil. Arctic drilling to extract natural gas and oil is more costly and technologically complicated than drilling for oil on land. Large amounts of water are consumed in the process, and the ability to respond to oil spills is highly limited. See Institute for Energy Economics and Financial Analysis, "Finance is leaving oil and gas", https://ieefa.org/finance-exiting-oil-and-gas.

FIGURE 51.
Estimated Global Investment in New Power Capacity, by Type, 2020



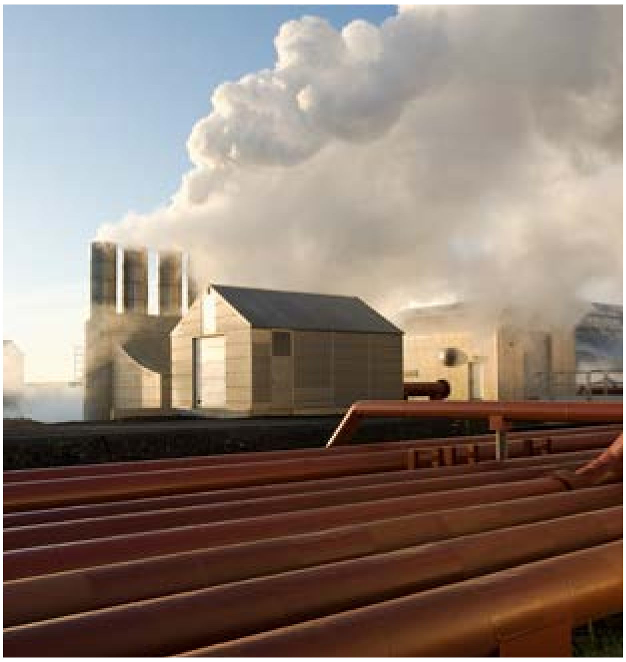
Note: Hydropower includes pumped storage. Other renewables include bio-power, geothermal power, concentrating solar power (CSP) and ocean power.
Source: IEA. See endnote 141 for this chapter.

suggests that between 2001 and 2018, more than half of energy utilities that prioritise growth in renewables over other technologies continued investing in natural gas and/or coal.[143] Of these utilities, 34% posted negative growth in coal and gas, and just 15% divested from both in their portfolios.[144] Two-thirds of the utilities prioritising renewable energy were located mainly in the United States and Europe (particularly Germany), while 10% were in China.[145]

A few concrete examples of "divest-invest" exist, including the pledge by 12 major cities[i] to divest from fossil fuel companies while investing in a "green and just recovery" from the COVID-19 crisis.[146] This commitment – "Divesting from Fossil Fuels, Investing in a Sustainable Future" – made by cities across three continents recognises the potential to create jobs, limit climate risk and facilitate the energy transition.[147] In another example, the Catholic Impact Investing Pledge represents 28 Catholic organisations with USD 40 billion in assets under management that have committed to invest in environmental and justice issues.[148]

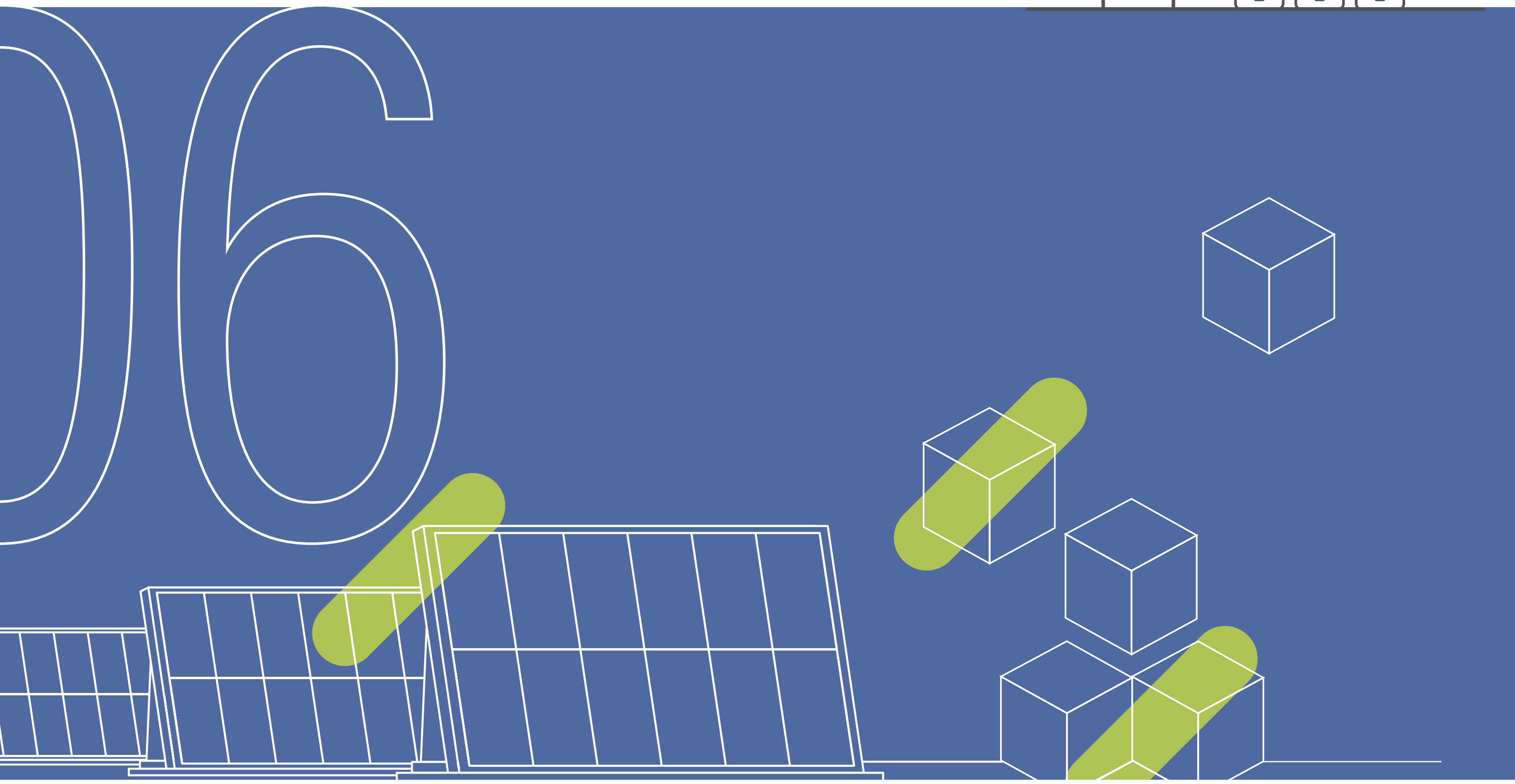
In 2014, the Rockefeller Brothers Fund pledged to divest from fossil fuels. As of December 2020, the Fund's total fossil fuel exposure was an estimated 0.3% of its total portfolio, down from 6.6% in April 2014.[149] The Fund also has set a target to allocate 20% of its portfolio to "impact" investments, prioritising investments in support of the United Nations Sustainable Development Goals, including clean energy development.[150]

The apparent impact of divestment campaigns lies in their ability to raise consciousness and change public attitudes about the fossil fuel industry and investments in fossil fuels.[151] However, general guidance still appears to be lacking regarding reinvestment for institutions and companies engaged in divestment.[152]



i The 12 cities are Berlin, Bristol, Cape Town, Durban, London, Los Angeles, Milan, New Orleans, New York City, Oslo, Pittsburgh and Vancouver.

A new energy storage project marks the next frontier of Apple's efforts to become carbon neutral for its supply chain and products by 2030.



06 ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

KEY FACTS

- Several power systems saw record levels of **variable renewable electricity (VRE)** penetration in 2020.
- **Digital technologies** were used to modernise grid monitoring and control, improve forecasting, and optimise the flexibility and capacity of existing grid infrastructure.
- **Wholesale electricity market design** enabled more participation for VRE power plants, energy storage and flexible demand in certain markets.
- In 2020, the **heat pump** market was up in North America and Europe but slowed in the Asia-Pacific region. **Electric car** sales rose 41%, a significant increase considering that global car sales overall were down for the year. New **battery storage** projects increased 62% compared to 2019.

Energy systems integration involves the co-ordinated design, implementation, operation, planning and adaptation of energy systems with the objective of delivering reliable, safe, cost-effective energy services with minimal environmental impact.[1] Here, it is addressed with a specific focus on the integration of higher levels of renewable energy in power grids, heating and cooling systems, and transport fuelling systems.

Renewable energy can lead to more sustainable and economical operation of energy systems.[2] However, as shares of renewable energy grow, the systems that have evolved or been designed around conventional[i] energy sources require adaptation efforts to maintain or improve the services that they deliver.[3] These efforts include top-down integration measures such as the planning and design of infrastructure, markets and regulatory frameworks, as well as the bottom-up development and advancement of supply- and demand-side technologies. To this end, governments, regulators, energy utilities, technology companies and energy consumers have been addressing barriers that may slow or halt the growth of renewables, working to expand existing end-uses of renewables, and creating new markets for renewable energy technologies and services.[4]

In the power sector in particular, rapid growth in the installed capacity and penetration of variable renewable electricity (VRE) sources – such as solar photovoltaic (PV) and wind power – has occurred in many countries.[5] VRE achieved unprecedented penetration levels during 2020 due to cost reductions and

i The word "conventional" is used here to describe non-renewable energy resources or large hydropower. In the context of the power sector, the term "conventional generators" describes fossil fuel, nuclear and large hydropower generators.

subsequent demand.[6] In addition, COVID-19 containment measures that depressed electricity demand resulted in increased VRE shares due to preferential dispatch protocols and marginal cost advantages.[7]

Several power systems reached record-high instantaneous VRE shares in 2020, forcing grid operators to apply a range of new and existing measures to ensure ongoing service.[8] Some power systems, for example in South Australia, reached such high VRE penetration levels that electricity supply routinely exceeded demand.[9] During the year, consumption of electricity from renewable sources surpassed that from coal in the United States for the first time in 130 years, while the United Kingdom's power system operated without coal power for 18 consecutive days – the longest period in nearly 140 years.[10]

At the end of 2020, renewables represented around 29% of global electricity generation, and more than 9% of the total generation was estimated to be from solar PV and wind power.[11] The penetration of modern renewables in transport and in the heating and cooling sector was much lower than this. (→ *See Global Overview chapter.*) Many examples of renewables integration in 2020 occurred in the power sector (or involved the electrification of end-uses in other sectors), particularly in countries and regions with supportive policy environments or energy markets such as Australia, China, Europe and North America. (→ *See Policy Landscape chapter.*)

In recent years, the growing shares of variable energy resources that require the use of power inverters[i], and the corresponding decentralisation of power systems, have created new requirements for control and monitoring systems.[12] These shifts in turn have prompted the wider digitalisation of transmission and distribution grids, and of downstream or "behind-the-meter" systems that incorporate electricity generation, storage and demand.[13] As power grids continue to evolve, numerous examples have emerged of the digitalisation of key operating nodes (such as control rooms and sub-stations) in order to more effectively process and manage more complex flows of information.[14] Advanced digital technologies including artificial intelligence and machine learning have been applied to improve the accuracy of both generation and demand forecasting, and to enable the aggregation of distributed energy resources[ii] to improve power system flexibility.[15]

Several technologies have supported the integration of renewables by enabling greater flexibility in energy systems or by promoting the linking of energy supply and demand across electricity, thermal and transport applications. Among the more mature or commercialised enabling technologies are heat pumps, electric vehicles (EVs) and certain types of energy storage, such as batteries. Other technologies that were still emerging during 2020 but that may help to reach higher shares of renewables in all sectors include renewable hydrogen, non-lithium-ion batteries (such as flow batteries) and novel forms of mechanical storage.

Power systems are adapting to higher shares of generation capacity based on power inverters, such as **wind and solar.**

i Technologies such as solar panels, wind turbines and batteries use power inverters to convert direct current (DC) into alternating current (AC) to allow them to interface with AC-based power systems. Resources that require the use of inverters do not have the rotational characteristics of conventional gas, steam or hydro generators, and impose different stability requirements on power systems as they become more prevalent.

ii Distributed energy resources include generators such as solar PV and wind plants, energy storage facilities and sources of demand.

INTEGRATION OF RENEWABLES IN THE POWER SECTOR

In numerous countries, the power sector has transformed rapidly in recent years, driven by the increased penetration of variable wind and solar power.[16] At least nine countries produced more than 20% of their electricity generation from VRE in 2020: Denmark, Uruguay, Ireland, Germany, Greece, Spain, the United Kingdom, Portugal and, for the first time, Australia.[17] (→ *See Figure 52.*)

Cost declines in wind, solar PV and battery technologies have profoundly impacted the rate of deployment of renewables in power systems. Solar PV and onshore wind have become the cheapest sources of new generation for around two-thirds of the world's population.[18] Battery storage has become the most cost-effective new-build technology for "peaking" services in natural gas-importing areas such as China, Europe, and Japan, and the ability of batteries to provide peak capacity has been found to improve as shares of solar electricity increase, due to a change[i] in generation patterns.[19]

Declining costs have made renewables more accessible, prompting numerous major multinationals to commit to achieving 100% renewable energy supply over the coming decade. Many have been driving innovation in the procurement and application of renewable energy.[20] (→ *See Feature chapter.*)

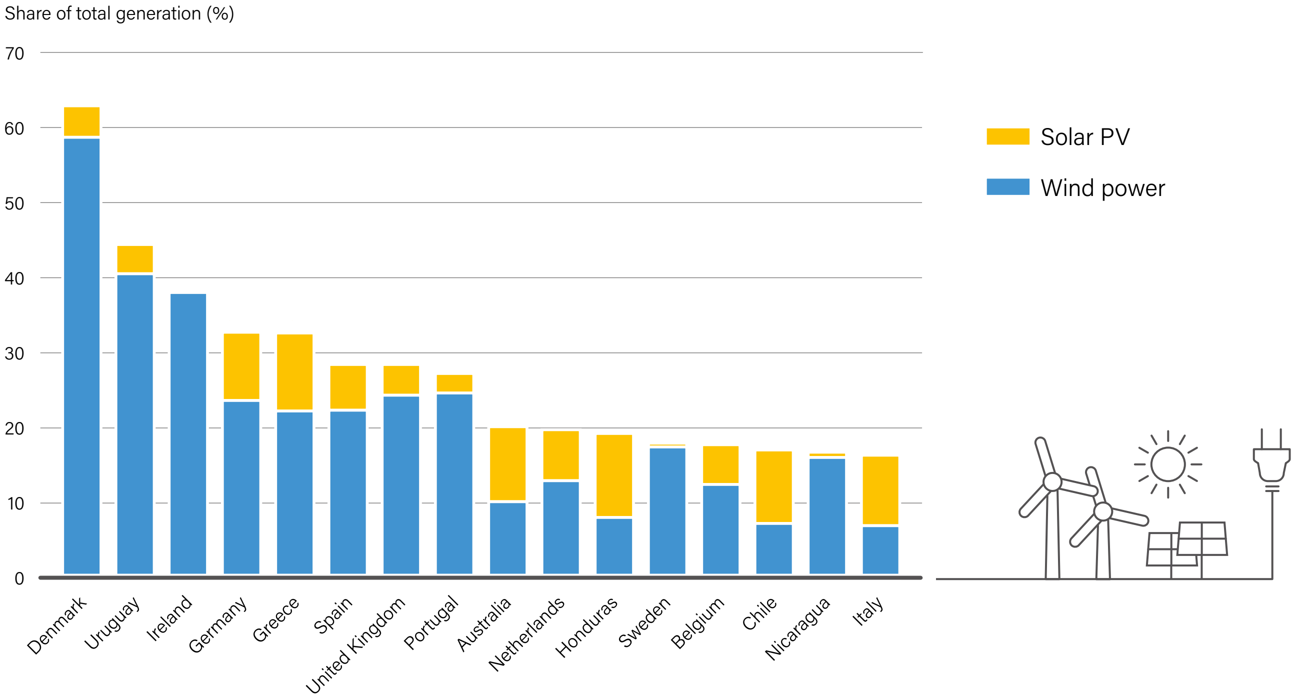
With the growth of VRE, the adaptation of power systems is occurring on several fronts. Many interventions have focused on maintaining or increasing system flexibility. As the grid evolves, flexibility is essential to ensuring safe and economical service delivery. Some of the key adaptations observed during 2020 involved:

- competitive wholesale market design to reward or promote flexibility and to allow for accurate pricing and remuneration of capacity and ancillary services from VRE and energy storage[ii];
- the wider integration of flexibility and ancillary services from sources of supply and demand, and from inverter-based energy resources;
- advances in the forecasting of electricity generation and demand, with the aid of advanced digital technologies; and
- enhanced grid interconnections and grid management systems to promote new linkages between VRE sources and demand centres, and to optimise the use of existing infrastructure.

i This change is colloquially known as the "duck curve" effect: increased shares of solar electricity can result in a generation surplus in the day and a deficit in the mornings and evenings when solar generation drops off. This can increase required generation ramp rates in the mornings and evenings and shorten peak demand periods to less than four hours, which in turn create conditions well suited to use of batteries for peak capacity supply. See endnote 19 for this chapter.

ii Electricity market design extends beyond wholesale markets. For brevity, the GSR covers key high-level developments at the wholesale level only.

FIGURE 52.
Share of Electricity Generation from Variable Renewable Energy, Top Countries, 2020



Note: Figure shows countries among the top 15 according to the best available data at the time of publication. Several smaller countries with low total generation and/or high imports are excluded from this list.

Source: See endnote 17 for this chapter.

COMPETITIVE WHOLESALE ELECTRICITY MARKET DESIGN

Many electricity markets source essential ancillary services – such as operating reserves, voltage support and "black start"[i] capabilities – from conventional generators based on fossil gas, steam and hydro turbines. Market adaptations are required to enable the procurement of these and other services from VRE generators, energy storage systems and sources of flexible demand.[21] To this end, market rules were adapted in several electricity markets during 2020 to allow for the participation of ancillary services from distributed energy resources.

In the United States, the Federal Energy Regulatory Commission instituted market reforms that allow behind-the-meter VRE generators, EVs, batteries and flexible demand resources to participate in wholesale electricity markets in an aggregated manner.[22] At the state level, the California Public Utilities Commission set new interconnection policies for distributed resources (including EVs) and behind-the-meter solar and batteries, which may allow these resources to incorporate flexibility into the grid.[23] The UK system operator National Grid implemented several mechanisms to procure grid support from distributed energy resources, including communication and control signals that will allow wind farms to provide voltage and frequency response as well as generation reserves.[24]

INTEGRATION OF FLEXIBILITY AND ANCILLARY SERVICES FROM SOURCES OF SUPPLY AND DEMAND

In conventional power systems with low VRE shares, the ability to balance generation and demand is obtained primarily from flexible or "dispatchable" conventional generators that adjust their output to follow demand.[25] With rising VRE shares in some power systems, the need for flexibility also has increased, with hour-to-hour ramping requirements growing in numerous major power systems including in China, the European Union (EU), India and the United States.[26]

In some cases, the flexibility of conventional generators has been enhanced in parallel with rising VRE shares. This has helped reduce the curtailment of both VRE and conventional generation, for example during periods of low demand and high VRE production, when conventional generators are increasingly required to ramp down production.[27] In parallel, flexibility and other ancillary services also have been recruited from VRE generators themselves, which have been continuously adapted to contribute essential reliability services to power grids, including frequency control and regulation, inertial response, voltage regulation, reactive power voltage support (also known as power factor correction) and even black start capabilities.[28] In Chile, for example, the National Electricity Coordinator approved during 2020 the provision of ancillary services from a 141 MW solar PV plant, including frequency management. During tests, the plant was shown to provide better performance for load response than equivalent gas-powered generators.[29]

A novel demonstration of ancillary service provision by VRE generators occurred when the UK energy utility ScottishPower used an offshore wind farm to restore part of the electricity grid after an outage, demonstrating the world's first "black start" using VRE.[30] The ability of solar and wind inverters to provide this type of "grid-forming" service was the subject of US government-funded research and development (R&D) by GE, which aims to improve synchronisation between multiple grid-forming inverters and to improve the stability of power systems with high shares of variable renewables.[31]

Demand flexibility also is an important enabler of higher shares of VRE, primarily through demand response initiatives that use market signals – such as time-of-use pricing, incentive payments and penalties – to influence the electricity use of consumers.[32] In 2020, demand response technologies were supported by enabling policies in countries such as Japan and the United States, and in California demand response provided significant system support during heat waves that put severe pressure on the power system.[33] Nonetheless, while demand response capacity has grown in recent years, particularly in Australia, the United States and some European countries, global growth rates remain below those targeted by sustainable development plans such as the United Nations Sustainable Development Strategy.[34]

Energy storage in the form of pumped hydropower has long contributed to grid stability. More recently, however, other storage technologies including batteries have been used to provide both

i A "black start" is the process of restoring power in a power grid following a total or complete shutdown. Black starts have traditionally been supported by hydropower or non-renewable generators.

grid flexibility and ancillary services.[35] In some cases, batteries have started to compete in capacity markets, for example in the United Kingdom, where more than 100 megawatts (MW) of utility-scale battery assets secured demand-side response contracts in capacity auctions during 2020.[36]

Aggregators have extracted grid services from fleets of behind-the-meter batteries, along with other distributed energy resources, through the use of digital technologies that can control fleets of assets providing flexibility services. By late 2020, the system operator National Grid, which operates in both the United Kingdom and the United States, had enrolled 13 aggregators and 900 individual sites on a centralised demand management system across the US states of Massachusetts, New York and Rhode Island to provide more than 400 MW of flexible load capacity.[37] In the United Kingdom, the aggregation platform developed by GridBeyond, a company specialising in advanced demand response, enabled the participation of both batteries and sources of flexible demand in auctions for grid balancing services conducted by National Grid.[38] In Japan, Next Kraftwerke, a German operator of "virtual power plants[i]", partnered with Toshiba to aggregate privately owned VRE and energy storage resources to provide grid balancing services in the control reserve market, which will allow participation of these sources starting in April 2022.[39]

Fleets of EVs have been aggregated to provide grid balancing services in the Netherlands, Norway, and Sweden, and the provision of similar services is planned in Germany.[40] (→ *See Electric Vehicles section in this chapter.*)

ADVANCES IN FORECASTING OF GENERATION AND DEMAND

Digital technologies have begun facilitating more accurate forecasting of both power system demand and VRE generation. This has allowed system operators to better anticipate VRE availability and to more cost-effectively balance generation and demand in short-term energy market scheduling. This can in turn reduce fuel costs, minimise curtailment of VRE and improve system flexibility and reliability.[41]

With the growing number of grid-connected, distributed VRE resources, generation forecasting has become increasingly complex and specialised.[42] Many grid operators have partnered with forecasting companies to more accurately predict VRE availability. For example, in Australia, the forecasting company Solcast started a demonstration project in 2020 for the South Australian grid, aimed at providing higher-resolution forecasts updated with greater frequency than pre-existing alternatives, that are designed specifically for the Australian energy market.[43]

Artificial intelligence has potential applications in increasing complex generation forecasting, and in managing and leveraging real-time supply and demand information produced by decentralising power systems.[44] In 2020, US federal funding was announced for 10 research projects that will use artificial intelligence and machine learning technologies to predict system failures, schedule maintenance, address data quality issues and combine disparate datasets, with the aim of improving both forecasting and maintenance activities.[45]

Electricity demand forecasting has started to move away from traditional worst-case methodologies to probabilistic studies that involve intense computation processes.[46] Advances in computational power are allowing artificial intelligence and machine learning systems to more rapidly analyse data from energy users, bringing a bottom-up view to electricity demand forecasting and enabling more precise balancing of demand with available generation.[47]

ENHANCED GRID INTERCONNECTIONS AND GRID MANAGEMENT SYSTEMS

Grid infrastructure can connect regions with strong wind and solar resources to demand centres; aggregate VRE resources over larger geographic areas to mitigate the effects of variability; and link or expand electricity markets to increase market scope and efficiency.[48] Conversely, grid infrastructure constraints have become a significant bottleneck for the integration of VRE capacity.[49] In the United States, 245 clean energy projects at an advanced permitting stage were withdrawn between 2016 and 2020, due largely to limited transmission capacity.[50] Large transmission projects also have faced regulatory and developmental hurdles, notably in Australia, Germany and the United States, due to public opposition, environmental concerns, and the complexity of land-use agreements and approval processes.[51]

Despite these barriers, numerous major transmission projects were advanced in 2020, driven by demand for grid capacity from VRE generators.[52] (→ *See Figure 53.*) In the United States, around 225 kilometres of the planned 1,600 kilometre, USD 2.6 billion Gateway West line was completed, which will eventually connect wind farms in the state of Wyoming with electricity markets in other western states, via Idaho.[53] Other major transmission projects, including long-range high-voltage direct current (HVDC[ii]) projects, were in planning across the country.[54] In India, seven new transmission projects were approved, which will allow the grid interconnection of new renewable energy parks in the country.[55]

South Africa's public utility Eskom announced plans in 2020 to implement an SAR 118 billion (USD 8.4 billion) transmission expansion project to accommodate new generation targets, including 25 gigawatts (GW) of wind and solar by 2030.[56]

> Digital technologies are increasing the usable capacity of existing transmission infrastructure, often a barrier to wider **VRE deployment.**

i Virtual power plants use digital technologies to co-ordinate and control energy demand, distributed generation and energy storage. See Glossary.

ii High-voltage direct current (HVDC) lines are used for high-efficiency, bulk transmission of power over large distances.

Several cross-border transmission projects were under construction or in planning during 2020. A new transmission line being built between the United Kingdom and France was one of several planned HVDC interconnections linking European electricity markets, with the objective of improving overall system flexibility and stability.[57] In Australia, an HVDC connection was proposed to connect solar generation in the country's Northern Territory with the city-state of Singapore.[58]

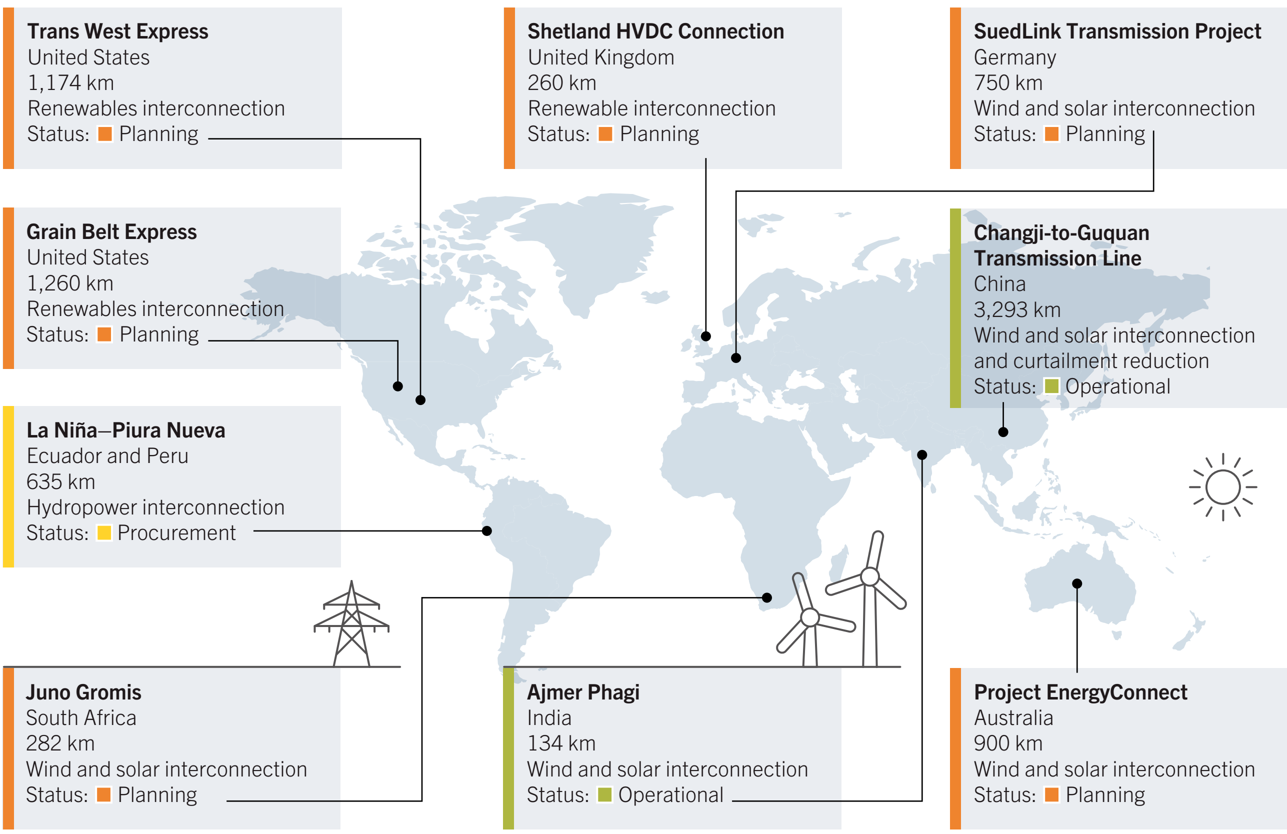
The digitalisation of power networks has helped to increase the efficiency and usable capacity of existing infrastructure. Digital technologies and methodologies – including power flow controls, dynamic line ratings and topology optimisation – can prioritise connections in the network that are below capacity in real time, reducing the need for infrastructure upgrades.[59] Several companies were developing technologies in these areas during 2020, including a number of start-ups.[60]

Many grid operators have expanded the digitalisation of grid control rooms, improved data management and communication technologies, built more robust security and enabled remote operations.[61] These efforts were accelerated in 2020 as lockdown measures related to COVID-19 forced many grid operations staff to work remotely.[62]

Changes also occurred at the level of the sub-station, where analogue communication and control systems were replaced with integrated digital solutions that enhance system visibility, operations and diagnostics; in India, for example, digital automation systems were retrofitted at more than 100 sub-stations over the past decade.[63] Improved data management capabilities at both the control room and sub-station levels of these network nodes supports the creation of "digital twins" – predictive grid simulations that promise to streamline maintenance.[64] Grid simulation systems, such as GE's Distribution Operations Training Simulator (DOTS), were used to train grid operations personnel and to run scenario analyses that cater to the growth of distributed energy resources.[65]

In some cases, digitalisation has prompted a shift of control away from centralised control rooms at the transmission level to smaller decentralised control points in the distribution system. WePower, a blockchain-based renewable energy financing and trading platform developed in Lithuania, was piloted in several markets, giving electricity distributors a more central role in the management of distributed energy resources and enabling the localised trade of electricity.[66]

FIGURE 53.
Transmission Projects to Integrate Higher Shares of Renewables



Note: All projects are high-voltage direct current (HVDC).
Source: See endnote 52 for this chapter.

ADVANCES IN THE INTEGRATION OF RENEWABLES IN TRANSPORT AND HEATING

In contrast to the power sector, shares of renewables in global transport and heating systems remained low in 2020, accounting for less than 4% of total final energy consumption in transport and less than 11% in heating and cooling.[67] (→ *See Global Overview chapter.*)

Integrating renewables in both transport and heating systems requires planning and adaptation to enable or increase the blending or substitution of fossil energy with renewable alternatives such as direct solar thermal or geothermal heat, biofuels, biogas or renewable hydrogen. Alternatively, electrification of end-uses within these sectors can enable consumption of variable or other forms of renewable electricity. In many cases, these adaptations require wide-ranging changes to the infrastructure and technologies that both deliver and consume energy, such as the adaptation of gas pipelines to accommodate renewable hydrogen, the implementation of new safety standards, and the replacement or conversion of heating systems and vehicles.[68] Many of these efforts faced cost barriers in 2020 as oil prices plummeted on the back of reduced demand during COVID-19 lockdowns.[69]

Despite limited overall progress in transport, certain segments saw notable pre-commercial and commercial activities that supported the integration of renewables. Integration in road-based transport was advanced mainly through the electrification of vehicles (→ *see Electric Vehicles section in this chapter*). By contrast, efforts to use renewables in the aviation sector were focused mostly on the use of advanced biofuels, as well as the early-stage development of aircraft adapted to use renewable hydrogen. In September 2020, the world's largest aircraft manufacturer, Airbus (France), announced three concept designs for hydrogen aircraft, along with plans to bring the first emission-free passenger aircraft to market by 2035.[70] Smaller prototypes for electric and fuel cell passenger aeroplanes were tested in 2020 in both Canada and the United States.[71]

A range of renewable fuel types were either available or under development for shipping applications as of 2020. Of these, biodiesel, biofuel oil and bio-liquefied natural gas (LNG)[i] were commercially available.[72] (→ *See Bioenergy section in Market and Industry chapter.*) Others such as biomass-to-liquid and renewable hydrogen and ammonia remained pre-commercial.[73] In 2020, hydrogen ships were under development in Europe and Japan, while the world's first electric container ship, the *Yara Birkeland*, was launched in Norway.[74]

Efforts also were under way to integrate renewables into rail transport, which is already widely electrified and can directly access growing shares of VRE in a number of markets. Countries such as India and Scotland advanced plans in 2020 to decarbonise rail transport through wider electrification of diesel-based networks, and the parallel implementation of VRE capacity.[75] A train running on renewable hydrogen also was piloted in the United Kingdom during the year.[76]

Heat pumps are a mature and widely deployed technology and possess vast but largely untapped potential as an enabling technology for the use of renewable energy in the heating and cooling sectors. Along with other enabling technologies such as EVs and energy storage, heat pumps can contribute greatly to power system flexibility to support higher shares of VRE. (→ *See Heat Pumps section in this chapter.*)

The potential of heat pumps for integration of renewables was illustrated by the Dutch transmission system operator Tennet in early 2021, when it announced plans to use heat pumps with intelligent controls to create up to 1 GW of flexible demand while maximising the use of available wind and solar power.[77] The UK government announced plans to aggressively scale up the installation of heat pumps to decarbonise heating demand, as part of the prime minister's green industrial strategy.[78] Geothermal heat, solar thermal heat and various forms of bioenergy also were being used for heating and cooling. (→ *See Bioenergy, Geothermal and Solar Thermal sections in Market and Industry chapter.*)

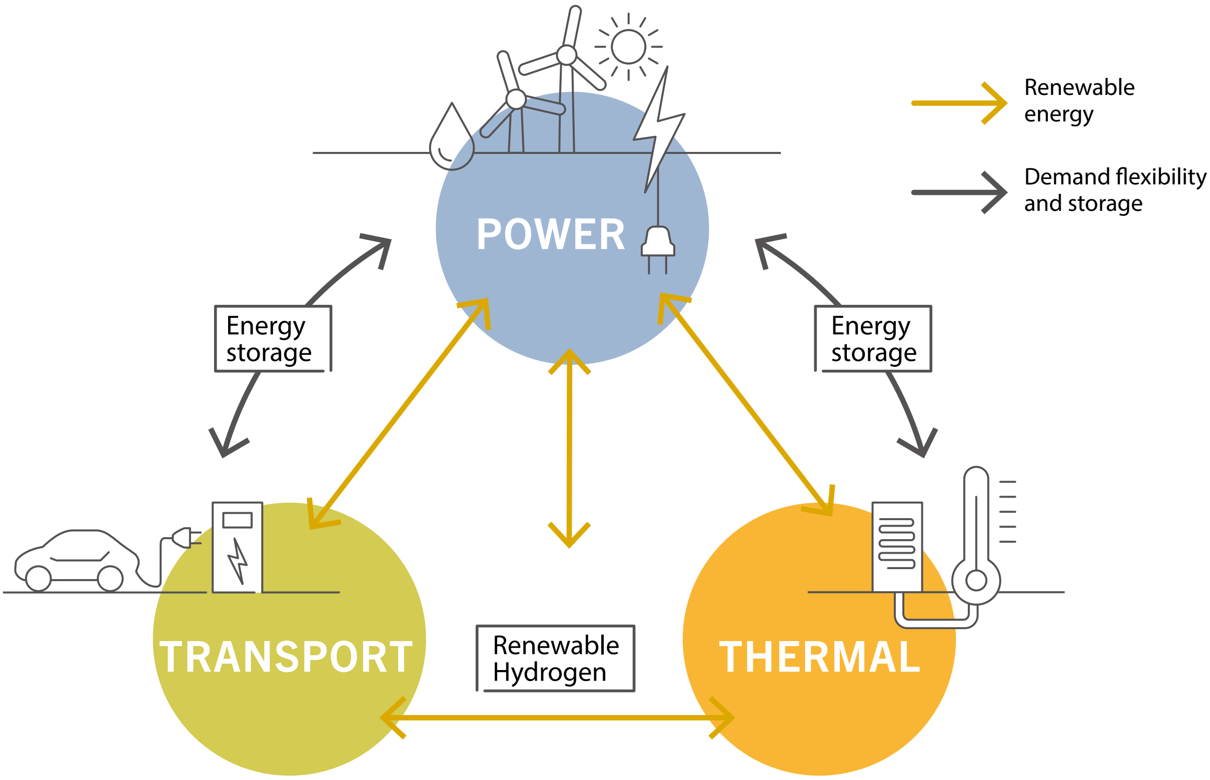
Electrification efforts faced cost barriers in 2020 as **oil prices plummeted** on the back of reduced demand during COVID-19 lockdowns.

i Biofuel oil is a fuel oil produced through the pyrolysis of biomass or municipal solid waste. Bio-LNG is a renewable alternative to natural gas that is produced during the anaerobic digestion process of food or animal waste.

ENABLING TECHNOLOGIES FOR SYSTEMS INTEGRATION

Heat pumps, electric vehicles and energy storage are important end-use technologies, supporting the integration of renewables and contributing to greater flexibility in power systems.[79] (→ *See Figure 54.*) All of these technologies experienced increased sales in 2020 despite the onset of the COVID-19 pandemic. While most of the technologies are well known, their level of uptake remains low relative to their potential. For example, heat pumps are widely present in new residential buildings in several countries, yet they still represent less than 5% of the global market for heating appliances.[80] EVs occupy only a small share of the vehicle market despite surging adoption in recent years. Meanwhile, the need for and interest in energy storage has increased with rising integration of VRE in power systems worldwide.

FIGURE 54.
Coupling of the Power, Thermal and Transport Sectors



Source: See endnote 79 for this chapter.

HEAT PUMPS

Heat pumps are commonly used to meet heating and cooling needs for residential, commercial and industrial applications – such as space heating and cooling, water heating, freezing and refrigeration – within a wide range of temperatures.[81] Heat pumps[i] typically are reversible units that can provide both heating and cooling functions by drawing on one of three main energy sources: the ground, ambient air and bodies of water.[82] During operation, these systems use an auxiliary source of energy (such as electricity or fossil gas) to transfer ambient energy from a low-temperature source to a higher-temperature sink in a refrigeration cycle.[83] Ambient heat sources include air, water, geothermal heat and different types of waste heat (such as from industrial processes and sewage treatment).[84]

Depending on the inherent efficiency of the heat pump itself, its external operating conditions and the system design, heat pumps that use varying ambient sources of energy differ in their installation costs and overall efficiency.[85] In general, heat pumps are highly efficient heating and cooling devices.

The most efficient systems, operating under optimal conditions, can deliver three to five units of thermal energy (either heating or cooling) for every one unit of external energy consumed.[86] The difference between the energy delivered and the energy consumed is considered the renewable portion of the heat pump output, regardless of the external energy source.[87] When the auxiliary energy used to drive the heat pump is renewable, so is 100% of the output of the heat pump.[88]

Electric heat pumps are among the most cost-effective solutions for decarbonising thermal energy, notably in buildings, and can be used in various environments, even in colder climates.[89] When used with appropriate control measures and thermal storage (e.g., thermal mass, hot water tanks, chilled water), they also can increase power system flexibility by using (surplus) solar and wind power, and coupling electricity generation with heating and cooling devices that have flexible demand characteristics. Adding large-scale heat pumps to district heating systems can increase flexibility through their inherent thermal storage capabilities.[90]

i In official statistics, heat pumps also can be recorded as "reversible air conditioners", depending on the energy services they provide. Typically, if the appliance supplies energy only for cooling, it is considered an "air conditioner", despite the fact that it is reversible. This chapter endeavours to report official statistics for heat pumps that are in use to provide energy for both heating and cooling.

When the energy used to drive a heat pump is renewable, so is **100% of its output.**

HEAT PUMP MARKETS

Although heat pump technology is widely used in the residential and commercial sectors, limited availability of data related to this market remains a barrier to full assessment of global heat pump uptake.

Globally, air-source heat pumps accounted for the highest sales volumes of all heat pump technologies in recent years, followed by ground-source heat pumps.[91] Although heat pumps are the most common heating technology in new buildings in several countries, they met only 5% of global building heating demand in 2019.[92]

In the Asia-Pacific region, despite subsidies in Japan and northern China favouring heat pump adoption, uptake has slowed due to a decline in Chinese infrastructure investment and because natural gas boilers are favoured under China's coal phase-out plan (as a less-expensive alternative to coal boilers in residential heating).[93] Additionally, because China does not classify heat pumps as a renewable technology at the national level, the devices cannot benefit from the clean heating subsidy offered in the country's north.[94] Even so, more than 117 million[i] heat pumps were sold nationwide in 2020, virtually all (99%) of which were air-to-air heat pumps, with the rest being air-to-water devices.[95]

In Japan, air-source heat pumps dominated heat pump sales in 2020, although the total number sold fell 0.7% from the previous year (to 10.7 million in 2020, down from 10.8 million in 2019).[96] This drop was due to lower demand in the commercial sector (down 14.3%) and only minor growth in the residential sector (up 0.6%).[97] Japan also is a significant market for heat pumps for water heating, sales of which increased 30% since 2015 to more than 500,000 water heaters sold in 2020.[98]

The capability of heat pumps to provide both heating and cooling is a key factor behind their increased adoption in North America.[99] The US heat pump market continued to grow, with 3.4 million units sold in 2020, up nearly 10% from 2019.[100] The majority of demand comes from new buildings and the replacement of oil and propane furnaces.[101] In Canada, more than 530,000 air-source heat pumps[ii] were sold in 2020, up 6% from 2019, thanks to an increase in residential installations (up 13%) that counterbalanced a decline in the commercial sector (down 21%).[102]

In Europe, despite facing shortages in the supply chain due to the COVID-19 crisis, 1.6 million heat pumps were installed in 2020, up 5% from the previous year.[103] France (394,000 units sold), Italy (233,000) and Germany (140,000) were the regional leaders, totalling 48% of all sales.[104] Spain, Sweden, Finland, Norway, Denmark, Poland and the Netherlands rounded out the top 10 countries.[105]

Germany experienced a 40% increase in heat pump installations, for a cumulative total of more than 1 million units by year's end, entering the top three in Europe for the first time.[106] Uptake in the country was boosted by an aggressive new subsidy scheme that aims to accelerate heat pump deployment (subsidising 35% of the cost in new construction and renovations and up to 45% if the heat pump replaces an oil-fuelled boiler).[107] Similar support schemes exist in France – where the level of subsidy depends on household income – as well as in Italy.[108] The United Kingdom has proposed a target of 600,000 annual heat pump installations by 2028.[109]

In industrial processes, the growing application of heat pumps for temperatures below 100 degrees Celsius (°C) has demonstrated the reliability and efficiency of waste heat recovery for industrial processes, directly combining cooling and heating demands.[110] However, despite the technology's availability and potential, heat pumps are still not widespread in the sector, even for new installed capacity where fossil fuel heating equipment remains the standard.[111] This is due, among others, to a lack of knowledge and awareness on the part of end-users and to a capital cost that remains high.[112]

Heat pump uptake slowed in Asia-Pacific in 2020, while **the market rose** 10% in the US, 6% in Canada, and 5% in Europe.

i Many of these units are used only for cooling, while heating demand is met via district heat or other sources.

ii Refers to residential and commercial units that are used for both heating and cooling. This number also includes ductless split units that are used for cooling only.

HEAT PUMP INDUSTRY

The heat pump industry in 2020 was characterised by several trends, including company acquisitions, new solutions integrating heat pumps with other energy devices, and the development of components adapted to refrigerants with low global warming potentials, and those for ground-source heat pumps.

Several acquisitions of companies occurred throughout the year. NIBE (Sweden) completed six acquisitions, including of: water heater manufacturer TIKI Group (Serbia), the heat pump manufacturer Waterkotte GmbH (Germany), a 50% share in the Üntes group of companies (Turkey), a 51% share in Nathan Holding B.V. (Netherlands), a 60% share in VEÅ AB (Sweden) and an 87.5% share in the element company Termotech s.r.l. (Italy).[113] In addition, Legal & General Capital (UK) acquired a 36% stake in the ground-source heat pump firm Kensa (UK), with the aim of establishing a portfolio of companies decarbonising heat and transport.[114] Bosch Thermotechnology (Germany) acquired a controlling share in Electra Industries (Israel), a manufacturer of heat pumps based in Haifa.[115] After installing heat pumps in its own stores, the retailer IKEA (Sweden) decided to commercialise residential heat pumps in Switzerland as part of its "clean energy offer".[116]

Both start-ups and well-established companies have begun offering or exploring energy solutions that integrate heat pumps with renewable or storage technologies. In 2020, the US Department of Energy explored existing European heat pump modular solutions that, by reducing the complexity of installation, could offer an effective solution to mass renovation of existing buildings in the United States and elsewhere.[117] LG Electronics (Republic of Korea) launched a hybrid system in early 2021 combining a heat pump, a solar PV system and battery storage to provide residential and small commercial buildings with heat and electricity.[118] The system also includes an energy management system, controlled by a software application, to maximise self-consumption.[119]

Factory Zero (Netherlands), Nilan (Denmark) and Drexel und Weiss (Germany) have proposed integrating a heat pump, hot water tank, ventilation system, solar PV system and monitoring equipment in a single "box".[120] Such integrated systems, designed for use in nearly zero-energy buildings, have the potential to unlock the US retrofit market and to help the EU optimise the heating and cooling energy consumption of buildings through mass renovation.[121]

The heat pump market continues to be dominated by vapour compression technologies; however, opportunities exist for innovation to address overall efficiency of the system, operation in cold climates and digitalisation to improve integration with electricity grids.[122] Innovation in Europe was driven in part by the EU's "F-gas" regulation, which gradually phases out the sale and manufacture of fluorinated gases – substances used mainly as refrigerants in air conditioning and other refrigeration systems with a high global warming potential – and encourages their replacement by alternatives with low global warming potential.[123] Heat pump manufacturers have focused on developing solutions to replace the refrigerants necessary for the exchange of heat within heat pump systems with HFO (hydrofluoro-olefin) and hydrocarbon refrigerants as well as carbon dioxide and ammonia – all of which have lower global warming potential.[124] Adapted components, such as compressors and heat exchangers, have been developed to accommodate the new refrigerants.[125]

Several notable ground-source heat pump pilot projects were approved, implemented or researched in 2020. The US state of Massachusetts approved two pilots for neighbourhood-wide deployment of the ground-source heat pump innovation concept GeoMicroDistrict, which uses the existing natural gas infrastructure to transfer thermal energy between a shared district water loop and a building's heating and cooling distribution systems.[126] In the United Kingdom, a housing provider started installing a demonstration project in 300 homes to show how ground-source heat pumps with digitalised heating controls can reduce heating costs for residents and help balance the electricity grid.[127] A study in Mongolia, where temperatures can drop to minus 40°C, revealed that ground-source heat pumps were the most cost-effective and low-carbon solutions for heating.[128] Meanwhile, the US ground-source heat pump company Dandelion Energy raised USD 30 million to scale up its technology and develop its product further.[129]

For processes requiring temperatures above 100°C, current research, development and demonstration is focusing on the 100-200°C range.[130] The low priority of industrial heat pumps in the EU research programme Horizon 2020 limited the number of European projects.[131] However, some national projects focusing on the 100-200°C range exist in Scandinavia and the Netherlands and have shown that heat pumps can achieve significant energy savings and emission reductions.[132]

In recent years, innovation in digital technologies to integrate heat pumps and electric grids has begun allowing them to benefit from operational cost reductions using demand-side flexibility as well as enabling new business models.[133]

ELECTRIC VEHICLES

Electric vehicles[i] are an important end-use for renewable energy, as they allow the displacement of fossil fuels in key transport modes, mainly in road and rail transport. On the demand side, EVs achieve a double benefit: not only are they more energy efficient than vehicles with internal combustion engines, but the required electricity can be supplied more readily from a wide variety of renewables. Allowing and interrupting the battery charging to coincide with renewable power generation could help integrate larger shares of VRE.[134] On the supply side, technology such as vehicle-to-grid can turn EVs into energy storage devices, allowing batteries to store energy from the electricity grid during off-peak periods and then to discharge it back to the network when it is most needed, increasing the overall flexibility of the grid.[135]

In 2020, key developments continued to focus on electric cars (passenger EVs), whereas electrification efforts for marine vehicles and aviation remained limited.[136] The rise in the number of EVs can be explained by the favourable support policy context (e.g., fiscal incentives, tightening of emission standards, support for charging infrastructure) and by the benefits such vehicles offer.[137] Consumers in Europe and the United States remained attracted, by order of importance, to the environmental benefit, the economic savings, the ease of driving and the novelty value of owning new technology.[138]

ELECTRIC VEHICLE MARKETS

While global car sales decreased in 2020 – falling 14% from the previous year, according to preliminary market data – global sales of electric cars (including both battery electric vehicles and plug-in hybrids[ii]) resisted the COVID-19-induced downturn with 2.9 million units sold, up 41% from 2019.[139] Among other factors, this is attributed to favourable existing policies, lower battery costs and the fact that EV buyers are mainly from high-income households, which tended to be less affected by the crisis.[140] As a result, the market share of electric cars in new car sales reached 4.6% in 2020, surpassing the 2019 record of 2.7%, and the global stock of electric cars grew to exceed 10 million units.[141] (→ *See Figure 55.*)

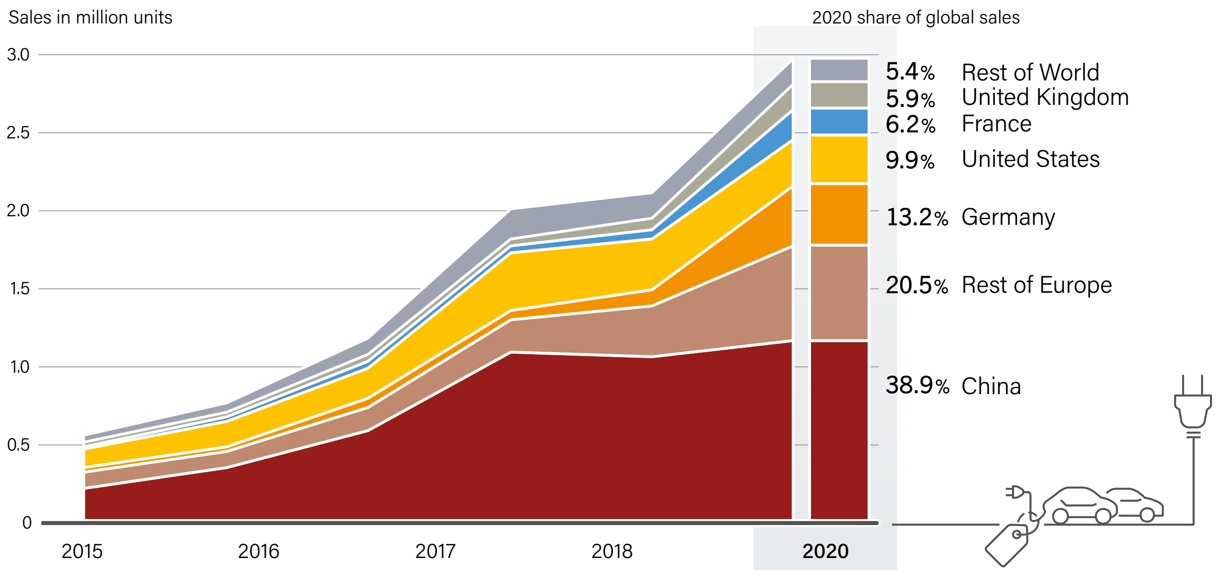
Europe[iii] was the only market that did not experience lower **electric car** sales during the first half of 2020 – showing a 55% increase – whereas global EV sales were on average 15% lower due to lockdown measures that affected both the supply and demand.[142] For the full year, electric car sales in Europe were up 142% compared to 2019 (reaching almost 1.4 million units), surpassing China for the first time since 2015 (with 1.16 million units sold, only a 9% increase).[143] The United States occupied the third position with 296,000 units sold despite a 10% decrease compared to 2019.[144] Japan and Australia were the only major markets where the EV market declined more than overall car sales in 2020.[145] Norway remained the leading country in EV market share (75% in 2020), followed by Iceland (52%) and Sweden (32%).[146]

i Electric vehicles include any transport vehicles that use electric drive and can take an electric charge from an external source, or from hydrogen in the case of fuel cell EVs. See Glossary.

ii Fuel cell electric vehicles represent a small share of the total EV market, accounting for less than 0.5% of total sales in 2020.

iii Including EU Member States and members of the European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland).

FIGURE 55.
Electric Car Global Sales, Top Countries and Rest of World, 2015-2020



Note: Includes battery electric passenger vehicles and plug-in hybrid passenger electric vehicles.
Source: IEA. See endnote 141 for this chapter.

The number of public charging stations totalled **1.3 million** in 2020, with most of the infrastructure built in China and Europe.

As of the end of 2020, around 290 million electric **two- and three-wheelers** were on the road globally.[147] Around one-third of all units sold during the year were electric, and 99% of new registrations were in China, with most of the rest also in Asia.[148] The Indian market fell 5.5% in 2020, with more than 25,000 electric two-wheelers sold.[149] While still being a minor market, the European market grew rapidly (up 30%).[150] Electric micro-mobility (particularly e-bikes) increased greatly in the second half of 2020, benefiting from the implementation of new bike lanes and other mobility measures; in the United States, e-bike sales more than doubled for the year.[151]

China remained the main **electric bus** market in 2020 (up 9% in 2020) and accounted for 99% of global sales from 2016 to 2020; however, adoption of the buses increased worldwide, especially in Europe (up 7%).[152] Electric buses were the second largest category of EV spending (based on preliminary sales data and estimated vehicle prices) after private vehicles.[153] Still, annual spending in this sector continued its downward trend, totalling USD 11 billion in 2020 (down 48% since 2016).[154] This was due mainly to changing market dynamics in China, specifically a reduction in e-bus prices, combined with a decrease in purchase subsidies and market saturation in large cities, which slowed annual sales.[155]

Around 4,000 electric buses (including battery electric, plug-in hybrid, trolley buses[i] and fuel cell buses) were circulating in Europe, representing 1% of the total fleet.[156] Around 2,100 new electric buses were registered in 2020, up 22% from 2019.[157] Denmark led in the market share of new e-buses (78%), followed by Luxembourg (67%) and the Netherlands (65%).[158] In Latin America, 2,000 buses – less than 1% of the region's fleet – were electric in 2020, despite steady interest and the fact that Santiago, Chile has the largest number of electric buses of any city outside of China (400 added in 2020 for a total stock of more than 800).[159] Bogotá (Colombia) added 470 electric buses in 2020 and placed an order for 596 more.[160]

In North America, only 580 new electric buses were registered in 2020, down nearly 15% from 2019.[161] California leads in US deployment due to the state's commitment to buy only electric buses (battery electric or fuel cell) from 2019 onwards.[162] India increased electric bus registrations 34% to 600 in 2020.[163]

Alongside the increased adoption of EVs, **charging infrastructure** is expanding as well. Investment in EV charging infrastructure has surged since 2016 and constituted a small portion of the spending on new cars in 2020 (USD 4.1 billion in public charging and USD 2.1 billion in home charging).[164] The number of public charging stations installed globally totalled 1.3 million in 2020, up 45% from the previous year, with most of the infrastructure built in China and Europe.[165]

In China, an estimated 10,000 new public and private charging stations were installed monthly in 2020, due mainly to the government response to the COVID-19 crisis, which included high investments in charger installation to stimulate the economy.[166] China had a total of around 810,000 chargers as of 2020, followed by Europe with 288,000 chargers.[167] The United States had only around 100,000 total charging stations due to a lack of public support and incentives.[168] Canada allocated funds in its COVID-19 recovery plan towards deploying charging stations to accelerate EV use.[169]

Globally, all urban and high-speed **rail** networks are electric, and in 2019 around 75% of conventional (not high-speed) passenger rail activity used electricity.[170] The electrification of conventional rail continued in 2020: India announced its commitment to a 100% electrified railway network by 2023, and Russian Railways announced new electrification of freight routes in the country, despite the fact that 86% of cargo volumes in the Russian Federation are already served by electric trains.[171] The United Kingdom also continued the electrification of its railways, with 251 kilometres electrified between 2019 and 2020.[172]

ELECTRIC VEHICLE INDUSTRY

In 2020, the leading manufacturers of passenger EVs globally were (by number of units produced) Tesla (US), Volkswagen (Germany), General Motors (US), R-N-M Alliance (France/Japan), Hyundai (Republic of Korea), BYD (China), BMW (Germany), Daimler AG (Germany), PSA (France) and Volvo (Sweden).[173] Tesla became the first automaker globally to produce 1 million electric cars, and its Model 3 became the all-time best selling EV, replacing the Nissan LEAF.[174]

In the European market, Renault (France) has a significant presence, with its Zoe model replacing Tesla's Model 3 as the best-selling battery electric car in Europe in 2020.[175] In China, three start-ups experienced a surge in sales in 2020: Nio (one of the best-performing US-listed Chinese companies in 2020) and Xpeng doubled their sales compared to 2019, while LiAuto saw a 150% increase.[176]

In 2020, traditional automakers continued announcing plans to shift production to EVs. Volvo started manufacturing its first fully electric car late in the year and said that half of the company's global sales would be fully electric by 2025.[177] General Motors announced plans for 40% of its models to be electric by 2025 and for all of its new light-duty vehicles to be zero-emission by 2035, while Jaguar (UK) committed to being a fully electric car manufacturer by 2025.[178]

i Instead of using an onboard battery, trolley buses draw power from overhead wires.

Both GM and Jaguar plan to include sport-utility vehicle (SUV) models in their electric transition (with the Hummer and Jaguar, respectively). Overall, nearly all major auto manufacturers – including Audi, Ford, Honda, Hyundai and Volkswagen – already have (or have announced) new electric SUVs in the coming years.[179] By 2020, 44% of EV models available worldwide were SUVs.[180] The increased offering of electric SUVs (100 models globally in 2019) compared to fossil-fuelled SUVs (180 models in 2019) is not yet reflected in sales, as the vast majority of SUVs sold (97%) are still fossil-fuelled.[181]

In total, 160 new EV models (battery electric and plug-in hybrid) were launched in 2020, mainly in China (77 models, 61 of them fully electric) and Europe (65 models, 30 of them fully electric).[182] Manufacturers in North America came in a distant third, launching only 15 new models.[183]

In 2020, seven truck manufacturers, including Daimler (Germany), Ford (US), Scania and Volvo (both Sweden), signed a pledge to stop selling diesel-fuelled trucks by 2040, a decade earlier than previously planned – focusing instead on the development of hydrogen battery and clean fuel technologies.[184] Meanwhile, Daimler's Mercedes-Benz abandoned its hydrogen car programme due to high costs and a lack of market interest.[185]

Several joint ventures were established in 2020, including Marathon Motor Engineering, a company created between Hyundai and Olympic champion Haile Gebrselassie, which began assembling the all-electric Hyundai Ioniq in Ethiopia.[186] Other joint ventures focused on the production of specific equipment for EVs. They included, among others: LG Electronics' association with the supplier Magna International to manufacture e-motors, inverters and onboard chargers; the launch of Automotive Cells Company, a battery manufacture created by Total and PSA (both France); and Volkswagen's acquisition of a more than 25% stake in Guoxuan High-tech Co Ltd, a Chinese battery manufacturer, in order to boost the German automaker's market penetration in China.[187] In Japan, seven companies established the e5 Consortium, aiming to develop zero-emission electric ships.[188]

Innovation in the EV battery industry, and in particular in lithium-ion batteries, was the main driver of technological progress in the electricity storage area.[189] Significant cost reductions were achieved due to an increase in manufacturing production, growth in battery EV sales and the introduction of new pack designs.[190] (→ *See Energy Storage Industry section in this chapter.*) With the sharp drop in battery costs (down 89% between 2010 and 2020) and depending on the automaker and location, EVs are nearing the cost (with the same margin for automakers) of comparable petrol-powered vehicles (cost parity is projected to occur by 2023).[191] Tesla announced its ambition to produce EV batteries using cobalt-free cathodes, since reducing the use of this costly material would make EVs more affordable.[192]

New charging technologies, crucial for mass adoption of EVs, also experienced significant developments. Wireless charging has been piloted in various cities – including in UK cities to charge taxis and in US cities to charge electric buses – and China announced a national standard for the technology.[193] Other charging innovations include pop-up pavement chargers[i] (an innovation of the start-up Urban Electric Networks, which concluded a successful trial period in 2020 and planned to start commercial production in 2021); electrified roads (transmitting energy directly to EVs); and lamp-post charging (such as London's "electric avenue", where 24 lamp-posts were converted by Siemens of Germany into charging units).[194]

In the United States, more than 35 utility-run managed charging demonstration projects were developed in 2019, in order to balance grid loads by changing customer behaviour or controlling charging time, scale and location.[195] Innovation also occurred in battery charging speeds, helping to reduce a key barrier for EV adoption; StoreDot (Israel) developed EV batteries that can be fully charged in just five minutes, using organic compounds combined with nano-materials.[196]

In 2020, around 80 vehicle-to-grid projects (mostly pilots) were in place mainly in Europe (51) and the United States (20), involving more than 6,700 EV chargers.[197] Only six projects were initiated during the year, involving 195 chargers, down from 9 projects started in 2019.[198]

Pilot projects for hydrogen-fuelled trains are under way in the United Kingdom and Scotland as a means to decarbonise the regional railway network.[199] Using hydrogen could be a less expensive option than electrifying the UK's rail system because existing diesel trains can be retrofitted to be hydrogen powered.[200] For shipping, Japan created an academic and corporate consortium to research integrating renewable hydrogen production systems in cargo ships to power them during low-wind periods.[201]

Electric aviation remains pre-commercial, with Rolls-Royce (UK) developing the fastest all-electric aircraft and Airbus (France) developing electric and hybrid-electric propulsion for commercial aircraft and partnering with Air Race E, the world's first all-electric aeroplane race.[202] Start-up Wisk continued to progress towards passenger trials of its autonomous air taxi service in New Zealand.[203]

i Pop-up pavement chargers are on-street devices that retract into the ground when not in use. EV owners can charge their cars using a standard cable and a mobile app to locate chargers around the city. See Urban Electric, https://www.urbanelectric.london.

ENERGY STORAGE

Energy storage has been in use for decades. Batteries were invented in the 1800s, and the first pumped storage projects were implemented in the early 1900s.[204] More recently, storage has been increasing alongside the use of portable electronics, electrification of the transport sector and the growth of VRE (mainly wind and solar power), among others. The recent increase in VRE production requires more flexibility in the power grid, which can be supplied by energy storage by balancing demand and production.[205] By reducing curtailment and improving flexibility, storage technologies have the potential to increase the share of VRE in power systems. In buildings and industry, thermal energy facilitates temporal shifts in renewable electricity or thermal energy supply to meet heating and cooling demands, and can allow (surplus) renewable electricity to serve thermal loads.[206]

Forms of energy storage (and key technologies) include mechanical (pumped storage, flywheels), electrochemical (batteries, including lithium-ion and lead-acid), chemical (hydrogen) and thermal energy storage (molten salt storage and hot water tanks). Depending on the type of technology, storage duration can greatly vary: from less than 10 hours (e.g., some batteries) to seasonal storage (e.g., pumped storage)[i]. Battery energy storage systems were among the technologies with the most activity in 2020, as they are easy to deploy and benefit from cost reduction trends. Renewable hydrogen also experienced lower costs and a more favourable policy context.

ENERGY STORAGE MARKETS

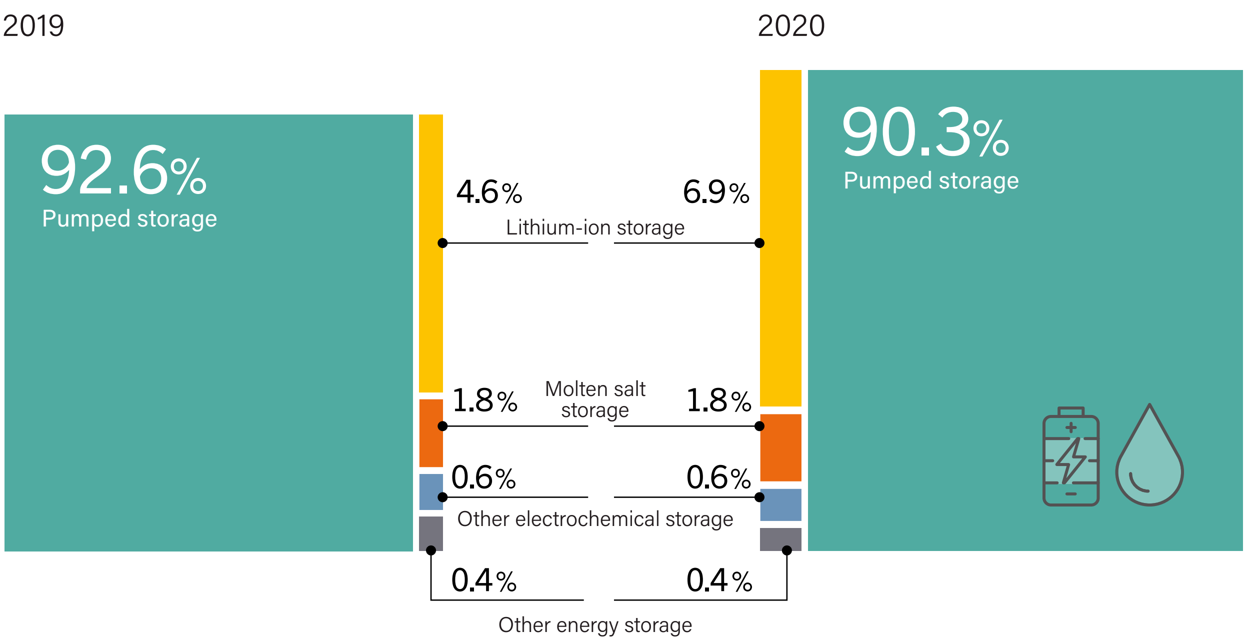
The COVID-19 crisis delayed the implementation of energy storage projects in 2020, as supply chains were disrupted and travel restrictions limited the ability to visit sites.[207] However, new electrochemical energy storage projects put into operation reached 4.73 GW in 2020, up 62% compared to 2019, when only 2.9 GW of capacity was added to electricity systems worldwide (nearly 30% less than in 2018).[208] The energy storage market also benefited from new opportunities in COVID stimulus packages that aim for a sustainable recovery and carbon-neutrality goals.[209]

Overall, the **global operational energy storage** capacity reached 191.1 GW in 2020, reflecting 3.4% growth year-on-year.[210] (→ *See Figure 56.*) The largest market was China (18.6% of the global total), which reached 35.6 GW by year's end, up 4.9% from 2019.[211] The United States added 1.5 GW due to a record fourth quarter in the deployment of front-of-the-meter storage, to reach an estimated 23.2 GW by year's end.[212] The European market grew 54%, adding 1.7 gigawatt-hours[ii] (GWh) of storage capacity for a cumulative capacity 5.4 GWh.[213] In addition, 4 GW was either announced or under construction across the region.[214]

i The terminology used to categorise energy storage by duration or discharge period varies widely in academia, industry and the media. The GSR considers "short-duration" storage to be energy storage for less than around 10 hours, and "long-duration" refers to periods of around 10 to 100 hours. "Long-term" or "seasonal" storage describes energy storage for periods in excess of 100 hours, typically for weeks, months and years. Pumped storage is a mature and widely commercialised form of long-term storage.

ii Due to data limitations, Europe's storage capacity is reported in GWh.

FIGURE 56.
Share of Global Energy Storage Installed Capacity, by Technology, 2019 and 2020



Source: See endnote 210 for this chapter.

Pumped storage continued to represent the majority of the installed capacity, with 90.3%, up 0.9% from 2019.[215] In China, pumped hydro capacity increased 4.9% for a total of 31.8 GW.[216] (→ *See Hydropower section in Market and Industry chapter.*)

Batteries continued their upward trend and constituted the second largest energy storage technology by capacity. In 2020, global battery storage capacity increased 1.7% to 14.2 GW (or 7.5% of total operating storage capacity).[217] Most of this battery capacity (92%) was lithium-ion batteries, with the rest being mainly sodium-sulphur (NAS) batteries (3.6%) and lead-acid batteries (3.4%).[218]

China surpassed 3 GW of battery capacity in 2020, up 91.2% from 2019, thanks notably to the addition of 1,083 MW of newly operational electrochemical storage, including the 200 MW / 200 MWh SPIC Huanghe New Energy Base project in Qinghai province.[219] The United States also experienced additions of large-scale batteries, surpassing the 1 GW mark in 2020 to reach 1.76 GW of overall capacity, up 72% from the previous year.[220] New installations totalled 734 MW and were located mainly in California, including the world's biggest batteries at the time of publication: Vistra Moss Landing (300 MW / 1,200 MWh) and the Getaway project (250 MW / 250 MWh).[221] Mega-battery projects also were added in nine other US states, mainly in Massachusetts and Texas.[222]

The residential behind-the meter battery sector grew strongly in the United States, with 90.1 MW deployed just in the fourth quarter of 2020, due mainly to rising interest among homeowners in California.[223] Germany also experienced a high increase in residential energy storage – from 185,000 installed units in 2019 to 285,000 in 2020 – for a combined 1.21 MW of capacity by year's end.[224] This was driven by the growing number of homeowners purchasing solar PV systems (which doubled compared to 2019), combined with the fact that half of them also invested in batteries.[225] In Australia, small-scale battery storage increased from around 1,500 units in 2016 to more than 9,000 in 2020.[226]

Thanks to a decline in battery prices and an increase in wind and solar generation, interest in renewables-plus-storage projects – which combine wind and/or solar power capacity with on-site batteries, creating a hybrid power plant – grew in recent years to become a significant driver of battery storage implementation.[227] In the United States, the number of hybrid sites doubled between 2016 and 2019, with solar PV-plus-storage more common than wind-plus-storage.[228] In 2020, China announced several hybrid projects of more than 1 GW of capacity, many of which opted for wind energy as the basis of generation, combined with solar or thermal energy.[229] In Japan, a 6 MW utility-scale solar-plus-storage project became commercially operational at year's end.[230]

Thermal energy storage (TES), mainly in the form of molten salts, represented 1.5% of the global operational energy storage capacity in 2020 (around 2.9 GW).[231] Due to its advanced technological readiness, molten salt storage is commonly deployed in concentrating solar thermal power (CSP) plants.[232] As of the end of 2020, the top five countries in installed molten salt storage capacity in CSP plants were Spain, the United States, South Africa, China and Morocco.[233]

Thermal energy also is commonly stored as water in tanks, large pits, boreholes, underground, or in a phase change material, which can be frozen and melted, thus storing and releasing heat.[234] The largest application of TES is in district heating and cooling networks, including those that generate heat from solar energy.[235] In these systems, TES can decouple the demand for district heating and cooling with available electricity generation, enabling seasonal storage of variable renewable energy sources.[236] In early 2021, five large-scale thermal storage pits[i] were in operation in Denmark connected to the local district

i In pit storages, water is stored in a pit with an insulated cover on top. See State of Green, "Large-scale thermal storage pit", https://stateofgreen.com/en/partners/ramboll/solutions/large-scale-thermal-pit-storage.

heating network.[237] District energy systems with thermal energy storage are present in Denmark, France, Germany, and Sweden, countries that make up more than 60% of total thermal storage capacity for district heating.[238] Use of TES in district heating also is rising in China, supported by the country's 13th Renewable Energy Development Five-Year Plan.[239]

Renewable hydrogen is an energy storage solution that can be produced by using renewable electricity to power an electrolyser that splits the hydrogen from water molecules.[240] Hydrogen also is produced directly from fossil fuels by using steam methane reforming or coal gasification.[241] More than 99% of global hydrogen production is currently based on fossil fuels (mainly natural gas).[242]

Interest in renewable hydrogen gained momentum in 2020, due in part to low electricity prices for VRE and to reductions in the cost of electrolysis equipment (leading to declines in production costs); in addition, several countries announced national hydrogen strategies and hydrogen energy frameworks (including Chile, Norway, the Russian Federation and some European countries).[243] At the time of publication, 8 countries and the EU had national strategies in place to support renewable hydrogen development, and several had hydrogen roadmaps or draft renewable hydrogen strategies in the pipeline.[244] China and India also have shown interest in ramping up their renewable hydrogen economies.[245] (→ *See Table 5 in Policy Landscape chapter.*)

By the end of 2020, the global operating capacity for hydrogen electrolysers was an estimated 82 MW (including all types of hydrogen) – or less than 0.05% of the global energy storage capacity.[246] The largest renewable hydrogen production site as of April 2021 was located in Quebec, Canada, offering 20 MW capacity of hydrogen produced with hydropower, doubling within a year the previous record set by Japan's 10 MW solar-powered hydrogen production facility.[247] As of the end 2020, additional renewable hydrogen projects of more than 130 GW were either announced, planned or under construction (most of them gigawatt-sized projects).[248]

Europe and Australia dominate the renewable hydrogen pipeline, with 11 proposed projects of 1 GW electrolyser capacity or more.[249] The largest is being developed by a consortium of European companies that plans to use 95 GW of solar capacity to power 67 GW of electrolysers across multiple locations in Europe by 2030.[250] The next largest project is the Asian Renewable Energy Hub in Pilbara, Australia, where 16 GW of onshore wind and 10 GW of solar capacity will be used to supply 14 GW of electrolyser capacity.[251] These are followed by projects in the Netherlands and Germany (10 GW capacity, combined with offshore wind power capacity), China (5 GW), Saudi Arabia (4 GW), Chile (1.6 GW), Denmark (1.3 GW) and Portugal (1 GW).[252] At a smaller scale, the European Marine Energy Centre announced in 2020 its plan to combine tidal power and battery technology to generate renewable hydrogen at a pilot project in Scotland.[253]

Other developments related to energy storage markets included the release in California of the first major procurement targeting long-duration storage projects (more than eight hours storage).[254] Companies answering this tender covered a range of technologies, including pumped storage, gravity-based, compressed air, and flow batteries, as well as the current market leader lithium-ion batteries.[255]

A total of 130 GW of **renewable hydrogen** projects were either announced, planned or under construction in 2020.

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

ENERGY STORAGE INDUSTRY

During 2020, the energy storage industry saw significant cost reductions and innovation in battery technologies, and an increased number of collaborations to produce renewable hydrogen.

Innovation has been particularly dynamic in the electricity storage sector, where inventions (estimated based on the number of international patent families[i]) increased 14% annually on average between 2005 and 2018, four times faster than for all technology fields.[256] This was driven mainly by **battery** innovation, particularly lithium-ion batteries used in consumer electronic devices and EVs.[257] (→ *See Electric Vehicles section in this chapter.*) Lithium-ion battery costs have fallen sharply, with prices dipping below USD 100 per kWh for the first time in 2020, and a market average of USD 137 per kWh.[258]

Battery R&D during the year included research on a long-duration solar flow battery that would benefit from a 20% efficiency record, and solid-state batteries that could be safer and contain more energy than traditional lithium-ion batteries (for example the lithium-metal battery of the start-up QuantumScap).[259] A power plant in the US state of Minnesota announced a pilot deployment of the "aqueous air" battery system, developed by the long-duration battery start-up Form Energy, which can discharge power capacity for up to 150 hours.[260] Among other investments, the state of California allocated USD 16.8 million for energy storage technologies beyond lithium-ion (employing mainly zinc), and Form Energy raised USD 70 million prior to its first commercial deployments.[261] Eos, the developer of an aqueous zinc battery, entered the stock exchange market in 2020.[262]

Environmental and social concerns related to the increased mining of lithium for battery production prompted development in new extraction technologies from geothermal waters, with the aim of producing "green lithium" with a reduced environmental footprint.[263]

Because battery technologies are driven mainly by the EV industry, most cannot provide the type of long-duration storage suitable to countries that have harsh climatic conditions and low capacity for operation and maintenance.[264] Moreover, the high cost of battery technology has prohibited batteries from being widely deployed in large-scale projects in developing countries, even though these areas may have the greatest deployment potential.[265] To remedy this, the World Bank convened a global partnership in 2019 fostering R&D, policies, and regulations, and in 2020 the Bank highlighted the importance of warranties for battery storage systems to mitigate the technical and operational risks of projects for buyers and investors.[266]

In the area of renewables-plus-storage, two collaborations emerged in the United Kingdom. The first is a joint venture between Macquarie's Green Investment Group and renewable energy developer Enso Energy to develop 1 GW of unsubsidised solar-plus-storage capacity.[267] In addition, the French electricity provider EDF partnered with the UK renewable energy developer Octo Energy to build 200 MW of solar-plus-storage capacity in England and Wales.[268]

i Each international patent family (IPF) represents "a unique invention and includes patent applications filed and published in at least two countries. IPFs are a reliable and neutral proxy for inventive activity because they provide a degree of control for patent quality and value by only representing inventions deemed important enough by the inventor to seek protection internationally". See International Energy Agency, *Innovation in Batteries and Electricity Storage* (Paris: 2020), https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage.

Thermal energy storage technologies outside of molten salt storage include the commercially viable thermal tanks (using water) and solid-state (using rocks, concrete and ceramic bricks) and liquid air variants – which made significant strides towards commercial viability in the near term.[269] A UK-based company started developing large-scale plants whose mechanism stores energy by supercooling air in pressurised above-ground tanks.[270] Solid-state thermal storage using concrete is being developed in China as part of a deployment of CSP demonstration projects, and a US research programme progressed in 2020 with the design of a pilot-scale facility, with testing expected in late 2021.[271]

Malta Inc. (US), a company developing pumped heat energy storage – a long-duration energy storage technology converting electricity to be stored as thermal energy – raised USD 50 million in funding in 2020.[272]

Renewable hydrogen was a key focus of international collaboration in 2020, with some of the world's largest energy companies including Enel (Italy), ENGIE (France), Equinor (Norway), Ørsted (Denmark), Shell (Netherlands), BP (UK) and Siemens (Germany) proposing projects, investments and partnerships in low-carbon hydrogen.[273] The United Nations' Green Hydrogen Catapult aims to scale up hydrogen production by 2026 and was initiated by, among others, IPP ACWA Power (Saudi Arabia), wind turbine manufacturer OEM Envision (China), offshore wind developer Ørsted (Denmark) and gas grid firm Snam (Italy).[274]

Several countries agreed to join efforts on hydrogen development, such as the United States and the Netherlands, which are collaborating on collecting, analysing and sharing information on hydrogen production and infrastructure technologies; Germany and Niger, which established a hydrogen exploration partnership that will expand to West Africa; and the Netherlands and Portugal, which signed an agreement to facilitate the transport of renewable hydrogen between the two countries.[275] Additionally, the 21 countries participating in the Clean Energy Ministerial Hydrogen Initiative (CEM H2I) will collaborate on policies, programmes and projects across all sectors of the economy to accelerate the commercial implementation of hydrogen and fuel cell technologies.[276]

With this rising interest, the cost of producing hydrogen from electricity has declined, falling 40% on average between 2015 and 2020.[277] However, the cost of producing renewable hydrogen in 2020 remained around twice as expensive as producing hydrogen using carbon capture.[278]

Boosted by cost declines and by national plans promoting investment in hydrogen production (as in France, Germany and Portugal), Europe has been centre stage for numerous new consortia.[279] In Portugal, the electric utility EDP, grid manager REN, and industrial group Martifer, together with Danish wind turbine manufacturer Vestas and other European partners, announced their intention to evaluate the viability of the H2Sines renewable hydrogen project.[280] In the Netherlands, NorthH2, a consortium comprising Shell, the gas grid operator Gasunie and the Port of Groningen, planned to develop a "Hydrogen Valley" linking offshore wind generation to renewable hydrogen production.[281]

Major electricity groups – including EDP, Enel, Iberdrola (Spain) and Ørsted – also created the joint initiative Choose Renewable Hydrogen to highlight hydrogen's role and to ensure its integration into EU COVID-19 recovery plans.[282] In early 2021, Sinopec, the Chinese oil giant and the world's largest producer of hydrogen, announced plans to move away from fossil-based hydrogen production and towards renewable hydrogen; it also entered a partnership with the world's largest solar PV manufacturer, Longi Green Energy Technology.[283]

In the United States, the hydrogen-specialised company Plug Power raised USD 1 billion to build a gigafactory that would produce both fuel cells and electrolysers.[284] Additionally, major energy player Xcel Energy targeted wind and solar investment in the state of Minnesota to plan a renewable hydrogen production pilot as well as energy storage and EV charging.[285]

The cost of producing renewable hydrogen in 2020 remained around **twice as expensive** as producing hydrogen using carbon capture.

In 2020, United Airlines pledged to reduce its greenhouse gas emissions by 100% by 2050, including the usage of sustainable aviation fuel.

07 ENERGY EFFICIENCY, RENEWABLES AND DECARBONISATION

KEY FACTS

- **Global carbon intensity has improved** due in part to an increase in renewable electricity production, but even more so due to greater energy efficiency, despite a recent decline in efficiency improvements.
- Increased penetration of renewables, along with rising electrification of key end-uses such as household appliances and industrial processes, have contributed greatly to **improving the carbon intensity of end-use sectors** such as buildings, industry and transport.
- Despite improvements in energy intensity, **total emissions have increased**, driven by rising energy demand (particularly electricity demand in buildings) in developing economies and by a growing trend towards energy-intensive transport.

RENEWABLE ENERGY AND CARBON INTENSITY

Renewable energy and energy efficiency have long been known to provide multiple benefits to society, such as lowering energy costs, improving air quality and public health, and boosting jobs and economic growth. Increasingly, renewables and efficiency are viewed as crucial for reducing carbon emissions. Energy production and use account for more than two-thirds of global greenhouse gas emissions, and together renewables and energy efficiency have made significant contributions to limiting the rise in carbon dioxide (CO_2) emissions.[1]

This is reflected by the growing number of countries pledging to achieve net zero emissions and making emission reduction commitments in their Nationally Determined Contributions (NDCs) under the Paris Agreement – providing a key driver for greater implementation of both renewables and efficiency. As of the end of 2020, 190 parties to the Paris Agreement mentioned renewable energy in their NDCs, while 144 parties mentioned energy efficiency, and 142 mentioned both.[2]

Previous editions of the *Renewables Global Status Report* have tracked the combined benefit of renewables and energy efficiency through trends in the share of renewable energy and in energy intensity. **Energy intensity** can be assessed both as primary energy supply per unit of gross domestic product (GDP), and as final energy consumption in an end-use sector relative to a sector-specific metric (for example, energy use per square metre in buildings).[3] Between 2015 and 2019, the annual rate of improvements in energy intensity slowed.[4]

However, energy intensity is an imperfect indicator for measuring the transition to more efficient and cleaner energy production and use. Trends in **carbon intensity**[i] – measured here as energy-based CO_2 emissions per unit of GDP – help to better understand the full impact of both energy efficiency and renewables. Unlike overall emissions, which until 2015 increased in parallel with GDP growth, carbon intensity of GDP reflects the technical or structural improvements that occur in various sectors.[5] As with changes in energy intensity, changes in carbon intensity result from a combination of factors beyond energy efficiency measures and the deployment of renewables alone, such as increased production from non-renewable energy sources and the growth of more carbon-intensive industries.[6]

Carbon intensity of GDP can be expressed as the product of the energy intensity of GDP and the *carbon intensity of energy* (that is, the CO_2 emissions associated with energy production and use).[7] Energy efficiency measures and the deployment of renewables can bring about improvements in both of these variables.

Renewable energy can improve the energy intensity of GDP by reducing the losses that occur in energy transformation and thus decreasing the amount of primary energy input that is needed to meet existing demand. Energy efficiency, in turn, can lower both the overall primary energy supply needed as well as the capacity and cost of the low-carbon energy systems needed to meet demand, thereby growing the share of renewables in the energy mix.[8]

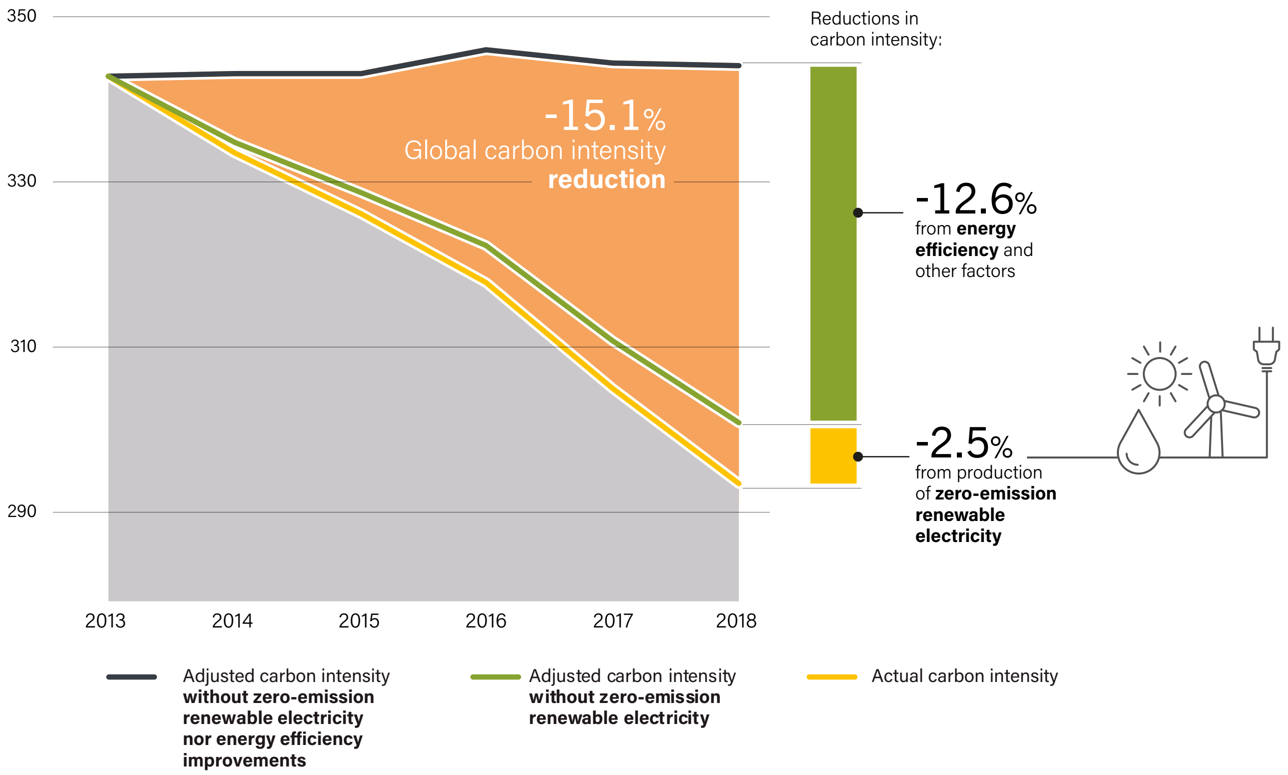
Carbon intensity can be analysed both from the perspective of the energy sector as a whole, and with respect to the carbon intensity of specific end-use sectors, namely buildings, industry and transport. Some measures in these sectors – such as energy codes for buildings or the deployment of distributed renewables, heat pumps and other technologies for electrification – impact carbon intensity as they can have both an energy efficiency and a renewable energy component. Other energy efficiency measures can play a role in each sector, including digitalisation in the buildings and industry sectors, and fuels and vehicle emission standards in the transport sector. In 2020, the COVID-19 pandemic impacted the energy efficiency of all three end-use sectors.[9] (→ *See Sidebar 7.*)

Energy production is associated with various sources of CO_2 emissions. These include, among others, oil and gas extraction and refining, fugitive emissions from mining and biofuels production, and the combustion of fossil fuels both for electricity production and for direct use in end-use sectors.[10]

Between 2013 and 2018, global energy-related CO_2 emissions grew 1.9% (0.4% per year on average), to nearly 38 gigatonnes (Gt).[11] The increase took place during a period of economic growth – global GDP grew 23% during the five-year period – but was slowed by improvements in the overall carbon intensity of GDP.[12] In other words, there was an overall decoupling of global economic growth and CO_2 emissions.[13] These improvements in carbon intensity were due in part to increased renewable electricity production and, to a greater extent, to improved energy efficiency.[14] (→ *See Figure 57.*) This was despite a decline in energy efficiency improvements that began in 2015 and has been reinforced by the COVID-19 crisis and low energy prices.[15]

i A "complete" accounting of the carbon intensity of GDP includes all greenhouse gas emissions from both energy and non-energy uses. However, considering that CO_2 is the main greenhouse gas emitted by the energy sector, this chapter focuses on the carbon intensity of GDP due to CO_2 emissions from energy use and refers to this concept as "carbon intensity of GDP".

FIGURE 57.
Estimated Impact of Renewables and Energy Efficiency on Global Carbon Intensity, 2013-2018



Note: This figure estimates the additional primary energy input that would have been required in the absence of renewable electricity uptake since 2013, all else being equal. The estimation accounts for the difference in transformation losses between conventional and renewable electricity generation. However, it does not account for potential feedback loops on the energy demand itself due to energy prices, structural changes in economic activity or similar effects. The figure is not intended to provide results of a comprehensive energy model. Sources of renewable energy in this figure include those that emit no CO_2 in production of electricity. Dollars are at constant purchasing power parities.

Source: See endnote 14 for this chapter.

Renewable energy and energy efficiency together help **lower carbon emissions** per unit of GDP.

SIDEBAR 7. COVID-19 and Energy Demand in Buildings, Industry and Transport

Throughout 2020, the COVID-19 pandemic affected most aspects of daily life across the globe, forcing individuals and communities to pivot quickly to new routines to prevent the spread of infection. Changes in energy use accompanied this major shift in societal behaviours.

Full lockdown measures reduced electricity demand 20% on average, depending on the country, with smaller effects for partial lockdowns. As a result, renewables claimed a greater share of global electricity generation (around 29% in 2020, up from 27% the previous year); this was in part because the output of renewables is often less directly influenced by electricity demand. (→ *See Global Overview chapter.*)

In **buildings**, remote working caused a shift in energy demand from commercial to residential buildings. In the first half of 2020, electricity use in residential buildings in some countries grew 20-30%, while it fell around 10% in commercial buildings. Depending on home size, heating or cooling needs, and the efficiency of computers and other information technology equipment and appliances used at home, a single day of teleworking can increase daily household energy consumption 7-23%, compared with a day working at the office. In some countries, consumers bought additional appliances (entertainment devices, teleworking equipment, etc.), which, coupled with the fact that people were spending more time at home, increased total appliance energy use. However, purchases of new, efficient appliances and replacement of old, inefficient models improve the energy intensity of the global appliances stock.

Most commercial buildings, even when offices remain unoccupied, continue to consume energy to maintain heating, ventilation and air conditioning systems and to power computing servers. The energy intensity of commercial buildings reportedly increased as the share of energy use from more energy-intensive essential sub-sectors grew. For example, food sales outlets, which largely continued to operate during the pandemic, were more than twice as energy intensive as the average office. Additionally, pre-COVID, around 30% of a building's energy was dissipated in ventilation and exfiltration of air; as more people returned to workplaces later in 2020, demands for higher ventilation rates (for health reasons) increased the energy intensity of commercial buildings.

Restrictions on the ability of professional contractors to access residential properties delayed efficiency upgrades. At the start of the COVID crisis, global construction activity slowed an estimated 24%, along with a 12% decrease in on-site work at buildings, but as the sector rebounded the overall slowdown in construction activity fell to 10% by the end of 2020. In some markets, increased rates of do-it-yourself renovations may have led to improved technical efficiency. For example, sales of insulation in Australia were 20% to 40% higher in the first half of 2020 than a year earlier, and sales at US home improvement chains increased compared to 2019.

In **industry**, reduced production and consumer demand lowered energy demand across all manufacturing sectors. Energy-intensive sub-sectors (such as iron and steel, and cement) saw a lower decline in their activity than less energy-intensive industrial sub-sectors (such as textiles, machinery and equipment). For example, the share of automotive manufacturing in the industry sector decreased 30% in the first half of 2020 relative to the previous year, whereas basic metals manufacturing fell only 15%. As a result, upstream energy-intensive industries made up a larger share of industry activity, thus increasing energy and carbon intensity.

In **transport**, the major trends emerging from the crisis in 2020 were related to the impact of travel restrictions and remote working measures on both urban transport and the aviation sector. Long-distance passenger load factors[i] in aviation fell dramatically, with the demand for commercial air travel dropping around 60% and rail demand declining 30%. This led to increased energy use per passenger and per kilometre travelled, despite the decline in overall energy use. A shift from aviation to rail can reduce energy intensity, whereas a shift from rail to road vehicles can increase it.

For those commuting by car, teleworking is estimated to reduce total energy consumption and emissions. However, for commuters who normally make only short trips by car (under 6 kilometres in the United States and under 3 kilometres in the European Union (EU), as well as commuters who mainly take public transport, teleworking is estimated to produce a small net increase in total energy demand and emissions. This is even before accounting for the fact that smaller numbers of bus and train passengers during 2020 increased the energy and carbon intensity of these modes of transport, per passenger-kilometre travelled. Due to social distancing efforts, people turned instead to private vehicles and active modes of transport, such as walking and cycling. Temporary bike lanes were installed in Paris (France) and Toronto (Canada), among many other cities, and some of these lanes have been converted into permanent infrastructure. Consequently, energy efficiency (per passenger-kilometre) of buses and trains decreased in tandem with lower passenger volumes.

Globally, as sales of new cars declined in 2020, the vehicle stock became relatively older and less efficient. However, this was partially offset by the fact that the relative share of electric vehicles (EVs) in new car sales rose, impacting the average efficiency of new road vehicles.

i Passenger load factors measure the capacity utilisation of an aircraft (i.e., how many of its seats are filled).

Source: See endnote 9 for this chapter.

DECARBONISATION OF END-USE SECTORS

Total final energy consumption (TFEC) – the energy remaining after losses during transformation, energy sector own-use, transmission and distribution – amounted to 378 exajoules in 2018, up 2% from the previous year.[16] This energy is consumed primarily in the three end-use sectors: buildings (residential and commercial), industry and transport.[17]

CO_2 emissions from final energy use reached 24 Gt in 2018.[18] Around 63% of this total was direct emissions, or emissions from sources that are directly controlled by a sector or entity (for example, emissions from combusting fossil gas in a boiler). The remainder was indirect emissions: these are released as a consequence of activities within a sector or entity (such as buildings), but they occur at sources owned or controlled by another sector (for example, emissions from producing the electricity that is later consumed in a building). Most indirect emissions come from electricity production.[19]

Reducing indirect emissions, as well as addressing direct emissions by improving the carbon intensity of final energy use, are key ways to decarbonise the entire energy sector. Between 2008 and 2018, the global carbon intensity of final energy decreased 2%.[20] At the same time, the global share of modern renewables in TFEC grew 38%.[21] (→ *See Figure 58.*)

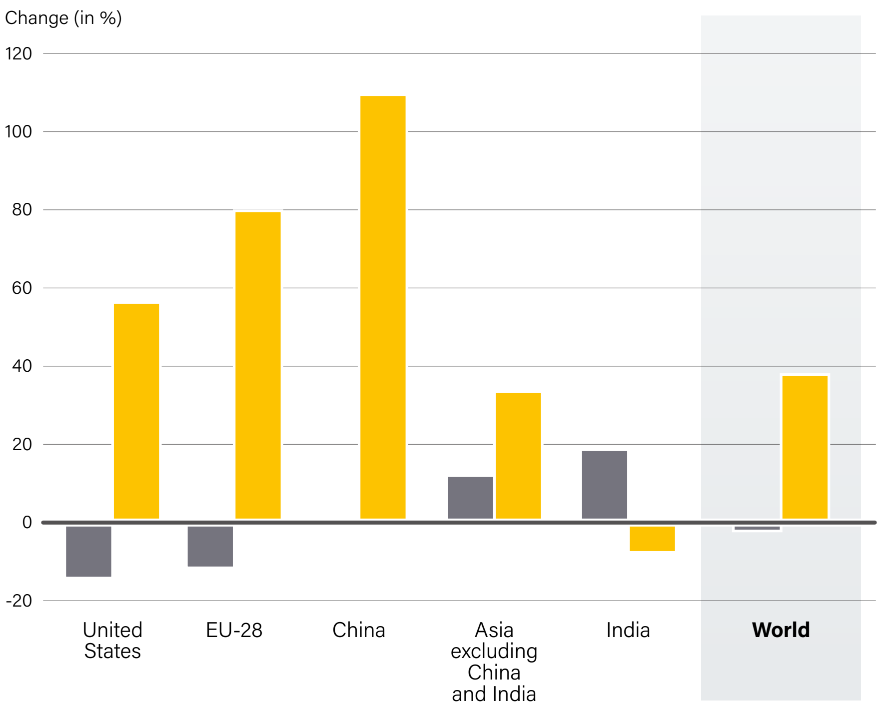
Parts of the developed world showed a similar trend over the decade: that is, improvements in the carbon intensity of energy were accompanied by an increase in the share of renewables. The United States and the EU-28 (two of the top-five emitting regions) experienced total decreases in their carbon intensities of 14% and 12%, respectively, during 2008-2018, together with respective increases in the share of modern renewables in TFEC of 56% and 80%.[22]

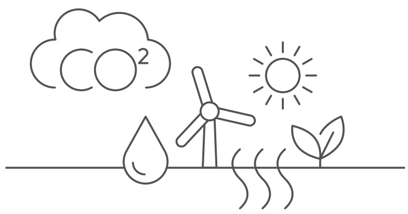
However, in certain developing and emerging countries, the rising share of renewables in TFEC did not necessarily coincide with an improvement in the carbon intensity of final energy. Despite a 109% increase in renewable energy uptake during 2008-2018 (4.4% annually), China's carbon intensity of final energy stayed relatively constant, for a total increase of 1% (0.05% annually).[23] In all Asian countries excluding China, the smaller increase in renewables – 29% over the decade – was not enough to halt the rise in carbon intensity, which grew 14%.[24]

Although the impact of increased renewable energy penetration varies depending on local circumstances, the rising share of renewables, together with increased electrification of key end-uses, has contributed greatly to improving the carbon intensity of end-use sectors.[25] (→ *See Sidebar 8.*) This highlights the importance of other decisions (for example, phasing out coal) that influence the energy mix, in addition to renewable energy uptake.

Additional decarbonisation can be achieved through a combination of direct deployment of renewables and energy efficiency measures in the end-use sectors. By reducing overall energy demand, or limiting its growth, energy efficiency in end-use sectors impacts both direct and indirect CO_2 emissions.

FIGURE 58.
Change in Carbon Intensity of Final Energy Consumption and Share of Modern Renewables, Selected Countries, 2008-2018





Source: Based on IEA data. See endnote 21 for this chapter.

SIDEBAR 8. Decarbonisation Through Monitoring, Reporting and Verification Systems

Accurate data and regular monitoring are key in tracking progress towards meeting the objectives of Sustainable Development Goal 7 (SDG 7), which calls for "affordable, reliable, sustainable and modern energy for all" by 2030. One such monitoring tool is RISE[i] (Regulatory Indicators for Sustainable Energy), a set of indicators used to compare countries' policies and regulatory frameworks towards achieving SDG 7. In particular, RISE can help indicate the readiness of policy makers to track the carbon intensity of end-use sectors such as power, buildings, industry and transport.

The RISE Carbon Pricing and Monitoring indicator measures two important aspects of regulating carbon emissions: 1) monitoring, reporting and verification (MRV) of emissions and 2) assigning an appropriate price to emissions. Carbon pricing is seen as an efficient way to account for the external costs associated with energy-related CO_2 emissions. Whether or not it is economically or politically feasible for a country to price carbon emissions, an MRV system can be a first step towards adopting low-carbon policies. Implementing an MRV system for emissions can help standardise data and support decision making on policies or investments related to carbon intensity.

Policy makers can implement an MRV system to monitor carbon emissions on a regular basis, particularly for the most energy-intensive sectors of the economy. A monitoring system not only provides key data to better inform policy decision making, but also builds institutional capacity and knowledge for regulators to oversee economic activity transparently and effectively. In complex economies with diverse economic sectors, an effective approach to reporting carbon emissions is a bottom-up system whereby individual entities report their own emissions in order to comply with an enforced mandate, which is then verified by a regulatory agency.

In January 2021, the Republic of Korea entered the third phase of a bottom-up monitoring programme for its emission trading scheme. This phase involves monitoring emissions from heat and electricity generation, industry, buildings, transport, water and public buildings. The programme requires an independent third-party verifier (selected by the government) to approve the emission reports submitted by each entity. Based on the approved data, the Korean Greenhouse Gas Inventory and Research Center regularly releases evaluation reports that include key emission statistics, market performance indicators and survey results from these entities. The information verified by regulators can provide a foundation to monitor and quantify the mitigation impact of investment in renewable energy technologies and energy efficiency measures. This, in turn, can help attract international private or public finance targeting the deployment of renewable energy technologies.

Another bottom-up example is the Emissions Trading Scheme (ETS) used by the European Union (along with Iceland, Liechtenstein and Norway) since 2005, which sets a limit (or cap) on the total amount of certain greenhouse gases that can be emitted by covered sectors. Within the cap, companies receive or buy emission allowances, which they can trade with one another as needed. This regional cap-and-trade system limits emissions from more than 10,000 heavy energy users within Europe, including power stations, industrial plants, and airlines, covering nearly half of the EU's greenhouse gas emissions. As the MRV system improved following the EU ETS' launch trial period (2005–2007), policy makers have used historic data to reform the programme by adjusting the limits on the total number of allowances via phased reforms over the past decade. This helped the programme overcome market failures due to volatility in the market price for allowances.

Top-down approaches, in contrast, require monitoring and verification of an entity's emissions by public regulators or approved third parties. Because this kind of system has much higher public sector staffing costs, it may be more appropriate for use in economic sectors that have a homogenous group of emitters, such as specialized industrial sectors. For example, China launched the first phase of its national emission trading scheme in January 2021[ii] through a federal pilot to monitor only coal- and gas-fired power plants. Assigning federal regulators to each power plant will help determine appropriate emission baselines to inform not only the scheme's design, but also energy conservation standards for other sectors, long-term plans for capacity retirements and China's contributions for reducing emissions under the Paris Agreement. However, it may not be feasible to assign this same level of oversight to entities in all economic sectors, especially in developing countries that have more limited public resources.

By the beginning of 2020, only 60 out of the 138 countries covered by RISE had established a mandated system for emissions MRV from different end-use sectors. However, uptake of MRV has nearly doubled since 2010, when only 27 countries had such regulations. Of the 60 countries with MRV regulations in early 2020, 44 countries also had in place a carbon pricing scheme (carbon tax and/or emissions trading), and more than a third of these countries were in Europe (with only four countries located in Africa). However, Africa has experienced the largest increase in uptake of MRV regulations (eight additional countries since 2010) followed by the Middle East (seven additional countries). In 2019, Europe had the largest share of countries with MRV policies for emissions in place (27%), followed by the Middle East (15%) and Africa (14%). (→ *See Figure 59.*)

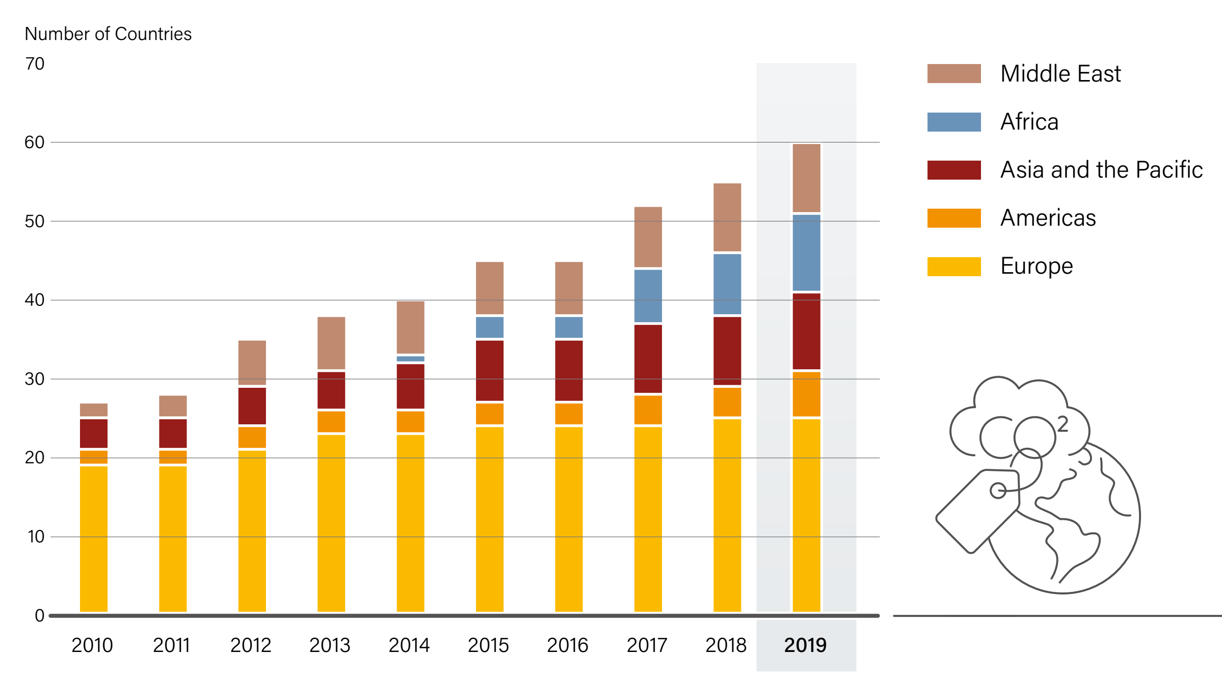
Within Africa, Malawi and South Africa are the only countries implementing both types of regulations (emissions MRV and carbon pricing). Malawi implemented its MRV programme in 2019 targeting emissions from oil and diesel generators and the transport sector, and the resulting tax revenues collected exceeded the country's expectations. In India, although there is no explicit carbon tax in place, the MRV system implemented for the coal industry in 2010 has informed the efficient fuel-switching programme for electricity generators, as policy makers have been able to set appropriate benchmarks for emission limits based on the verified emission data. Subsequently, between 2010 and 2015, the Indian government introduced coal emission limits and corresponding excise duty penalties in a transparent step-phase approach. The limits and penalties are adjusted yearly based on historic data from the MRV system, giving emitters the ability to plan operations accordingly.

i The 2020 edition of RISE includes 31 indicators distributed among four pillars (access to electricity, access to clean cooking, renewable energy and energy efficiency), measured across 138 countries globally and covering more than 95% of the world's population. By providing empirical evidence of the support provided by policy frameworks, the RISE database helps countries attract investments in their sustainable energy sectors. Private investors and developers also use RISE to carry out due diligence related to new projects, products and services. RISE indicators can help policy makers benchmark their own national energy framework against those of regional and global peers. See https://rise.esmap.org.

ii China's Emission Trading Scheme was designed by the National Development and Reform Commission beginning in 2018 but was not officially implemented until the first phase began in January 2021.

Source: See endnote 25 for this chapter.

FIGURE 59.
Number of Countries with Carbon Emission Monitoring, Reporting and Verification Policies, by Region, 2010-2019



Source: World Bank Group. See endnote 25 for this chapter.

BUILDINGS

The buildings sector accounted for around 33% of TFEC in 2018, a share that has risen about 1% annually since 2008.[26] Residential buildings consumed nearly three-quarters of this energy, while the remainder was used in commercial and public buildings.[27] Total energy-related CO_2 emissions from buildings increased to a record 10 Gt in 2019, only 3.1 Gt of which were direct emissions.[28] Indirect emissions thus are highly relevant within the buildings sector, due notably to its dominant share of global electricity consumption (around 55% in 2019).[29]

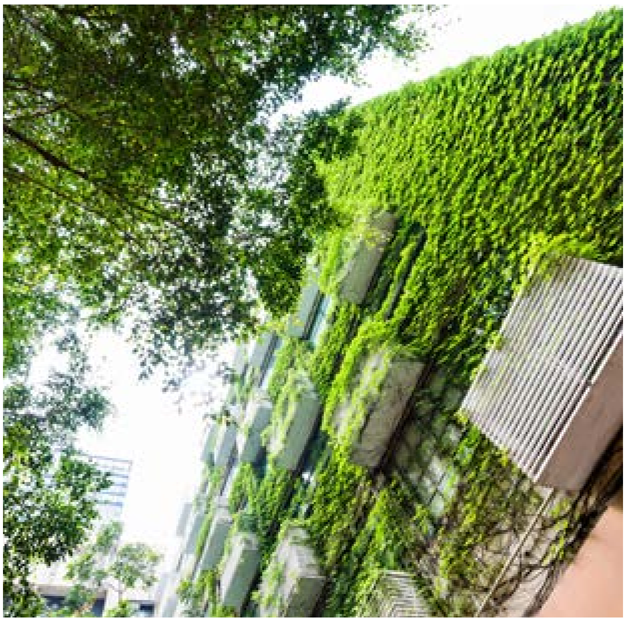
Carbon intensity in buildings is driven by indirect emissions (around 70%), notably by electricity generation.

Between 2013 and 2016, carbon intensity improvements in the power sector were sufficient to cause CO_2 emissions to level off in buildings, illustrating the general effectiveness of rising electrification in buildings, combined with the decarbonisation of electricity generation itself.[30] Electricity can power various services efficiently in buildings through the use of appliances and equipment (some of which are typically fossil fuel-powered) that are already widespread, such as fans, refrigerators, water boilers, cook stoves and heat pumps.[31] Additionally, electric appliances tend to be more efficient than the equipment they replace.[32] On a final energy basis, heat pumps can be three to five times more energy efficient than their natural gas counterparts.[33]

However, between 2000 and 2019, electricity use in buildings grew five times faster than improvements in the carbon intensity of electricity generation.[34] This is due in part to changes in rapidly developing countries (where electricity remains carbon intensive) – including rising electricity demand for space cooling and appliances, increased access to modern energy services, and changing consumer behaviour[i], such as purchases of less-expensive but inefficient air conditioners.[35]

In developed countries, however, energy efficiency improvements largely offset increased electricity demand from increasing digitalisation[ii] and electrification.[36] Between 2008 and 2018, the carbon intensity of buildings in member countries of the Organisation for Economic Co-operation and Development (OECD) improved 2.7% annually in the residential sector (from an average of 4.6 tonnes of CO_2 per dwelling in 2008 to 3.5 tonnes in 2018), and it improved 3.6% annually in the commercial sector (from 3.8 tonnes of CO_2 per employee to 2.6 tonnes over the decade).[37]

In parallel, efforts in energy efficiency have progressed due to increasing digitalisation in building operations.[38] Digital solutions for building operations serve three essential functions: monitoring energy consumption (for example, via "smart meters"); identifying potential energy savings; and reducing energy consumption through intelligent controls.[39] Smart technologies range from applications that measure and optimise the use of energy or guide users' behaviour, to software for professional facility management.[40] Digital technologies can reduce building energy use nearly 20% in several types of commercial buildings, including offices, retail, hotels and hospitals.[41] Digital energy management devices are increasingly prevalent as well. Smart thermostats are the second most common smart home device (following audio speakers) in UK households, with 6% penetration, followed by smart lighting (5%).[42]



In addition to the energy savings realised by electrification measures and digital technologies, improved building performance – that is, energy usage per square metre – is critical. Improving energy performance is generally simpler in new buildings than in existing buildings, as efficiency improvements can be integrated into the design stage.

The EU's Energy Performance of Buildings Directive requires all new buildings from 2021 onward to be nearly zero-energy buildings (NZEBs).[43] However, since the directive does not provide a specific accounting method, tracking the market penetration of NZEBs can be challenging.[44] For example, the uptake of NZEBs in France appeared rapid because the country's NZEB accounting method matches the current thermal regulation (hence all new buildings are considered NZEBs), whereas in Italy the uptake seemed slower as the national accounting method is stricter compared to the building code requirements.[45]

In the United States and Canada, the number of zero-energy projects has increased steadily, reaching 27,965 in 2019, although the yearly rate of increase has declined from previous years (falling from 59% in 2018 to 26% in 2019).[46] Meanwhile, such standards often are lacking in developing countries that have rapidly growing urban populations (especially in Asia and Africa); in many of these countries, building codes either do not exist or do not apply to all building energy use.[47]

i For example, opting for larger homes or increasing the building floor area and appliance ownership per household, although these trends are not exclusive to developing countries.

ii In buildings, this refers to the data collection, representation, observation and control of physical systems by digital means, often called digital or "smart" technologies/solutions.

In developed countries, lower rates of new construction mean that decarbonising the existing building stock – a much greater challenge – is more critical to decarbonising the sector as a whole.[48] In the EU, however, only around 1% of existing buildings are renovated for energy efficiency improvements annually, compared to a required 3% in order to meet the region's 2030 emissions target.[49] In some OECD countries, energy-efficient renovations, including improving building insulation and installing more efficient heating systems, contributed to carbon intensity improvements for space heating.[50] In Finland, France and New Zealand, the carbon intensity of space heating was reduced more than 30% between 2008 and 2018.[51]

Integrating renewable energy solutions in buildings – such as solar water heaters, heat pumps and renewables-based district heating and cooling – can help reduce carbon emissions and is more effective in terms of implementation when planned in conjunction with building renovations or design.[52] The Energiesprong renovation programme, which began in the Netherlands and now operates in France, Germany, Italy, the United Kingdom and the US state of New York, can provide a framework to increase the uptake of NZEBs through a combination of standardisation, prefabricated building components and third-party finance.[53] Some buildings financed by Energiesprong have produced more energy than they consumed by combining energy efficiency technologies with renewables, using insulated rooftops with solar panels, and installing ventilation and cooling systems.[54]

INDUSTRY

The industrial sector accounted for 34% of TFEC in 2018, and its direct emissions totalled 7.9 Gt of CO_2[i] – representing 33% of direct greenhouse gas emissions from final energy use.[55] Global industrial direct CO_2 emissions due to energy consumption increased 13% between 2008 and 2018.[56]

A combination of factors influences changes in carbon intensity in the industrial sector – including the fuel mix of electricity generation, technological improvements and structural changes in the share of carbon-intensive industries in the economy. Nonetheless, it is noteworthy that, in a selection of OECD countries[ii], carbon intensity in industry improved 25% between 2008 and 2018, as the share of electrification increased to 13%.[57] (→ *See Figure 60.*)

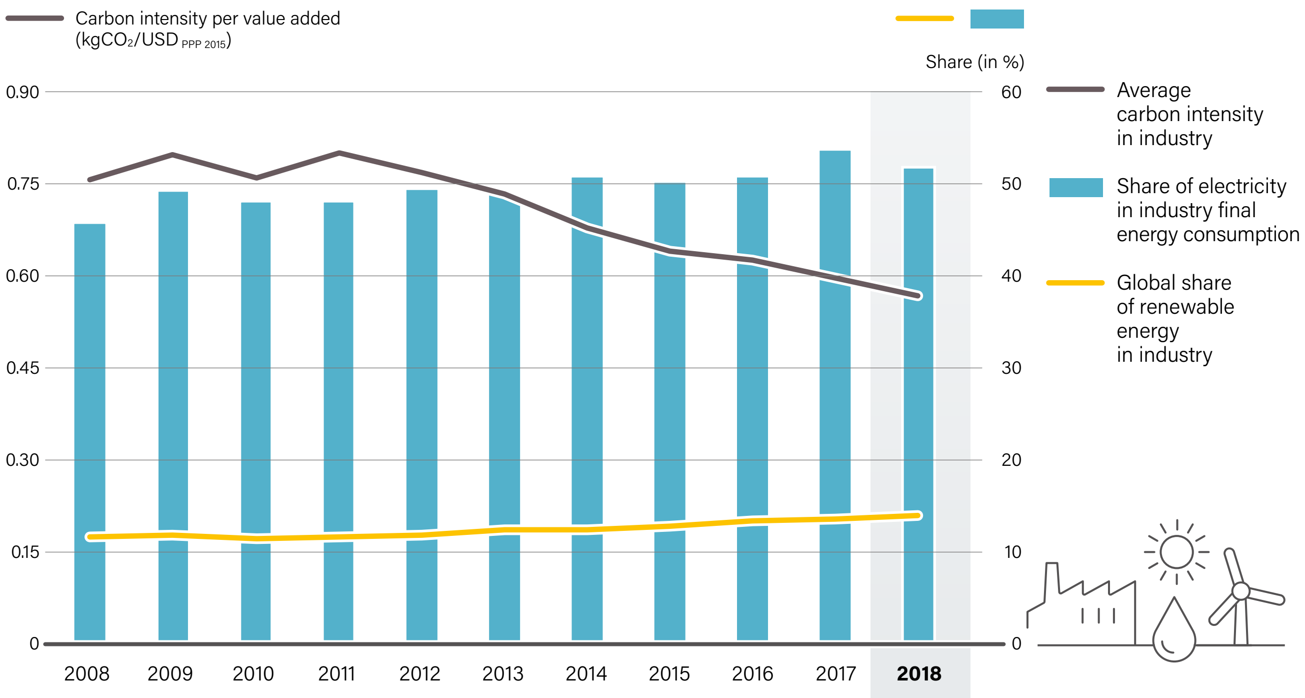
As with electric appliances in the buildings sector, electrically driven technologies in the industry sector are, in general, more energy efficient than conventional ones.[58] From a technical point of view, all energy required to generate heat for industrial processes up to around 1,000 degrees Celsius could be replaced by electricity.[59] However, the technologies involved can be more expensive than the conventional options, and policy support is needed to promote their uptake in industrial processes.[60] (→ *See Policy Landscape chapter.*)

Another effective strategy for achieving significant carbon intensity improvements is to implement heat recovery technologies.

i Data for indirect emissions were not available for the industry sector, and direct emissions data were provided only up to 2018.

ii Due to data availability, the analysis includes the following countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

FIGURE 60.
Carbon Intensity and Share of Electricity in Industry, Selected Countries, 2008-2018



Note: The countries included are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

Source: See endnote 57 for this chapter.

These tap into waste energy streams and reuse them for various purposes within a facility (e.g., space heating or cooling) or within the process itself (e.g., pre-heating air and boiler make-up water). Active[i] heat recovery equipment, such as heat pumps, make it possible to increase the temperature of a waste heat stream to a higher, more-useful temperature.[61] Consequently, heat pumps can facilitate energy savings beyond those achieved by conventional passive heat recovery.[62] (→ *See Systems Integration chapter.*)

Industry-wide, low-temperature waste heat streams have the greatest potential to use waste heat recovery. However, barriers – such as the variability in temperature, availability and contaminating content of low-grade heat sources – continue to impede significant uptake.[63] While the deployment of heat pumps in industry is still low, a number of applications do exist, mainly in heating and drying applications.[64]

In recent years, the uptake of renewables in industrial processes (mainly bioenergy, as well as geothermal and solar heat) has helped improve industrial carbon intensity.[65] Although solar thermal has not yet been widely adopted in the sector, some 479 gigawatts-thermal of capacity was in operation in industrial processes at the end of 2020.[66] (→ *See Market and Industry chapter.*)

Finally, digitalisation has allowed industrial sites to more comprehensively analyse energy use and to continuously improve energy performance.[67] Modern digitally driven energy management systems, as well as standards such as ISO 50001, help industries identify opportunities to adopt and improve cost-saving technologies, including those that do not necessarily require high capital investment (whether energy efficiency technologies, renewables or both).[68] Additionally, by collecting data and simplifying monitoring, energy management systems ensure better performance, thereby improving the bankability of company projects and encouraging investments to improve carbon emissions.[69]

TRANSPORT

The transport sector accounted for 33% of TFEC in 2018.[70] Road transport represented the bulk of the transport sector's energy demand (75%), followed by aviation (12%), marine transport (10%) and rail (2%).[71] (→ *See Global Overview chapter.*)

Direct CO_2 emissions from transport totalled 8.1 Gt in 2018, which represented 34% of direct[ii] greenhouse gas emissions from final energy use.[72] Emissions from transport grew 19% between 2008 and 2018, at an average annual rate of 1.8%.[73] This upward trend reflects the increase in the size and number of, as well as distances travelled by, road vehicles and to a lesser extent aviation.[74] It also underlines the increasing prevalence of sport utility vehicles (SUVs), which are larger and less fuel efficient than other passenger cars.[75] Total emissions from road transport in SUVs tripled globally between 2010 and 2020.[76]

In OECD countries, even as the demand for transport increased between 2008 and 2017 – with vehicle-kilometres travelled rising 0.73% annually during this period – the carbon intensity of transport (i.e., the CO_2 emitted per vehicle-kilometre for cars and light trucks) improved at an annual rate of 0.64%.[77] (→ *See Figure 61.*) In general, this carbon intensity improvement was due partly to the implementation of fuel economy and greenhouse gas emission standards for light-duty vehicles.

As of 2017, 10 out of the top 15 vehicle markets worldwide (including China, the EU, India and the United States) had established fuel economy and/or emission standards for light-duty vehicles.[78] This is significant considering that at the end of 2007, only four governments had mandatory standards of either kind.[79] In total, as of 2017, nearly 80% of new light-duty vehicles sold globally were subject to some kind of fuel economy or emission standards.[80] (→ *See Policy Landscape chapter.*)

However, challenges remain to determine the full impact of such regulations on global transport carbon intensity, as regulations in some countries became stricter (for example, in Japan and the Republic of Korea), while others were less binding (for example, in India).[81]

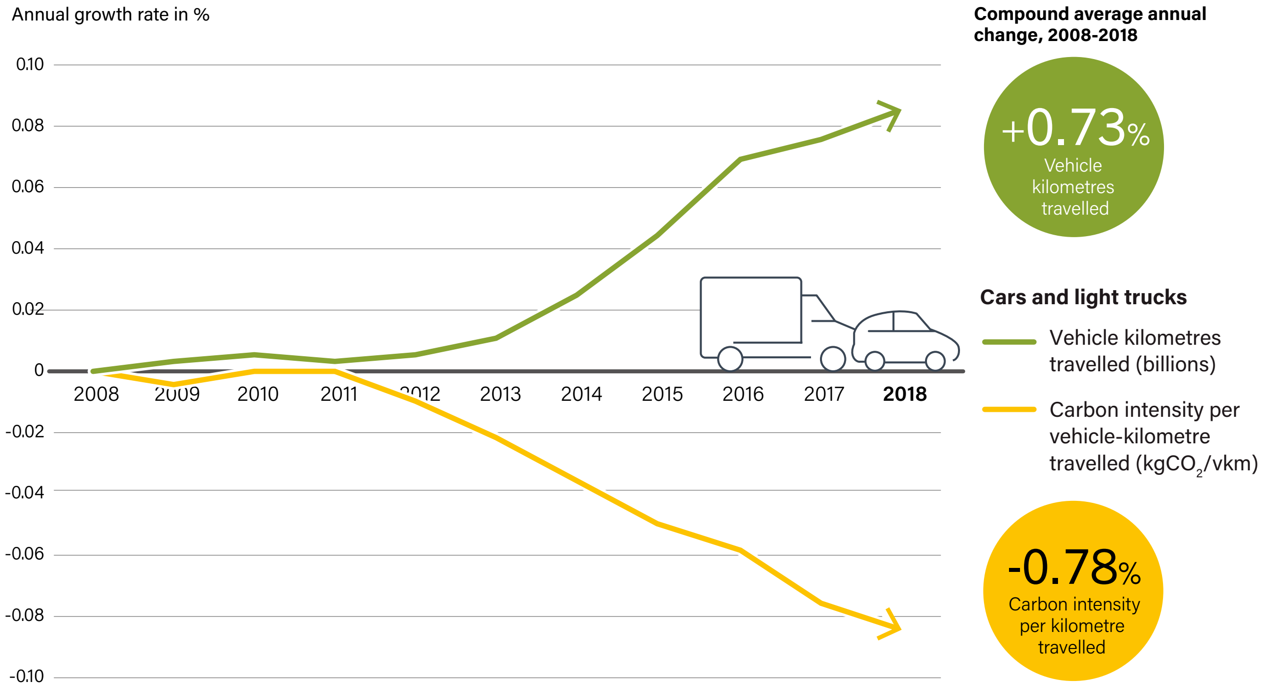
In developing countries, the carbon intensity of road transport is determined largely by the used vehicle market: 70% of the world's used exported light-duty vehicles are shipped to Africa (the largest importer at 40%), Eastern Europe (24%), Asia-Pacific (15%), the Middle East (12%) and Latin America (9%).[82] While import and export regulations tend to lower carbon emissions, such measures often are lacking in importing countries.[83] For example, Kenya imposes an age limit for imported cars of 8 years, whereas neighbouring Uganda has a limit of 15 years, and Rwanda has no age limit for imports.[84] All three of these countries import used vehicles from Japan, but because Kenya has a stricter import policy, the average fuel consumption and CO_2 emissions of its fleet are around 25% lower than those of its neighbours.[85]

The energy efficiency (kilometres travelled per unit of energy) of electric vehicles is higher than that of internal combustion

i Contrary to passive heat recovery, active heat-recovery equipment requires an external energy source to operate.

ii Data for indirect emissions were not available for the transport sector, and direct emissions data were provided only up to 2018.

FIGURE 61.
Indexed Carbon Intensity and Kilometres Travelled, Passenger Vehicles in Selected Countries, 2008-2018



Note: The countries included are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Portugal, the Republic of Korea, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

Source: See endnote 77 for this chapter.

engine vehicles, and EVs produce zero direct CO_2 emissions.[86] EVs also can have a positive impact on the carbon efficiency of the global vehicle fleet, particularly when the share of renewable energy in the electricity mix is high.[87] While the CO_2 emissions benefit of EVs is somewhat less significant when considering indirect emissions during production and disposal of the vehicle and battery system, as well as the electricity generation necessary, the life-cycle emissions of EVs are typically much lower than those of internal combustion engine vehicles.[88]

Boosted by national and local government decisions to phase out petrol and diesel vehicles, sales of electric cars topped 3.2 million globally in 2020, surpassing the record year of 2019.[89]

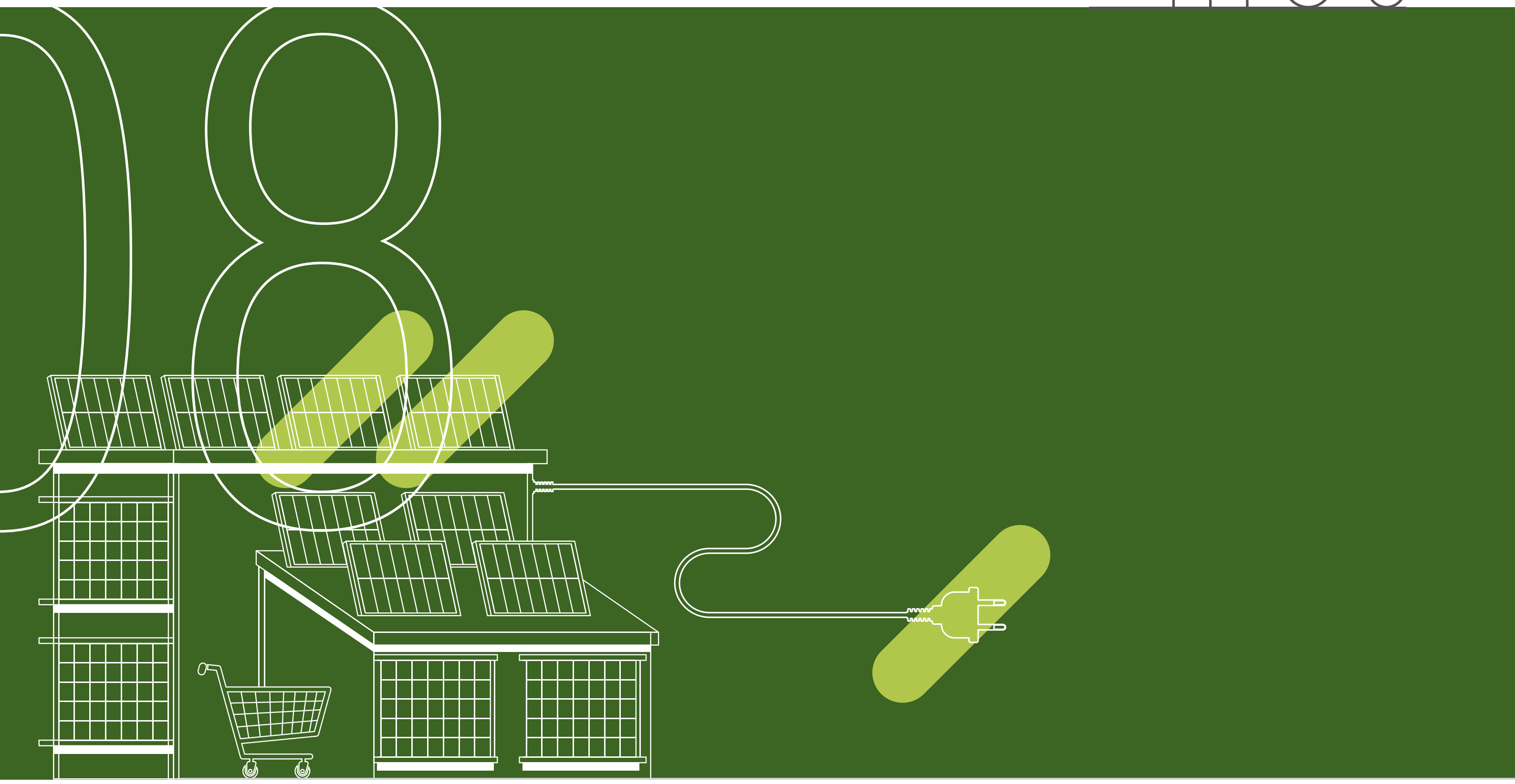
The life-cycle emissions of EVs are typically **much lower** than those of internal combustion engine vehicles.

(→ *See Systems Integration chapter.*) However, the current overall impact of EVs on the carbon efficiency of the transport sector is minimal, as the share of electricity in TFEC of transport remains low, around 1.1%, of which less than 30% is from renewables.[90] Furthermore, few countries explicitly link EV targets with renewable electricity targets. (→ *See Policy Landscape chapter.*)

Mobility systems focusing on shared transport, or mobility as a service, also improve energy and carbon efficiency per passenger.[91] While mobility innovations such as e-scooters have increased greatly in recent years and may have the potential to replace personal car use, their impact on improving energy intensity and carbon intensity remains anecdotal and is undetermined globally.[92]

During 2020, the COVID-19 crisis impacted existing mobility trends, with a growing tendency towards individual transport modes, thus decreasing public transport's energy efficiency and increasing its carbon intensity.[93] (→ *See Sidebar 7.*) Restrictive measures encouraging remote working also impacted energy consumption in the sector.[94]

IKEA has invested heavily in wind and solar power over the past decade alongside other sustainability initiatives, such as sourcing all of its cotton from sustainable agriculture.



08 FEATURE: BUSINESS DEMAND FOR RENEWABLES

KEY FACTS

- **Businesses are increasing their uptake of renewables** across power, heating and cooling, and transport needs. Company membership in business coalitions promoting renewable energy procurement surged across sectors.
- Despite a challenging business year, the **new renewable energy capacity** that businesses sourced through power purchase agreements increased 18% in 2020.
- Corporations increasingly sourced **low-temperature renewable energy for heating and cooling** from solar thermal heat, geothermal heat and bioenergy, as well as renewables-based electrification.
- Businesses source **renewable energy for their transport needs** mainly from biofuels, renewables-based electricity and renewable hydrogen across the road, rail, maritime and aviation sectors.

Business has a significant role to play in renewable energy deployment. Companies worldwide are contributing in various ways, including through manufacturing and production, research and development, installation, project financing and energy infrastructure, as well as by procuring their energy from renewable sources. Despite the impacts of the COVID-19 pandemic and related recession, corporate sourcing of renewable electricity through power purchase agreements (PPAs) rose 18% in 2020.[1] Businesses also increased their use of renewables for heat and transport, although to a far lesser extent.[2]

Firms and industries have different energy needs, and uneven patterns of business demand for renewables exist depending on the sector, technology and geography. Whereas corporate sourcing of renewable electricity is advancing quickly, the use of renewable energy in industrial heat and transport is not.[3] However, innovations in markets, financing mechanisms, policies and technologies (such as renewable hydrogen) are helping to close gaps and facilitate greater demand.

DRIVERS OF BUSINESS DEMAND FOR RENEWABLE ENERGY

A combination of factors is contributing to growing business demand for renewables across all sectors. These include environmental and ethical considerations, cost savings, competitiveness, risk mitigation, and business coalitions and collaboration. Government policy also continues to play a key role in incentivising business demand for renewable energy on various fronts. (→ *See Policy Landscape chapter.*)

Renewables are central to companies' efforts to achieve their zero-emission or other ambitious **emission reduction goals**. For some companies, the drive to increase the use of renewable energy is part of larger environmental goals and, often, a fundamental element of a broader sustainability strategy.[4] Stakeholders such as customers, workers, local communities, suppliers and shareholders increasingly expect companies to play their part in climate action and to become more accountable as well as more publicly transparent about their sustainability practices.[5]

Renewable energy is a core area of business sustainability reporting (for example, providing updates on current use of renewables and on targets set for future use); this has become more standardised worldwide through the efforts of the Global Reporting Initiative, the Carbon Disclosure Project (CDP) and similar entities.[6] Investor and shareholder interest in renewable energy companies also is burgeoning. Investment in sustainability-related funds surged around 300% in 2020, and share prices in renewables and other clean energy firms[i] rose 142%; meanwhile, share prices for oil and gas companies fell 38%.[7]

Cost savings and competitiveness are another key driver of business demand for renewables. Renewable electricity in particular has become increasingly attractive commercially compared to new and existing fossil fuels, and has been cost competitive compared to nuclear power for some time.[8] In some cases, it can be less expensive for companies to source their own renewable electricity directly from suppliers or to produce it themselves than to buy it from the grid.[9] In electricity generation, renewables now offer more attractive cost options for at least two-thirds of the global population.[10] (→ *See Sidebar 6 in Market and Industry chapter.*)

Risk mitigation objectives also drive companies to adopt renewables, as these energy sources can help reduce energy supply risks, price risks and reputational risks as environmental values take deeper root in global society.[11] In addition, renewables can reduce policy and regulatory risks arising from potential future changes, such as carbon taxes and the market transition towards a low-carbon economy. Firms have come under growing pressure to disclose and address climate-related financial risk, particularly for credit rating agency assessments.[12]

Business coalitions promoting greater demand for renewables have grown quickly. The RE100 group of companies, committed to achieving 100% renewable electricity, nearly doubled its membership in just over two years, from 155 members in January 2019 to 309 members by May 2021.[13] Membership in EV100 – a group of companies committed to transitioning their vehicle fleets to electric vehicles (although without a direct link to renewables) – grew similarly.[14] Other organisations are providing leadership and support frameworks to help leverage business demand for renewables.[15] (→ *See Box 9.*)

Renewables are central to companies' efforts to achieve **emission reduction goals.**

i Clean energy firms refer here to those with activities in renewable energy, energy efficiency, emission abatement or other technology-based decarbonisation sectors.

RENEWABLE ELECTRICITY

Business demand for renewable energy is most common in the electricity sector. The four main categories of such "corporate sourcing" of renewable electricity are:

- *Self-generation and consumption:* Companies develop their own renewable energy projects and use the electricity generated. These installations may be on site (for example, rooftop solar) or off site (such as a wind power project built relatively near the firm's facilities).
- *Power purchase agreements (PPAs):* Companies sign long-term contracts (typically 10 years) with an independent power producer or utility that commits them to procure a specific amount of renewable energy at a fixed price for a specified duration. Virtual PPAs are more popular in larger markets due to their flexibility, as buyers and sellers do not need to be connected to the same grid provider. One advantage that corporate PPAs offer is "aggregation", where smaller purchasing companies form a consortium and aggregate their demand to secure more competitively priced deals and reduce financial risk.[16]
- *Utility green procurement:* Companies buy renewable electricity through green premium products (green label-certified and -priced) or bespoke contract arrangements, such as green tariffs (special rates). Energy utilities offer both options, allowing their business customers to buy renewable energy directly through billing and without requiring a long-term contractual commitment. However, the trade-off is a less competitive price than that offered by PPAs.[17]
- *Environmental attribute certificates (EACs):* Companies purchase EACs from energy suppliers or brokers, effectively buying ownership rights to a specified amount of renewable electricity. The certificates are primarily "unbundled", meaning that they are bought and sold separately from the associated electricity generated.[18] These certificates, referred to as renewable energy certificates (RECs) in North America and Guarantees of Origin (GOs) in Europe, are the most common corporate sourcing method.[19]

By the end of 2020, the only available global-level aggregated data on corporate sourcing covered PPAs. Despite a challenging business environment during the year, the capacity of new renewable corporate PPAs sourced by businesses worldwide increased 18% in 2020, reaching 23.7 gigawatts (GW) of additional renewable power capacity that year.[20] This compares to added capacity of just 0.1 GW in 2010 and 4.7 GW in 2015.[21] (→ *See Figure 62.*) The fourth quarter of 2020 alone saw a record 7.3 GW of contracts signed globally.[22]

North America continued to dominate the corporate PPA market in 2020, accounting for 57% (13.6 GW) of the global total, although this share fell from 81% (16.3 GW) in 2019.[23] Renewable capacity procured in 2020 nearly tripled in countries across Europe, the Middle East and Africa, surging from 2.6 GW to 7.2 GW.[24] Procurement in the Asia-Pacific region grew from 1.2 GW to 2.9 GW.[25]

BOX 9. Organisations Leveraging Business Demand for Renewables

The Renewable Energy Buyers Alliance is an association of energy buyers seeking to procure renewable energy across the United States. Its goal is to reach 60 GW of new renewable energy projects by 2025 by unlocking procurement options for large-scale energy buyers. The Alliance counts more than 200 members, including stakeholders from energy companies, commercial and industrial businesses, and nonprofit organisations.

The RE-Source Platform is a global alliance of stakeholders representing clean energy buyers and suppliers. It co-ordinates activities to promote a better framework for corporate renewable energy sourcing in the European Union (EU) and at national levels. Its goal is to increase the number of active corporates using renewable energy sourcing from 100 to 100,000.

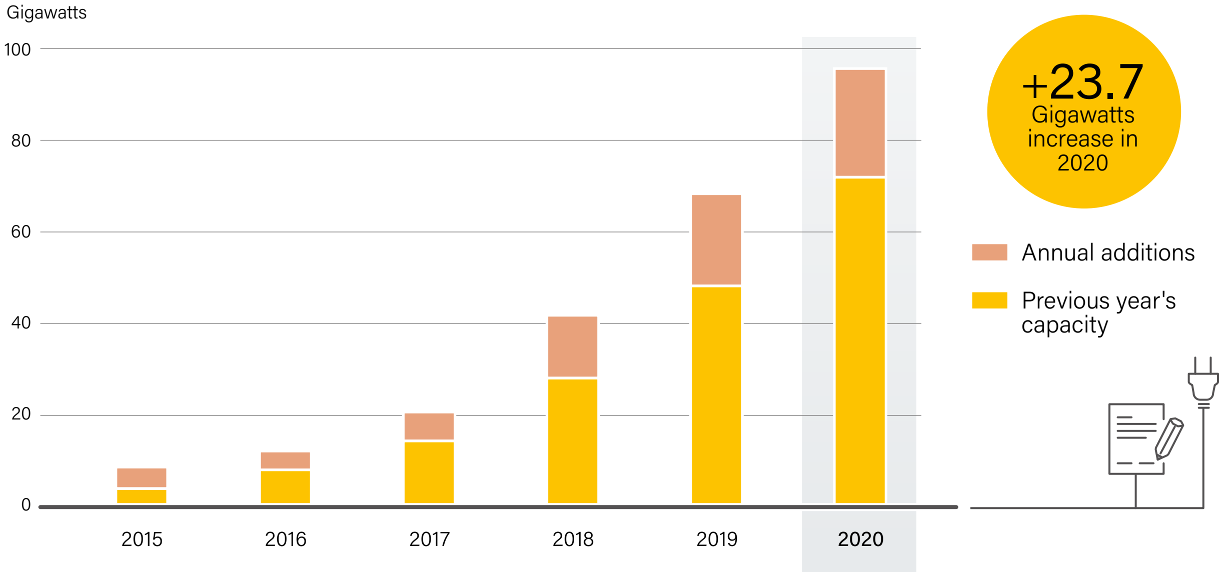
The Renewable Thermal Collaborative is a global coalition of companies, institutions and governments committed to scaling up renewable heating and cooling at their facilities. Its members identify market barriers and aim to use their collective purchasing power to reduce costs and scale deployment of these technologies.

Additional organisations leveraging business demand for renewables include:

- We Mean Business, a global non-profit coalition working with businesses to set science-based emission reduction targets, to identify and prioritise government policies, and to organise public-private partnerships;
- the Mission Possible Partnership, which aims to decarbonise some of the highest-emitting sectors by convening coalitions such as Clean Skies for Tomorrow (aviation), the Getting to Zero Coalition (shipping), the Clean Cement and Concrete Coalition, the Net-Zero Steel Initiative and more;
- the RE-Users platform in Japan, which allows corporate energy users to share information and best practices to accelerate renewable procurement in the country and also organises annual summits; and
- four initiatives by The Climate Group – RE100, EV100, EP100 and SteelZero – that aim to source renewable electricity, buy electric vehicles, improve energy productivity and create demand for low-carbon steel.

Source: See endnote 15 for this chapter.

FIGURE 62.
Corporate Renewable Energy PPAs, Global Capacity and Annual Additions, 2015-2020



Note: Data are provided in direct current (DC) and do not include on-site power purchase agreements (PPAs).
Source: BloombergNEF. See endnote 21 for this chapter.

Trends in corporate sourcing markets that began two or three years ago continued in 2020.[26] Companies had already started to seek more flexible terms in PPA contracts to account for potential changes in technology, policy and new generating capacity that could affect market prices over the lifespan of the agreement. In addition, buyers began demanding that energy providers offer contracts for a shorter term than the standard 10-year agreement.[27]

An increasing number of companies began adopting a "24/7 consumption matching" approach, where the supply of electricity matches real-time demand.[28] This load balancing depends on the smart management of wind and solar energy supported by energy storage.[29] Deals in 2020 included agreements between Microsoft (US) and Swedish energy provider Vattenfall, and between Daimler (Germany) and Norwegian energy company Statkraft.[30] Also during the year, Google announced a goal to source its power on a 24/7 basis and introduced a new computing system, shifting data centre tasks to optimal times for wind and solar power generation.[31]

Companies also have started attempting to decarbonise their **supply chains**, addressing emissions for which they are indirectly responsible. Corporate sourcing previously had focused mainly on emissions generated directly by a company, as well as emissions from energy producers that supply the company's energy needs. However, a growing number of large companies are requiring their supply chain partners, both upstream and downstream, to power their operations with renewable energy.[32]

As of early 2021, more than 40 of Apple's major suppliers had signed on to the company's Supplier Clean Energy Programme, which covered 4 GW of power capacity in 2020.[33] For smaller supplier companies, however, securing PPAs on the same favourable terms as large companies has been a challenge, due to a lack of resources and market leverage.[34] Aggregation deals involving the major company itself have provided one solution.[35]

Capacity of new **renewable corporate PPAs** increased 18% in 2020.

Regionally, national energy regulators across the EU further harmonised their rules to enable the use of cross-border PPAs, with the aim of creating a unified large market similar to that in the United States.[36] In Europe, corporate buyers and energy suppliers are often in different countries, and they face different national regulations that may be incompatible; they also may be hindered by the lack of cross-border grid connections.[37] To address some of these challenges, a single European market for cross-border PPAs was under development at the end of 2020, spurred by the EU's new Renewable Energy Directive and by the European Green Deal.[38]

Challenges remain to corporate sourcing in regions beyond the leading markets of the United States and Europe. While the Asia-Pacific region reported the largest increase in RE100 membership in both 2019 and 2020, companies in the region identified regulatory and market barriers, including the relatively high costs of renewable power technologies as a result of unfavourable policy frameworks.[39] Elsewhere, a major challenge has been limited or no availability of corporate sourcing mechanisms, such as in Argentina, China, Chinese Taipei, New Zealand, the Republic of Korea, the Russian Federation and Singapore.[40]

COMPANY EXAMPLES AND BUSINESS GROUPS

Corporate sourcing of renewable electricity increased in 2020, particularly among larger firms. Many are part of the RE100 group, whose membership grew by more than 60 companies in 2020.[41] Amazon was the leading corporate PPA buyer in 2020 with 5.1 GW (3.1 GW of solar photovoltaic (PV) power and 2.0 GW of wind power) (→ *see Box 10*), followed by Total (3.0 GW) and Taiwan Semiconductor Manufacturing Company (TSMC, 1.2 GW).[42] TSMC signed the world's largest PPA on record (920 megawatts, MW) with the Danish energy provider Ørsted for an offshore wind power project to be built off the coast of Chinese Taipei.[43]

On a cumulative basis, Amazon moved into first place during the year with 7.5 GW of corporate PPAs, ahead of Google (6.6 GW) and Facebook (5.9 GW).[44] Also notable was an aggregation PPA involving Honda, AT&T, McDonald's, Google and several other firms for 1.3 GW of solar power from the US developer Invenergy.[45]

Information and communication technology (ICT) companies have accounted for around half of the global corporate sourcing of renewables in recent years.[46] The burgeoning growth in their data centres and data transmission networks has created a rapidly expanding demand for electricity, accounting for around 1% of global electricity consumption in 2020.[47] The ICT sector has become a focus of both corporate sourcing activity and innovation. For example, in 2020, Microsoft experimented with using renewable hydrogen[i] to power fuel cells at some of its data centres, and plans to use it instead of diesel generators to provide back-up power capacity.[48]

i Renewable hydrogen refers to hydrogen produced through water electrolysis using renewable electricity. (→ *See Systems Integration chapter.*)

BOX 10. Amazon's Sourcing of Renewable Electricity

Amazon (US) became the world's leading corporate sourcing firm in 2020, completing 26 new projects across eight countries and four continents during the year, for a total of 127 projects worldwide. The largest deal signed in 2020 (and the largest offshore wind corporate PPA in Europe to date) was a 10-year PPA for 250 MW from Ørsted's planned 900 MW Borkum Riffgrund 3 offshore wind farm in Germany[i]. Amazon also signed PPAs for 650 MW of solar PV from French utility ENGIE. In February 2021, Amazon's largest single renewable energy investment to date was a PPA with the Shell-HKN Offshore Wind project for 380 MW (half the project's total capacity) in the Netherlands, expected to come online in 2024.

Amazon's stated objective is to power all of its offices and distribution and data centres with renewables by 2030 and to become net zero in its energy needs by 2040. In 2019, the company co-founded The Climate Pledge, a coalition of more than 50 large firms (as of early 2021) that are committed to becoming net zero carbon emission businesses by 2040. This includes meeting requirements for regular reporting on progress, decarbonisation strategies in line with the Paris Agreement (including renewable energy use across all sectors), and additional and quantifiable offsets. The initiative also includes a USD 2 billion fund to bring to market new renewable energy and energy efficiency technologies.

i The project is expected to be operational by 2025. In 2020, Ørsted also signed a large offshore wind PPA with TSMC.

Source: See endnote 42 for this chapter.

RENEWABLE HEATING AND COOLING IN INDUSTRY

Several key industries use heating and cooling (thermal energy) processes, mainly for transforming raw material inputs into products. These include iron and steel, chemicals, cement, aluminium, paper and pulp, and food and tobacco. Renewables have made only limited inroads into many of these industrial sectors, representing around 10% of the total industrial thermal energy demand; of this renewable share, 90% comes from bioenergy sources.[49]

In 2020, industry accounted for 34% of total final energy consumption; of this, around three-quarters is in the form of direct thermal demand, with the rest in the form of electricity (some of it used to produce thermal energy).[50] Virtually all cooling in industry is done with electricity.[51] (→ *See Industry section in Global Overview chapter.*)

A range of renewable energy technologies exist for meeting industrial heating and cooling needs; they include renewables-based electrification, renewable gases, and direct-use applications through geothermal heat, solar thermal heat and modern bioenergy.[52] Commercially and technically viable options for bioenergy use already exist in the food and tobacco and pulp and paper industries, thanks to the availability of organic waste by-products and the lower process temperatures required.[53] In the aluminium and non-ferrous metals industry, both the use of electric arc furnaces and "sector coupling[i]" opportunities for utilising renewable electricity are growing.[54]

Environmental attribute certificate markets expanded to **include thermal energy** during 2020.

However, the most energy-intensive industry sectors, such as steel, chemicals and cement, currently do not rely significantly on renewable heat. Each has its own specific thermal energy needs. Those with the highest temperature requirements generally have tended to rely heavily on fossil fuels, which have reached shares exceeding 80% in each of these three sectors[ii].[55]

The business dynamics of industrial thermal energy are notably different from power generation, due mainly to the inherently high levels of self-consumption in industry.[56] Firms in the heating and cooling sector often operate in local markets, and energy often is produced directly at the point of demand.[57] As such, industrial energy users simultaneously produce and consume the thermal energy they need for heating and cooling on-site, without having to procure it from the market. Self-generation is thus the norm for thermal energy.

In thermal processes, procurement mechanisms for renewables that are similar to corporate sourcing of renewable electricity are rare, although some developments have emerged. Most projects for industrial renewable heat have involved the use of bioenergy and solar thermal heat. For example, in 2020 Elpitiya Plantations (Sri Lanka) met 87% of its heat demand using locally sourced modern bioenergy and third-party suppliers (→ *see Box 11*), and Goess Brewery (Austria) met 42% of its heat demand using renewables, including from solar thermal installations.[58] Worldwide, nearly 900 solar thermal systems totalling more than 792 megawatts-thermal were supplying industrial process heat by the end of 2020, with new projects concentrated in China, Mexico and Germany. (→ *See Solar Thermal section in Market and Industry chapter.*)

Another option for industry sectors that have lower-temperature heat requirements is to procure renewable thermal energy from district heating providers.[59] In 2020, Denmark's largest industrial company, Danfoss, sourced 11% of the industrial thermal demand for its production processes from renewable district heating and recovery.[60] The company procures renewable thermal energy for many of its factories that manufacture energy efficiency technology and other products, with the aim of becoming carbon neutral in its heating and cooling needs globally by 2030.[61]

In 2020, the EU announced that its GO certificate system would extend beyond renewable electricity as of mid-2021 to include renewable heating and cooling, in line with the region's Renewable Energy Directive and the European Green Deal.[62] In North America, a REC market for industrial thermal energy using biomethane and other "low-carbon fuels" was under development in 2020.[63] The market's Green-e certified fuel certificate standard was being trialled on a small pilot basis in the region.[64]

i See Glossary.

ii The costs of converting these high-temperature processes to renewables are a major barrier, as the predominant energy source has been low-cost coal and coke, which are much less expensive than, for example, pelletised biomass fuels. The very large scale is also a barrier; for example, a large steel plant uses more energy than a large power station. (→ *See Industry section in Global Overview chapter.*)

BOX 11. Elpitiya Plantations' Sourcing of Renewable Heat

Elpitiya Plantations PLC (EPP) is a Sri Lankan plantation firm operating across 13 estates and focused primarily on manufacturing tea and crepe rubber. EPP's main thermal energy need is heated air to wither and dry tea leaves. Operating temperatures for these processes range between 50 degrees Celsius (°C) and 100 °C. In rubber production, process heat is used to evaporate the surface moisture from the material.

EPP has developed a sustainability strategy formulated around six relevant United Nations Sustainable Development Goals, including Goal 7 on affordable and clean energy. EPP's target is to source 100% of its thermal energy consumption from self-produced sustainable biomass feedstocks by 2030. In 2020, EPP's annual biomass use for thermal applications represented 88% of the company's total energy consumption. EPP sourced 23% of this from its own biomass material – mainly uprooted rubber and eucalyptus trees – and procured the rest from other sustainable biomass suppliers.

EPP aims to increase reliance on its own biomass fuelwood through its Forestry Management Plan. By 2020, nearly 400 hectares of tree species had been grown for this purpose. However, given space constraints and the need to use the company's existing land to grow its commercial crops, EPP, like many plantation firms with similar renewable thermal energy goals, will still have to purchase significant biomass feedstocks from other suppliers.

Source: See endnote 58 for this chapter.

COMPANY EXAMPLES AND BUSINESS GROUPS

The highest renewable energy shares in process heat are found in industries with lower temperature needs. However, some energy-intensive sectors that require high-temperature heat have launched initiatives to increase the use of renewables in some markets. Actions in the aluminium industry as of early 2021 included a commitment by BMW (Germany) to source aluminium produced using solar power, and the announcement by Norsk Hydro (Norway), an aluminium and renewable energy company, that it was exploring the development and use of renewable hydrogen for some of its aluminium plants.[65]

Projects to produce steel from renewable hydrogen were under development in Germany and Sweden, among other countries. In early 2021, German steel producer Salzgitter began operations using hydrogen produced from wind energy.[66] In Sweden, the HYBRIT demonstration plant is scheduled to start producing steel based on the direct reduced iron process using renewable hydrogen in 2026.[67] The commercial venture received strong state backing when it was launched in 2016 and is a 20-year, USD 46 billion collaboration among steel maker SSAB, the state-owned iron ore producer LKAB and the utility company Vattenfall.[68] In early 2021, Swedish firm H2 Green Steel announced that it also would produce steel using renewable hydrogen, beginning in 2024.[69]

A few business coalitions exist to support the use of renewables in industry. The Renewable Thermal Collaborative (RTC) commits members from both the public and private sectors to procure renewable thermal heat from suppliers, as well as to help promote the RTC's work in developing corporate sourcing markets and mechanisms for renewable heat.[70] In December 2020, Stanley Black and Decker (US) became the RTC's 21st member company.[71]

Also in December, The Climate Group, in partnership with the Responsible Steel initiative, launched SteelZero, the first business coalition of its kind in the industrial thermal energy sector.[72] SteelZero comprises firms that have committed to procure 100% net zero[i] steel by 2050 and that have made an intermediate commitment to procuring, specifying or stocking 50% of their net zero steel requirement by 2030.[73] SteelZero began with eight steel-buying company members, from sectors including construction, real estate and property development, steel production and renewable energy development.[74] While it aims primarily to drive business on the demand side, it also is lobbying for greater investment in renewable technologies and policies to facilitate the steel industry's transition to zero carbon.[75]

i See Glossary.

RENEWABLES IN TRANSPORT

Energy use for transport comprises four main sectors: road, rail, maritime shipping and aviation. Although these sectors use varying amounts of renewable energy and face unique challenges, business demand for renewables generally increased across all sectors in 2020. (→ *See Transport section in Global Overview chapter, and* ***Reference Table R19*** *in GSR 2021 Data Pack.*)

ROAD TRANSPORT

Business demand for renewables in road transport mainly involves company vehicle fleets, including company cars, rental vehicles, short-haul or "last-mile" delivery vans, heavy-duty vehicles (such as long-haul freight trucks and refuse trucks), buses, taxis and special purpose vehicles. Fleet vehicles contribute half of all emissions from road transport worldwide, despite accounting for only 20% of global vehicle sales.[76]

Renewable energy can fuel road vehicles through the combustion of biofuels or renewable hydrogen in an internal engine, or by powering the vehicles with renewable-based electricity. Most business demand during 2020 was for electric vehicles (EVs), with many companies scaling up their fleets and committing to a shift to 100% EVs (although this was not necessarily linked directly to renewable electricity).[77] Demand from businesses seeking to use biofuels in commercial fleets also grew in certain markets, and bioenergy remained the largest renewable energy contributor in the transport sector.

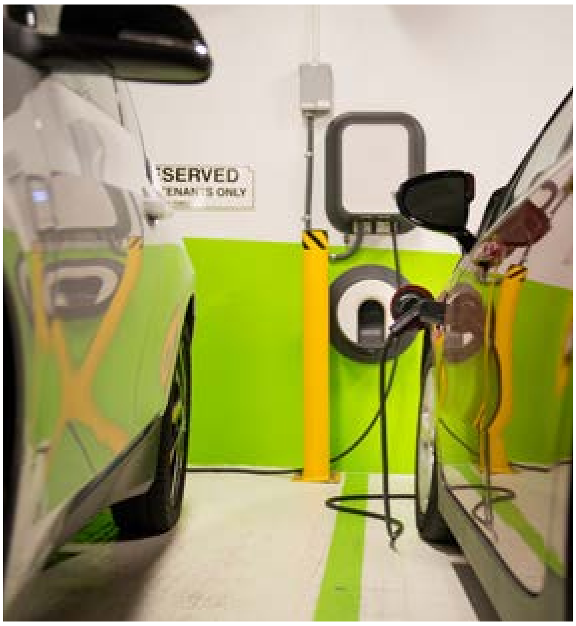
In Europe, 6 out of 10 cars sold are company cars, but less than 4% of these were EVs in 2020.[78] By early 2021, fleet vehicles represented 59% of the EVs on European roads, but very few of these were electric heavy-duty vehicles, due mainly to a lack of such models in the market.[79] However, in early 2021 a range of new electric heavy-duty vehicles were scheduled for launch, including the Tesla Semi.[80] Uptake of liquefied biogas in heavy-duty vehicles also increased in 2020, as infrastructure and investment in the technology grew, particularly in Scandinavia.[81]

Where companies have shown interest in electrifying their fleets, they have tended to first electrify a small share of vehicles to test driver sentiment and comfort, vehicle suitability, and depot charging capabilities (including the availability of charging station infrastructure). They also consider factors such as vehicle costs (especially relative to petrol/diesel fuel alternatives) and the total cost of ownership, as well as vehicle range, the operational considerations of integrating EVs into their fleets and financing models best suited to vehicle procurement.[82]

Emission standards also have helped to accelerate fleet electrification, especially among companies operating in the more than 300 "zero-emission zones" in cities worldwide.[83] Such standards and restrictions have influenced business decisions to invest in biogas for trucks as well in many regions.[84]

Company vehicle fleets have certain unique characteristics that make scaling up electrification particularly advantageous. These include the predictability of journeys, the constancy of distances travelled, fixed destinations and stopovers that support electric charging management. Given the high use rates for corporate fleet vehicles, their transition to electric also can make long-term economic sense because of the reduced servicing, maintenance and fuel costs associated with EVs.[85]

For hydrogen fuel cell vehicles, the business demand has been mainly for buses. As of early 2020, nearly all of the hydrogen produced worldwide was based on fossil fuels. However, some countries have begun adopting targets and policies to support renewable hydrogen specifically. (→ *See Systems Integration chapter, and Table 5 in Policy chapter.*) Investment in hydrogen fell 20% in 2020, to an estimated USD 1.5 billion.[86] This was driven by a COVID-induced slump in demand for hydrogen fuel cell buses, with investment falling from USD 865 million to USD 400 million.[87]



Company Examples and Business Groups

Some companies took action to increase their direct use of renewables in road transport. In 2020, "MY Renewable Diesel", produced by Neste (Finland) from waste and residue raw materials, became available to businesses and private consumers at more than 500 fuelling stations across Europe and in the US states of California and Oregon.[88] IKEA Finland partnered with Neste to begin using MY Renewable Diesel as part of its broader strategy to achieve emission-free deliveries by 2025.[89] McDonald's Netherlands and the logistics company HAVI (Germany) also partnered with Neste to supply used cooking oil from McDonald's to make MY Renewable Diesel for HAVI's delivery trucks.[90] In addition, companies expanded their use of biogas: for example, Lidl partnered with IVECO, LC3 and Edison in early 2020 to introduce five biomethane-fuelled vehicles for use in Lidl's Italian fleet.[91]

Many companies also were using electric fleet vehicles based on renewable electricity. As of 2020, Deutsche Post DHL operated the largest EV fleet in Germany, and in early 2021 the company announced that it would power its entire delivery fleet of more than 80,000 vehicles with renewable electricity by 2030.[92] In the United States, a joint venture among First Student, First Transit and NextEra Energy Resources announced a plan in January 2021 to transition more than 55,000 buses across North America to renewably powered EVs.[93]

Business coalitions and collaborations have emerged to support decarbonised and electrified transport. As of early 2021, more than 100 companies had committed through EV100 to switching their fleets to electric and/or installing charging infrastructure by 2030.[94] The Transport Decarbonisation Alliance targets emission reductions in the road freight sector, which accounts for more than 60% of freight transport emissions; due to rising freight demand, these emissions are on track to double by 2050.[95] In the United States, the Drive to Zero programme works with buyer companies, energy providers and government agencies at the city, regional and national levels to promote business demand for zero-emission and near-zero-emission trucks, buses and other vehicles.[96]

RAIL TRANSPORT

The rail transport industry comprises a mix of state-owned enterprises and private sector companies that develop and provide rail network infrastructure, manufacture trains and provide both passenger and freight services.[97] Rail is the most electrified transport sector globally, with around 75% of passenger rail and 50% of rail freight running on electric power as of 2019.[98] More than one-quarter of rail electricity worldwide is estimated to be renewable.[99] Business demand for renewables in rail transport has focused almost entirely on the direct use of biofuels and on renewable electricity, but developments also have occurred in renewable hydrogen.[100] At least two companies set targets for net zero carbon emissions during 2020: Indian Railways by 2030 and UK-based Network Rail by 2050.[101]

Company Examples and Business Groups

Direct use of renewables in trains has been under way for some time. In 2007, Virgin Group (UK) launched Europe's first regular biofuel-powered passenger train service in the United Kingdom, and trains in parts of India have been running on biodiesel since at least 2015.[102] Florida Power and Light (US) began supplying biodiesel for high-speed inter-city rail service in 2017.[103] Also that year, Arriva (France) won a contract to provide 18 new biodiesel trains to the Netherlands starting in 2020, and successful trials were completed in July 2020.[104]

Rail freight companies that seek to decarbonise using renewable electricity can opt to procure electric-power trains from manufacturers; however, if they wish to source their electricity from renewables, they may have to depend on network infrastructure providers. In some cases, companies have invested directly in renewable power capacity to provide electricity for their activities. In early 2020, Amp Energy (India) partnered with Hyderabad Metro Rail to install a 7.8 MW solar PV plant to power the railway's operations.[105] Japan's largest railway company, East Japan Railway, began investing in solar power in 2013 for operational use, and in early 2021 the company announced plans to increase its share of renewable power in order to reach its target of zero carbon dioxide emissions by 2050.[106]

A growing number of rail companies have experimented with green hydrogen. Between February and March 2020, testing advanced on the world's first renewable hydrogen passenger train, as a group of French and Dutch companies[i] was able to successfully refuel the train in Groningen (Netherlands).[107] Energy company ENGIE (France) continued working with Gasunie (Netherlands) to develop a large-scale renewable hydrogen plant in Groningen, as a part of a long-term push to shift passenger trains in the northern Netherlands from diesel to green hydrogen.[108] In Italy, Enel Green Power and the transport firm FNM formed a joint venture in early 2021 to develop green hydrogen options for the rail network of Lombardy, as part of the H2IseO project to create a Hydrogen Valley in the province.[109]

i ENGIE refuelled the train, working alongside French train manufacturer Alstom, French rail services company Arriva, Dutch railway infrastructure agency ProRail and the independent testing organisation DEKRA.

MARITIME SHIPPING

Business demand for renewables in maritime shipping has focused primarily on biofuels, with interest also growing in renewable hydrogen and ammonia.[110] In 2020, biofuels accounted for around 0.1% of the total global demand for shipping fuel.[111] Although biofuels have been more expensive compared to fossil-based options, cost differentials continued to narrow, leading them to be considered both a commercially and technically viable alternative.[112]

Company Examples and Business Groups

A growing number of shipping companies have shown interest in increasing their use of renewable fuels, and some have completed successful voyages with them. In June 2020, a dredging vessel operated by Jan De Nul Group (Belgium) was the first to sail 2,000 hours on 100% renewable fuels, in collaboration with MAN Energy Solutions (Germany) and GoodFuels (Netherlands), marking the longest continuous use of 100% renewable fuels in the sector.[113] In March 2021, a Höegh Autoliners (Norway) vessel completed its first nearly carbon-neutral voyage between South Africa and Europe using advanced biofuels – reducing carbon emissions around 90% – and the company announced plans to scale up its procurement of shipping biofuels.[114]

Other companies were in the testing phase during 2020. The cargo firm Stena Bulk (Sweden) conducted a test voyage on a medium-range tanker ship using 100% biofuel (MR1-100) – based on waste cooking oil supplied by GoodFuels – and was able to reduce overall carbon emissions more than 80%.[115] Eastern Pacific Shipping (Singapore) also contracted with GoodFuels to supply biofuel bunkers for a medium-range tanker, with the aim of trialling biofuels in other classes of ships in the near future.[116] Under the GoodShipping programme, automaker BMW (Germany) partnered with the shipping firm UECC (Norway) to test marine biofuel on UECC ships carrying BMW cars, with the goal of reducing emissions 80-90%.[117] Also in 2020, the Finnish firms SSAB Raahe, Gasum and ESL Shipping began testing the use of liquefied biogas in shipping, following agreements signed in 2019 by several Scandinavian shipping companies, including Preem (Sweden) and Hurtigruten (Norway), to use the fuel.[118]

Interest and activity in renewable hydrogen and ammonia also increased in the maritime sector.[119] In 2020, the HySHIP consortium, led by Norwegian shipping company Wilhelmsen, obtained EUR 8 million (USD 9.8 million) in EU funding to build a prototype ship powered by renewable hydrogen.[120] In addition, the ShipFC consortium of 14 European companies and institutions received EUR 10 million (USD 12.3 million) in EU funding to retrofit (in 2024) an offshore vessel with the world's first fuel cell powered by green ammonia.[121]

Maritime ports are working with shipping companies (and each other) to promote increased demand for renewable fuels. The World Ports Climate Action Programme, a coalition of 12 leading ports[i], aims to reduce carbon emissions from shipping and ports through the accelerated development of commercially viable "low-carbon fuels", among other steps.[122] In a different approach, 26 global shipping banks and top industry players from Asia, Europe and North America developed the Poseidon Principles to encourage more sustainable shipping practices, including greater use of renewables, in alignment with the International Maritime Organization's emission reduction goals[ii].[123]

i Members include: Antwerp, Barcelona, Gothenburg, Hamburg, Le Havre, Long Beach, Los Angeles, New York and New Jersey, Rotterdam, Valencia, Vancouver and Yokohama.

ii In 2018, the International Maritime Organization, the international shipping regulatory body, set a goal of reducing greenhouse gas emissions in the sector 50% by 2050 (compared to 2008 levels), with carbon intensity reduction targets also set for 2030 and 2050.

AVIATION

Business demand for renewable energy in aviation comes mainly from airline and airport companies. Sustainable aviation fuels (SAF)[i] have been developed primarily from bioenergy sources and technology, and e-fuels are produced from synthesising carbon dioxide (such as synthetic paraffinic kerosene, or SPK) and renewable hydrogen. The latter also can be used in fuel cells to power aviation systems based on electric propulsion.

The first flight using aviation biofuel was made in 2008, and by the end of 2020 more than 40 airlines had used SAF.[124] Since 2011, more than 315,000 commercial flights have flown on a blend of SAF, and 6 billion litres of the fuels have been purchased through forward purchase agreements[ii].[125] However, SAF accounted for less than 0.1% of total aviation fuel demand in 2020.[126]

Biofuels used in aviation typically must be combined with fossil-based jet kerosene to achieve certain blend rates.[127] These blends could potentially reach 50% but in practice tend to be less than 1%, due to the relatively high cost of SAF (some of the fuels can cost five times their kerosene equivalent) and to the limited availability of even the most commercially viable aviation biofuels.[128] By the end of 2020, most SAF demand was in Europe and California (US), where dedicated policy incentives exist for SAF and other "low-carbon fuels".[129] Five airports worldwide – in Bergen, Brisbane, Los Angeles, Oslo and Stockholm – had facilities that regularly distributed SAF, while others offered semi-regular supply.[130]

Interest in the electrification of aviation has increased. As of May 2021, mostly just drones or small planes had been developed, although some companies were planning fully electric airliners to carry more than 120 passengers.[131] Others are aiming for hydrogen-powered electric planes.[132] So far, none of these ventures has had a direct link to renewable energy.

Company Examples and Business Groups

Some airlines are boosting their sustainable aviation ambitions. In 2020, Scandinavian Airlines committed to running all domestic flights (representing less than 20% of the company's total fuel demand) on SAF by 2030.[133] KLM (Netherlands) is working with Amsterdam's Schiphol airport and fuel producer Neste to develop SAF supply facilities by 2022.[134] In 2020, British Airways, FinnAir, Lufthansa (Germany) and Virgin (UK) pledged to scale up their demand for aviation biofuel, as have air cargo carriers Amazon Air, FedEx and UPS (all US).[135] In addition, a few countries have conditioned their allocation of COVID-19 bailout funds to the aviation industry on a stronger commitment to renewable fuels. (→ *See Sidebar 3 in Policy chapter.*)

Companies also continued to develop electric and hydrogen aircraft, although in most cases these efforts do not specify the use of renewable energy. In 2020, Wright Electric announced the launch of an electric propulsion programme to develop a 186-seat aircraft for the carrier EasyJet.[136]

The business-based coalition Clean Skies for Tomorrow (CST) is committed to achieving broad adoption of SAF by 2030 and includes nearly 90 aviation companies, among them Airbus, Boeing, KLM Royal Dutch Airlines, Amsterdam's Schiphol Airport, London's Heathrow Airport, Shell, SkyNRG and SpiceJet.[137] CST is part of the broader Mission Possible Partnership developed by the World Economic Forum, the We Mean Business coalition, RMI and the Energy Transitions Commission. Its plan includes developing a mechanism to aggregate airline demand for aviation biofuel, similar to an aggregated corporate PPA for renewable electricity.[138]

Business demand for **renewables in aviation and shipping** continued to advance at a slow pace.

i SAF are produced from renewable sustainable feedstocks from bioenergy sources.

ii These are customised contracts between two parties to buy or sell an asset at a specified price on a future date.

ENERGY UNITS AND CONVERSION FACTORS

METRIC PREFIXES

kilo	(k)	=	10^3
mega	(M)	=	10^6
giga	(G)	=	10^9
tera	(T)	=	10^{12}
peta	(P)	=	10^{15}
exa	(E)	=	10^{18}

VOLUME

1 m^3	=	1,000 litres (l)
1 US gallon	=	3.785412 l
1 Imperial gallon	=	4.546090 l

Example: 1 TJ = 1,000 GJ = 1,000,000 MJ = 1,000,000,000 kJ = 1,000,000,000,000 J

ENERGY UNIT CONVERSION

Multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Toe = tonnes (metric) of oil equivalent

1 Mtoe = 41.9 PJ

Example: 1 MWh x 3.600 = 3.6 GJ

BIOFUELS CONVERSION

Ethanol: 21.4 MJ/l

Biodiesel (FAME): 32.7 MJ/l

Biodiesel (HVO): 34.4 MJ/l

Petrol: 36 MJ/l

Diesel: 41 MJ/l

SOLAR THERMAL HEAT SYSTEMS

1 million m^2 = 0.7 GW_{th}

Used where solar thermal heat data have been converted from square metres (m^2) into gigawatts thermal (GW_{th}), by accepted convention.

Note on Biofuels:

1) These values can vary with fuel and temperature.
2) Around 1.7 litres of ethanol is energy equivalent to 1 litre of petrol, and around 1.2 litres of biodiesel (FAME) is energy equivalent to 1 litre of diesel.
3) Energy values from http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_(toe) except HVO, which is from *Neste Renewable Diesel Handbook*, p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

DATA COLLECTION AND VALIDATION

REN21 has developed a unique renewable energy reporting culture, allowing it to become recognised as a neutral data and knowledge broker that provides credible and widely accepted information. **Transparency is at the heart** of the REN21 data and reporting culture, and the following text explains some of the GSR's key processes for data collection and validation.

DATA COLLECTION

Production of REN21's GSR is a continuous process occurring on an annual basis. The data collection process begins following the launch of the previous year's report with an Expression of Interest form to mobilise REN21's GSR contributors. During this time, the GSR team also prepares the questionnaires that will be filled in by contributors. The questionnaires are updated each year with emerging and relevant topics as identified by the REN21 Secretariat.

REN21 collects data in five main ways:

1. **Country questionnaire.** In the country questionnaire, contributors from around the world submit data on renewable energy in their respective countries or countries of interest. This covers information about annual developments for renewable energy technologies, market trends, policy developments and local perspectives. The questionnaire also collects data related to energy access from respondents with a focus on developing and emerging countries, covering the status of electrification and clean cooking, as well as policies and programmes for energy access and markets for distributed renewables. Each data point is provided with a source and verified independently by the GSR team. Data collection with the country questionnaire typically begins in October.
2. **Peer review.** To further collect data and project examples and to ensure that significant developments have not been overlooked, GSR contributors and reviewers participate in an open peer review process that takes place twice during each report cycle. The first round typically occurs in January and includes Round 1 chapters such as Policy Landscape, while the second round is held typically in March/April and includes Round 2 chapters such as Global Overview and Market and Industry Trends. Peer review is open to all interested experts.
3. **Expert interviews.** REN21's global community consists of a wide range of professionals who provide their expert input on renewable energy trends in the target year through interviews and personal communication with the REN21 GSR team and chapter authors. The vast majority of the information is backed up by primary sources.
4. **Desk research.** To fill in remaining gaps in the GSR and to pursue new topics, the REN21 GSR team and chapter authors conduct extensive desk research. Topics of research vary widely between GSR years and depend on emerging topics, important trends and annual availability of formal or informal data in the target sector.
5. **Data sharing agreements.** REN21 holds several data sharing agreements with some of the largest and most reliable data providers/aggregators in the energy sector. These formal data are used exclusively in some cases or, in others, form the foundation of calculations and estimations presented in the GSR.

DATA VALIDATION

REN21 ensures the accuracy and reliability of its reports by conducting data validation and fact-checking as a continuous process. Beginning during the first submission of the country questionnaires, data are continually verified up through the design period and until the final report is published. **All data provided by contributors, whether written or verbal, are validated by primary sources, which are published alongside the full report.**

METHODOLOGICAL NOTES

This 2021 report is the 16th edition of the *Renewables Global Status Report* (GSR), which has been produced annually since 2005 (with the exception of 2008). Readers are directed to the previous GSR editions for historical details.

Most 2020 data for national and global capacity, output, growth and investment provided in this report are preliminary. Where necessary, information and data that are conflicting, partial or older are reconciled by using reasoned expert judgment. Endnotes provide additional details, including references, supporting information and assumptions where relevant.

Each edition draws from thousands of published and unpublished references, including: official government sources; reports from international organisations and industry associations; input from the GSR community via hundreds of questionnaires submitted by country, regional and technology contributors as well as feedback from several rounds of formal and informal reviews; additional personal communications with scores of international experts; and a variety of electronic newsletters, news media and other sources.

Much of the data found in the GSR is built from the ground up by the authors with the aid of these resources. This often involves extrapolation of older data, based on recent changes in key countries within a sector or based on recent growth rates and global trends. Other data, often very specific and narrow in scope, come more-or-less prepared from third parties. The GSR attempts to synthesise these data points into a collective whole for the focus year.

The GSR endeavours to provide the best data available in each successive edition; as such, data should not be compared with previous versions of this report to ascertain year-by-year changes.

NOTE ON ESTABLISHING RENEWABLE ENERGY SHARES OF TOTAL FINAL ENERGY CONSUMPTION (TFEC)

Assumptions Related to Renewable Electricity Shares of TFEC

When estimating electricity consumption from renewable sources, the GSR must make certain assumptions about how much of the estimated gross output from renewable electricity generating resources actually reaches energy consumers, as part of total final energy consumption.

The International Energy Agency's (IEA) *World Energy Statistics and Balances* reports electricity output by individual technology. However, it does not report electricity consumption by technology – only total consumption of electricity.

The difference between gross output and final consumption is determined by:

- The energy industry's own-use, including electricity used for internal operations at power plants. This includes the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants, and other uses such as electricity use in coal mining and fossil fuel refining.
- Transmission and distribution losses that occur as electricity finds its way to consumers.

Industry's own-use. The common method is to assume that the proportion of consumption by technology is equal to the proportion of output by technology. This is problematic because logic dictates that industry's own-use cannot be proportionally the same for every generating technology. Further, industry's own-use must be somewhat lower for some renewable generating technologies (particularly non-thermal renewables such as hydropower, solar PV and wind power) than is the case for fossil fuel and nuclear power technologies. Such thermal power plants consume significant amounts of electricity to meet their own internal energy requirements (see above).

Therefore, the GSR has opted to apply differentiated "industry own-use" by generating technology. This differentiation is based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as on the apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries is attributed to fossil fuel generation.

Differentiated own-uses by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); concentrating solar thermal power (CSP) (14.2%); and bio-power (15.2%). For comparison, the undifferentiated (universal) combined losses and industry own-use would be 16.7% of gross generation. Estimated technology-specific industry own-use of electricity from renewable sources is based on data for 2018 from IEA, World Energy Balances, 2020 edition (Paris: 2020).

Transmission and distribution losses. Such losses may differ (on average) by generating technology. For example, hydropower plants often are located far from load centres, incurring higher than average transmission losses, whereas some solar PV generation may occur near to (or at) the point of consumption, incurring little (or zero) transmission losses. However, specific information by technology on a global scale is not available.

Therefore, the GSR has opted to apply a global average for transmission and distribution losses. Global average electricity losses are based on data for 2018 from IEA, *World Energy Balances*, 2020 edition (Paris: 2020).

NOTES ON RENEWABLE ENERGY IN TOTAL FINAL ENERGY CONSUMPTION, BY ENERGY USE

GSR 2021 presents an illustration of the share of renewable energy in total final energy consumption (TFEC) by sector in 2018. (→ *See Figure 4 in Global Overview chapter.*) The share of TFEC consumed in each sector is provided as follows: thermal (51%), transport (32%) and electricity (17%). There are three important points about this figure and about how the GSR treats end-use TFEC in general:

1. Definition of Heating and Cooling and Thermal Applications

In the GSR, the term "heating and cooling" refers to *applications of thermal energy* including space and water heating, space cooling, refrigeration, drying and industrial process heat, as well as any use of energy other than electricity that is used for motive power in any application other than transport. In other words, thermal demand refers to all end-uses of energy that cannot be classified as electricity demand or transport.

2. Sectoral Shares of TFEC

In Figure 4, each sectoral share of TFEC portrays the energy demand for all end-uses within the sector. The shares of TFEC allocated to thermal and to transport also account for the electricity consumed in these sectors – that is, electricity for space heating and space cooling, industrial process heat, etc., and electricity for transport. These amounts have been reallocated from final demand in the electricity sector. Therefore, the share of TFEC allocated to the electricity sector comprises all final end-uses of electricity that *are not used for heating, cooling or transport*. This is a methodological change from GSR 2018 that was intended to strengthen the accuracy of the representation. In total, the final energy consumption of all electrical energy accounted for 25.6% of TFEC in 2018.

3. Shares of Non-renewable Electricity

Figure 3 illustrates the share of *non-renewable electricity* in thermal and in transport to emphasise that electricity demand is being allocated to each sector. The share of non-renewable electricity is not critical to the figure content, so the percentage value of non-renewable electricity in each sector is not explicitly shown, but it is included in this note. In 2018, all electricity for heating and cooling met 7.8% of final energy demand in the sector (2.1% renewable and 5.7% non-renewable electricity). All electricity for transport met 1.1% of final energy demand in the sector (0.3% renewable and 0.8% non-renewable electricity).

NOTES ON RENEWABLE ENERGY CAPACITIES AND ENERGY OUTPUT

A number of issues arise when counting renewable energy capacities and energy output. Some of these are discussed below:

1. Capacity versus Energy Data

The GSR aims to give accurate estimates of capacity additions and totals, as well as of electricity, heat and transport fuel production in the focus year. These measures are subject to some uncertainty, which varies by technology. The Market and Industry chapter includes estimates for energy produced where possible, but it focuses mainly on power or heat capacity data. This is because capacity data generally can be estimated with a greater degree of confidence than generation data. Official heat and electricity generation data often are not available for the target year within the production time frame of the GSR.

2. Constructed Capacity versus Connected Capacity and Operational Capacity

Over a number of years in the past decade, the solar PV and wind power markets saw increasing amounts of capacity that was connected to the grid but not yet deemed officially operational, or constructed capacity that was not connected to the grid by year's end. Therefore, since the 2012 edition the GSR has aimed to count only capacity additions that were grid-connected or that otherwise went into service (e.g., capacity intended for off-grid use) during the previous calendar (focus) year. However, it appears that this phenomenon is no longer an issue, with the exception of wind power installations in China, where it was particularly evident over the period 2009-2019. For details on the situation in China and on the reasoning for capacity data used in this GSR, see endnote 24 in the Wind Power section of the Market and Industry chapter.

3. Retirements and Replacements

Data on capacity retirements and replacements (re-powering) are incomplete for many technologies, although data on several technologies do attempt to account for these directly. It is not uncommon for reported new capacity installations to exceed the implied net increase in cumulative capacity; in some instances, this is explained by revisions to data on installed capacity, while in others it is due to capacity retirements and replacements. Where data are available, they are provided in the text or relevant endnotes.

4. Bioenergy Data

Given existing complexities and constraints, the GSR strives to provide the best and latest data available regarding bioenergy developments. The reporting of biomass-fired combined heat and power (CHP) systems varies among countries; this adds to the challenges experienced when assessing total heat and electricity capacities and total bioenergy outputs.

Wherever possible, the bio-power data presented include capacity and generation from both electricity-only and CHP systems using solid biomass, landfill gas, biogas and liquid biofuels. Electricity generation and capacity numbers are based on national data for the focus year in the major producing countries and on forecast data for remaining countries for the focus year from the IEA.

The methodology is similar for biofuels production data, with data for most countries (not major producers) from the IEA; however, data for hydrotreated vegetable oil (HVO) are estimated based on production statistics for the (relatively few) major producers. Bio-heat data are based on an extrapolation of the latest data available from the IEA based on recent growth trends. (→ *See Bioenergy section in Market and Industry chapter.*)

5. Hydropower Data and Treatment of Pumped Storage

Starting with the 2012 edition, the GSR has made an effort to report hydropower generating capacity without including pure pumped storage capacity (the capacity used solely for shifting water between reservoirs for storage purposes). The distinction is made because pumped storage is not an energy source but rather a means of energy storage. It involves conversion losses and can be fed by all forms of electricity, renewable and non-renewable.

Some conventional hydropower facilities do have pumping capability that is not separate from, or additional to, their normal generating capability. These facilities are referred to as "mixed" plants and are included, to the extent possible, with conventional hydropower data. It is the aim of the GSR to distinguish and separate only the pure (or incremental) pumped storage component.

Where the GSR presents data for renewable power capacity not including hydropower, the distinction is made because hydropower remains the largest single component by far of renewable power capacity, and thus can mask developments in other renewable energy technologies if included. Investments and jobs data separate out large-scale hydropower where original sources use different methodologies for tracking or estimating values. Footnotes and endnotes provide additional details.

6. Solar PV Capacity Data[i]

The capacity of a solar PV panel is rated according to direct current (DC) output, which in most cases must be converted by inverters to alternating current (AC) to be compatible with end-use electricity supply. No single equation is possible for calculating solar PV data in AC because conversion depends on many factors, including the inverters used, shading, dust build-up, line losses and temperature effects on conversion efficiency. The difference between DC and AC power can range from as little as 5% (conversion losses or inverter set at the DC level) to as much as 40% (due to grid regulations limiting output or to the evolution of utility-scale systems), and most utility-scale plants built in 2019 have ratios in the range of 1.1 to 1.6[ii].

The GSR attempts to report all solar PV capacity data on the basis of DC output (where data are known to be provided in AC, this is specified) for consistency across countries. Some countries (for example, Canada, Chile, India, Japan, Malaysia, Spain, Sweden and the United States) report official capacity data on the basis of output in AC; these capacity data were converted to DC output by data providers (see relevant endnotes) for the sake of consistency. Global renewable power capacity totals in this report include solar PV data in DC; as with all statistics in this report, they should be considered as indicative of global capacity and trends rather than as exact statistics.

7. Concentrating Solar Thermal Power (CSP) Data

Global CSP data are based on commercial facilities only. Demonstration or pilot facilities and facilities of 5 MW or less are excluded. Discrepancies between REN21 data and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals. The GSR aims to report net CSP capacities for specific CSP plants that are included. In certain cases, it may not be possible to verify if the reported capacity of a given CSP plant is net or gross capacity. In these cases net capacity is assumed.

8. Solar Thermal Heat Data

Starting with GSR 2014, the GSR includes all solar thermal collectors that use water as the heat transfer medium (or heat carrier) in global capacity data and the ranking of top countries. Previous GSRs focused primarily on glazed water collectors (both flat plate and evacuated tube); the GSR now also includes unglazed water collectors, which are used predominantly for swimming pool heating. Since the GSR 2018, data for concentrating collectors are available. These include new installations overall as well as in key markets and total in operation by year's end. The market for solar air collectors (solar thermal collectors that use air as the heat carrier) and hybrid or PV-thermal technologies (elements that produce both electricity and heat) is small and the data rather uncertain. All three collector types – air, concentrating and hybrid collectors – are included where specified.

Revised gross additions for 2019 included in this GSR (26.1 GW_{th}) are significantly lower than those published in GSR 2020 (31.3 GW_{th}) for two reasons: First, the Chinese Solar Thermal Industry Federation (CSTIF) adjusted downwards its number for China's new additions in 2019, from 22.75 GW_{th} (a preliminary figure, available as of early 2020) to 20 GW_{th}. Second, data for new additions in China are based on produced collector area, rather than on annual installations in China; as a result, export volumes have been included in China's national statistics for 2020 and earlier years. In past editions of the GSR, this has resulted in a double counting of some collector area because the majority of coated vacuum tubes installed worldwide are purchased from China. For more details, see endnotes 1 and 5 in the Solar Thermal Heating section of the Market and Industry chapter.

OTHER NOTES

Editorial content of this report closed by 31 May 2021 for technology data, and by 15 May 2021 or earlier for other content.

Growth rates in the GSR are calculated as compound annual growth rates (CAGR) rather than as an average of annual growth rates.

All exchange rates in this report are as of 31 December 2020 and are calculated using the OANDA currency converter (http://www.oanda.com/currency/converter).

Corporate domicile, where noted, is determined by the location of headquarters.

i See Solar PV section of the Market and Industry chapter for sources on capacity data.

ii See IEA PVPS, *Trends in Photovoltaic Applications 2019*, p. 9, and IEA PVPS, *Snapshot of Global PV Markets 2020*, p. 11.

GLOSSARY

Absorption chillers. Chillers that use heat energy from any source (solar, biomass, waste heat, etc.) to drive air conditioning or refrigeration systems. The heat source replaces the electric power consumption of a mechanical compressor. Absorption chillers differ from conventional (vapour compression) cooling systems in two ways: 1) the absorption process is thermochemical in nature rather than mechanical, and 2) the substance that is circulated as a refrigerant is water rather than chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), also called Freon. The chillers generally are supplied with district heat, waste heat or heat from co-generation, and they can operate with heat from geothermal, solar or biomass resources.

Adsorption chillers. Chillers that use heat energy from any source to drive air conditioning or refrigeration systems. They differ from absorption chillers in that the adsorption process is based on the interaction between gases and solids. A solid material in the chiller's adsorption chamber releases refrigerant vapour when heated; subsequently, the vapour is cooled and liquefied, providing a cooling effect at the evaporator by absorbing external heat and turning back into a vapour, which is then re-adsorbed into the solid.

Auction. See Tendering.

Bagasse. The fibrous matter that remains after extraction of sugar from sugar cane.

Behind-the-meter system. Any power generation capacity, storage or demand management on the customer side of the interface with the distribution grid (i.e., the meter). (Also see Front-of-meter system.)

Biodiesel. A fuel produced from oilseed crops such as soy, rapeseed (canola) and palm oil, and from other oil sources such as waste cooking oil and animal fats. Biodiesel is used in diesel engines installed in cars, trucks, buses and other vehicles, as well as in stationary heat and power applications. Most biodiesel is made by chemically treating vegetable oils and fats (such as palm, soy and canola oils, and some animal fats) to produce fatty acid methyl esters (FAME). (Also see Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA).)

Bioeconomy (or bio-based economy). Economic activity related to the invention, development, production and use of biomass resources for the production of food, fuel, energy, chemicals and materials.

Bioenergy. Energy derived from any form of biomass (solid, liquid or gaseous) for heat, power and transport. (Also see Biofuel.)

Biofuel. A liquid or gaseous fuel derived from biomass, primarily ethanol, biodiesel and biogas. Biofuels can be combusted in vehicle engines as transport fuels and in stationary engines for heat and electricity generation. They also can be used for domestic heating and cooking (for example, as ethanol gels). Conventional biofuels are principally ethanol produced by fermentation of sugar or starch crops (such as wheat and corn), and FAME biodiesel produced from oil crops such as palm oil and canola and from waste oils and fats. Advanced biofuels are made from feedstocks derived from the lignocellulosic fractions of biomass sources or from algae. They are made using biochemical and thermochemical conversion processes, some of which are still under development.

Biogas/Biomethane. Biogas is a gaseous mixture consisting mainly of methane and carbon dioxide produced by the anaerobic digestion of organic matter (broken down by microorganisms in the absence of oxygen). Organic material and/or waste is converted into biogas in a digester. Suitable feedstocks include agricultural residues, animal wastes, food industry wastes, sewage sludge, purpose-grown green crops and the organic components of municipal solid wastes. Raw biogas can be combusted to produce heat and/or power. It also can be refined to produce biomethane.

Biomass. Any material of biological origin, excluding fossil fuels or peat, that contains a chemical store of energy (originally received from the sun) and that is available for conversion to a wide range of convenient energy carriers.

Biomass, traditional (use of). Solid biomass (including fuel wood, charcoal, agricultural and forest residues, and animal dung), that is used in rural areas of developing countries with traditional technologies such as open fires and ovens for cooking and residential heating. Often the traditional use of biomass leads to high pollution levels, forest degradation and deforestation.

Biomass energy, modern. Energy derived from combustion of solid, liquid and gaseous biomass fuels in high-efficiency conversion systems, which range from small domestic appliances to large-scale industrial conversion plants. Modern applications include heat and electricity generation, combined heat and power (CHP) and transport.

Biomass gasification. In a biomass gasification process, biomass is heated with a constrained amount of air or oxygen, leading to the partial combustion of the fuels and production of a mix of combustion gases that, depending on the conditions, can include carbon monoxide and dioxide, methane, hydrogen and more complex materials such as tars. The resulting gas can either be used for power generation (e.g., in an engine or turbine) or else further purified and treated to form a "synthesis gas". This can then be used to produce fuels including methane, alcohols, and higher hydrocarbon fuels, including bio-gasoline or jet fuel. While gasification for power or heat production is relatively common, there are few examples of operating plants producing gas of high enough quality for subsequent synthesis to more complex fuels.

Biomass pellets. Solid biomass fuel produced by compressing pulverised dry biomass, such as waste wood and agricultural residues. Pellets typically are cylindrical in shape with a diameter of around 10 millimetres and a length of 30-50 millimetres. Pellets are easy to handle, store and transport and are used as fuel for heating and cooking applications, as well as for electricity generation and CHP. (Also see Torrefied wood.)

Biomethane. Biogas can be turned into biomethane by removing impurities including carbon dioxide, siloxanes and hydrogen sulphides, followed by compression. Biomethane can be injected directly into natural gas networks and used as a substitute for natural gas in internal combustion engines without risk of corrosion. Biomethane is often known as renewable natural gas (RNG), especially in North America.

Blockchain. A decentralised ledger in which digital transactions (such as the generation and sale of a unit of solar electricity) are anonymously recorded and verified. Each transaction is securely collected and linked, via cryptography, into a time-stamped "block". This block is then stored on distributed computers as a "chain". Blockchain may be used in energy markets, including for micro-trading among solar photovoltaic (PV) prosumers.

Building energy codes and standards. Rules specifying the minimum energy standards for buildings. These can include standards for renewable energy and energy efficiency that are applicable to new and/or renovated and refurbished buildings.

Capacity. The rated power of a heat or electricity generating plant, which refers to the potential instantaneous heat or electricity output, or the aggregate potential output of a collection of such units (such as a wind farm or set of solar panels). Installed capacity describes equipment that has been constructed, although it may or may not be operational (e.g., delivering electricity to the grid, providing useful heat or producing biofuels).

Capacity factor. The ratio of the actual output of a unit of electricity or heat generation over a period of time (typically one year) to the theoretical output that would be produced if the unit were operating without interruption at its rated capacity during the same period of time.

Capital subsidy. A subsidy that covers a share of the upfront capital cost of an asset (such as a solar water heater). These include, for example, consumer grants, rebates or one-time payments by a utility, government agency or government-owned bank.

Carbon neutrality. See Net zero emissions.

Combined heat and power (CHP) (also called co-generation). CHP facilities produce both heat and power from the combustion of fossil and/or biomass fuels, as well as from geothermal and solar thermal resources. The term also is applied to plants that recover "waste heat" from thermal power generation processes.

Community energy. An approach to renewable energy development that involves a community initiating, developing, operating, owning, investing and/or benefiting from a project. Communities vary in size and shape (e.g., schools, neighbourhoods, partnering city governments, etc.); similarly, projects vary in technology, size, structure, governance, funding and motivation.

Competitive bidding. See Tendering.

Concentrating photovoltaics (CPV). Technology that uses mirrors or lenses to focus and concentrate sunlight onto a relatively small area of photovoltaic cells that generate electricity (see Solar photovoltaics). Low-, medium- and high-concentration CPV systems (depending on the design of reflectors or lenses used) operate most efficiently in concentrated, direct sunlight.

Concentrating solar collector technologies. Technologies that use mirrors to focus sunlight on a receiver (see Concentrating solar thermal power). These are usually smaller-sized modules that are used for the production of heat and steam below 400°C for industrial applications, laundries and commercial cooking.

Concentrating solar thermal power (CSP) (also called solar thermal electricity, STE). Technology that uses mirrors to focus sunlight into an intense solar beam that heats a working fluid in a solar receiver, which then drives a turbine or heat engine/generator to produce electricity. The mirrors can be arranged in a variety of ways, but they all deliver the solar beam to the receiver. There are four types of commercial CSP systems: parabolic troughs, linear Fresnel, power towers and dish/engines. The first two technologies are line-focus systems, capable of concentrating the sun's energy to produce temperatures of 400°C, while the latter two are point-focus systems that can produce temperatures of 800°C or higher.

Conversion efficiency. The ratio between the useful energy output from an energy conversion device and the energy input into it. For example, the conversion efficiency of a PV module is the ratio between the electricity generated and the total solar energy received by the PV module. If 100 kWh of solar radiation is received and 10 kWh of electricity is generated, the conversion efficiency is 10%.

Crowdfunding. The practice of funding a project or venture by raising money – often relatively small individual amounts – from a relatively large number of people ("crowd"), generally using the Internet and social media. The money raised through crowdfunding does not necessarily buy the lender a share in the venture, and there is no guarantee that money will be repaid if the venture is successful. However, some types of crowdfunding reward backers with an equity stake, structured payments and/or other products.

Curtailment. A reduction in the output of a generator, typically on an involuntary basis, from what it could produce otherwise given the resources available. Curtailment of electricity generation has long been a normal occurrence in the electric power industry and can occur for a variety of reasons, including a lack of transmission access or transmission congestion.

Degression. A mechanism built into policy design establishing automatic rate revisions, which can occur after specific thresholds are crossed (e.g., after a certain amount of capacity is contracted, or a certain amount of time passes).

Demand-side management. The application of economic incentives and technology in the pursuit of cost-effective energy efficiency measures and load-shifting on the customer side, to achieve least-cost overall energy system optimisation.

Demand response. Use of market signals such as time-of-use pricing, incentive payments or penalties to influence end-user electricity consumption behaviours. Usually used to balance electrical supply and demand within a power system.

Digitalisation. The application of digital technologies across the economy, including energy.

Digitisation. The conversion of something (e.g., data or an image) from analogue to digital.

Distributed generation. Generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption.

Distributed renewable energy. Energy systems are considered to be distributed if 1) the systems are connected to the distribution network rather than the transmission network, which implies that they are relatively small and dispersed (such as small-scale solar PV on rooftops) rather than relatively large and centralised; or 2) generation and distribution occur independently from a centralised network. Specifically for the purpose of the chapter on Distributed Renewables for Energy Access, "distributed renewable energy" meets both conditions. It includes energy services for electrification, cooking, heating and cooling that are generated and distributed independent of any centralised system, in urban and rural areas of the developing world.

Distribution grid. The portion of the electrical network that takes power off the high-voltage transmission network via sub-stations (at varying stepped-down voltages) and distributes electricity to customers.

Drop-in biofuel. A liquid biofuel that is functionally equivalent to a liquid fossil fuel and is fully compatible with existing fossil fuel infrastructure.

Electric vehicle (EV). Includes any road-, rail-, sea- and air-based transport vehicle that uses electric drive and can take an electric charge from an external source, or from hydrogen in the case of a fuel cell electric vehicle (FCEV). Electric road vehicles encompass battery electric vehicles (BEVs), plug-in hybrids (PHEVs) and FCEVs, all of which can include passenger vehicles (i.e., electric cars), commercial vehicles including buses and trucks, and two- and three-wheeled vehicles.

Energy. The ability to do work, which comes in a number of forms including thermal, radiant, kinetic, chemical, potential and electrical. Primary energy is the energy embodied in (energy potential of) natural resources, such as coal, natural gas and renewable sources. Final energy is the energy delivered for end-use (such as electricity at an electrical outlet). Conversion losses occur whenever primary energy needs to be transformed for final energy use, such as combustion of fossil fuels for electricity generation.

Energy audit. Analysis of energy flows in a building, process or system, conducted with the goal of reducing energy inputs into the system without negatively affecting outputs.

Energy conservation. Any change in behaviour of an energy-consuming entity for the specific purpose of affecting an energy demand reduction. Energy conservation is distinct from energy efficiency in that it is predicated on the assumption that an otherwise preferred behaviour of greater energy intensity is abandoned. (See Energy efficiency and Energy intensity.)

Energy efficiency. The measure that accounts for delivering more services for the same energy input, or the same amount of services for less energy input. Conceptually, this is the reduction of losses from the conversion of primary source fuels through final energy use, as well as other active or passive measures to reduce energy demand without diminishing the quality of energy services delivered. Energy efficiency is technology-specific and distinct from energy conservation, which pertains to behavioural change. Both energy efficiency and energy conservation can contribute to energy demand reduction.

Energy intensity. Primary energy consumption per unit of economic output. Energy intensity is a broader concept than energy efficiency in that it is also determined by non-efficiency variables, such as the composition of economic activity. Energy intensity typically is used as a proxy for energy efficiency in macro-level analyses due to the lack of an internationally agreed-upon high-level indicator for measuring energy efficiency.

Energy service company (ESCO). A company that provides a range of energy solutions including selling the energy services from a (renewable) energy system on a long-term basis while retaining ownership of the system, collecting regular payments from customers and providing necessary maintenance service. An ESCO can be an electric utility, co-operative, non-governmental organisation or private company, and typically installs energy systems on or near customer sites. An ESCO also can advise on improving the energy efficiency of systems (such as a building or an industry) as well as on methods for energy conservation and energy management.

Energy subsidy. A government measure that artificially reduces the price that consumers pay for energy or that reduces energy production cost.

Energy sufficiency. Entails a change or shift in actions and behaviours (at the individual and collective levels) in the way energy is used. Results in access to energy for everyone while limiting the impacts of energy use on the environment. For example, avoiding the use of cars and spending less time on electrical devices.

Ethanol (fuel). A liquid fuel made from biomass (typically corn, sugar cane or small cereals/grains) that can replace petrol in modest percentages for use in ordinary spark-ignition engines (stationary or in vehicles), or that can be used at higher blend levels (usually up to 85% ethanol, or 100% in Brazil) in slightly modified engines, such as those provided in "flex-fuel" vehicles. Ethanol also is used in the chemical and beverage industries.

Fatty acid methyl esters (FAME). See Biodiesel.

Feed-in policy (feed-in tariff or feed-in premium). A policy that typically guarantees renewable generators specified payments per unit (e.g., USD per kWh) over a fixed period. Feed-in tariff (FIT) policies also may establish regulations by which generators can interconnect and sell power to the grid. Numerous options exist for defining the level of incentive, such as whether the payment is structured as a guaranteed minimum price (e.g., a FIT), or whether the payment floats on top of the wholesale electricity price (e.g., a feed-in premium).

Final energy. The part of primary energy, after deduction of losses from conversion, transmission and distribution, that reaches the consumer and is available to provide heating, hot water, lighting and other services. Final energy forms include, among others, electricity, district heating, mechanical energy, liquid hydrocarbons such as kerosene or fuel oil, and various gaseous fuels such as natural gas, biogas and hydrogen.

(Total) Final energy consumption (TFEC). Energy that is supplied to the consumer for all final energy services such as transport, cooling and lighting, building or industrial heating or mechanical work. Differs from total final consumption (TFC), which includes all energy use in end-use sectors (TFEC) as well as for non-energy applications, mainly various industrial uses, such as feedstocks for petrochemical manufacturing.

Fiscal incentive. An incentive that provides individuals, households or companies with a reduction in their contribution to the public treasury via income or other taxes.

Flywheel energy storage. Energy storage that works by applying available energy to accelerate a high-mass rotor (flywheel) to a very high speed and thereby storing energy in the system as rotational energy.

Front-of-meter system. Any power generation or storage device on the distribution or transmission side of the network. (Also see Behind-the-meter system.)

Generation. The process of converting energy into electricity and/or useful heat from a primary energy source such as wind, solar radiation, natural gas, biomass, etc.

Geothermal energy. Heat energy emitted from within the earth's crust, usually in the form of hot water and steam. It can be used to generate electricity in a thermal power plant or to provide heat directly at various temperatures.

Green bond. A bond issued by a bank or company, the proceeds of which will go entirely into renewable energy and other environmentally friendly projects. The issuer will normally label it as a green bond. There is no internationally recognised standard for what constitutes a green bond.

Green building. A building that (in its construction or operation) reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment. Countries and regions have a variety of characteristics that may change their strategies for green buildings, such as building stock, climate, cultural traditions, or wide-ranging environmental, economic and social priorities – all of which shape their approach to green building.

Green energy purchasing. Voluntary purchase of renewable energy – usually electricity, but also heat and transport fuels – by residential, commercial, government or industrial consumers, either directly from an energy trader or utility company, from a third-party renewable energy generator or indirectly via trading of renewable energy certificates (such as renewable energy credits, green tags and guarantees of origin). It can create additional demand for renewable capacity and/or generation, often going beyond that resulting from government support policies or obligations.

Heat pump. A device that transfers heat from a heat source to a heat sink using a refrigeration cycle that is driven by external electric or thermal energy. It can use the ground (geothermal/ground-source), the surrounding air (aerothermal/air-source) or a body of water (hydrothermal/water-source) as a heat source in heating mode, and as a heat sink in cooling mode. A heat pump's final energy output can be several multiples of the energy input, depending on its inherent efficiency and operating condition. The output of a heat pump is at least partially renewable on a final energy basis. However, the renewable component can be much lower on a primary energy basis, depending on the composition and derivation of the input energy; in the case of electricity, this includes the efficiency of the power generation process. The output of a heat pump can be fully renewable energy if the input energy is also fully renewable.

Hydropower. Electricity derived from the potential energy of water captured when moving from higher to lower elevations. Categories of hydropower projects include run-of-river, reservoir-based capacity and low-head in-stream technology (the least developed). Hydropower covers a continuum in project scale from large (usually defined as more than 10 MW of installed capacity, but the definition varies by country) to small, mini, micro and pico.

Hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA). Biofuels produced by using hydrogen to remove oxygen from waste cooking oils, fats and vegetable oils. The result is a hydrocarbon that can be refined to produce fuels with specifications that are closer to those of diesel and jet fuel than is biodiesel produced from triglycerides such as fatty acid methyl esters (FAME).

Inverter (and micro-inverter), solar. Inverters convert the direct current (DC) generated by solar PV modules into alternating current (AC), which can be fed into the electric grid or used by a local, off-grid network. Conventional string and central solar inverters are connected to multiple modules to create an array that effectively is a single large panel. By contrast, micro-inverters convert generation from individual solar PV modules; the output of several micro-inverters is combined and often fed into the electric grid. A primary advantage of micro-inverters is that they isolate and tune the output of individual panels, reducing the effects that shading or failure of any one (or more) module(s) has on the output of an entire array. They eliminate some design issues inherent to larger systems, and allow for new modules to be added as needed.

Investment. Purchase of an item of value with an expectation of favourable future returns. In this report, new investment in renewable energy refers to investment in: technology research and development, commercialisation, construction of manufacturing facilities and project development (including the construction of wind farms and the purchase and installation of solar PV systems). Total investment refers to new investment plus merger and acquisition (M&A) activity (the refinancing and sale of companies and projects).

Investment tax credit. A fiscal incentive that allows investments in renewable energy to be fully or partially credited against the tax obligations or income of a project developer, industry, building owner, etc.

Joule. A joule (J) is a unit of work or energy equal to the work done by a force equal to one newton acting over a distance of one metre. One joule is equal to one watt-second (the power of one watt exerted over the period of one second). The potential chemical energy stored in one barrel of oil and released when combusted is approximately 6 gigajoules (GJ); a tonne of oven-dry wood contains around 20 GJ of energy.

Levelised cost of energy/electricity (LCOE). The cost per unit of energy from an energy generating asset that is based on the present value of its total construction and lifetime operating costs, divided by total energy output expected from that asset over its lifetime.

Long-term strategic plan. A strategy to achieve energy savings over a specified period of time (i.e., several years), including specific goals and actions to improve energy efficiency, typically spanning all major sectors.

Mandate/Obligation. A measure that requires designated parties (consumers, suppliers, generators) to meet a minimum – and often gradually increasing – standard for renewable energy (or energy efficiency), such as a percentage of total supply, a stated amount of capacity, or the required use of a specified renewable technology. Costs generally are borne by consumers. Mandates can include renewable portfolio standards (RPS); building codes or obligations that require the installation of renewable heat or power technologies (often in combination with energy efficiency investments); renewable heat purchase requirements; and requirements for blending specified shares of biofuels (biodiesel or ethanol) into transport fuel.

Market concession model. A model in which a private company or non-governmental organisation is selected through a competitive process and given the exclusive obligation to provide energy services to customers in its service territory, upon customer request. The concession approach allows concessionaires to select the most appropriate and cost-effective technology for a given situation.

Merit order. A way of ranking available sources of energy (particularly electricity generation) in ascending order based on short-run marginal costs of production, such that those with the lowest marginal costs are the first ones brought online to meet demand, and those with the highest are brought on last. The merit-order effect is a shift of market prices along the merit-order or supply curve due to market entry of power stations with lower variable costs (marginal costs). This displaces power stations with the highest production costs from the market (assuming demand is unchanged) and admits lower-priced electricity into the market.

Mini-grid / Micro-grid. For distributed renewable energy systems for energy access, a mini-grid/micro-grid typically refers to an independent grid network operating on a scale of less than 10 MW (with most at very small scale) that distributes electricity to a limited number of customers. Mini-/micro-grids also can refer to much larger networks (e.g., for corporate or university campuses) that can operate independently of, or in conjunction with, the main power grid. However, there is no universal definition differentiating mini- and micro-grids.

Molten salt. An energy storage medium used predominantly to retain the thermal energy collected by a solar tower or solar trough of a concentrating solar power plant, so that this energy can be used at a later time to generate electricity.

Monitoring. Energy use is monitored to establish a basis for energy management and to provide information on deviations from established patterns.

Municipal solid waste. Waste materials generated by households and similar waste produced by commercial, industrial or institutional entities. The wastes are a mixture of renewable plant and fossil-based materials, with the proportions varying depending on local circumstances. A default value that assumes that at least 50% of the material is "renewable" is often applied.

Net metering / Net billing. A regulated arrangement in which utility customers with on-site electricity generators can receive credits for excess generation, which can be applied to offset consumption in other billing periods. Under net metering, customers typically receive credit at the level of the retail electricity price. Under net billing, customers typically receive credit for excess power at a rate that is lower than the retail electricity price. Different jurisdictions may apply these terms in different ways, however.

Net zero emissions. Can refer to all greenhouse gas emissions or only carbon emissions, and involves emissions declining to zero. Carbon neutral refers to the balancing of carbon emissions caused by an entity with funding an equivalent amount of carbon savings elsewhere. Although carbon neutrality is sometimes considered to be a synonym for net zero carbon emissions, carbon neutrality can be achieved at the domestic level by using offsets from other jurisdictions, whereas net zero does not necessarily include this feature.

Net zero carbon building / Net zero energy building / Nearly zero energy building. Various definitions have emerged of buildings that achieve high levels of energy efficiency and meet remaining energy demand with either on-site or off-site renewable energy. For example, the World Green Building Council's Net Zero Carbon Buildings Commitment considers use of renewable energy as one of five key components that characterise a net zero building. Definitions of net zero carbon, net zero energy and nearly zero energy buildings can vary in scope and geographic relevance.

Ocean power. Refers to technologies used to generate electricity by harnessing from the ocean the energy potential of ocean waves, tidal range (rise and fall), tidal streams, ocean (permanent) currents, temperature gradients (ocean thermal energy conversion) and salinity gradients. The definition of ocean power used in this report does not include offshore wind power or marine biomass energy.

Off-take agreement. An agreement between a producer of energy and a buyer of energy to purchase/sell portions of the producer's future production. An off-take agreement normally is negotiated prior to the construction of a renewable energy project or installation of renewable energy equipment in order to secure a market for the future output (e.g., electricity, heat). Examples of this type of agreement include power purchase agreements and feed-in tariffs.

Off-taker. The purchaser of the energy from a renewable energy project or installation (e.g., a utility company) following an off-take agreement. (See Off-take agreement.)

Pay-As-You-Go (PAYGo). A business model that gives customers (mainly in areas without access to the electricity grid) the possibility to purchase small-scale energy-producing products, such as solar home systems, by paying in small instalments over time.

Peaker generation plant. Power plants that run predominantly during peak demand periods for electricity. Such plants exhibit the optimum balance – for peaking duty – of relatively high variable cost (fuel and maintenance cost per unit of generation) relative to fixed cost per unit of energy produced (low capital cost per unit of generating capacity).

Pico solar devices / pico solar systems. Small solar systems such as solar lanterns that are designed to provide only a limited amount of electricity service, usually lighting and in some cases mobile phone charging. Such systems are deployed mainly in areas that have no or poor access to electricity. The systems usually have a power output of 1-10 watts and a voltage of up to 12 volts.

Plug-in hybrid electric vehicle. This differs from a simple hybrid vehicle, as the latter uses electric energy produced only by braking or through the vehicle's internal combustion engine.

Therefore, only a plug-in hybrid electric vehicle allows for the use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs.

Power. The rate at which energy is converted into work, expressed in watts (joules/second).

Power purchase agreement (PPA). A contract between two parties, one that generates electricity (the seller) and one that is looking to purchase electricity (the buyer).

Power-to-gas (P2G). The conversion of electricity, either from renewable or conventional sources, to a gaseous fuel (for example, hydrogen or methane).

Primary energy. The theoretically available energy content of a naturally occurring energy source (such as coal, oil, natural gas, uranium ore, geothermal and biomass energy, etc.) before it undergoes conversion to useful final energy delivered to the end-user. Conversion of primary energy into other forms of useful final energy (such as electricity and fuels) entails losses. Some primary energy is consumed at the end-user level as final energy without any prior conversion.

Primary energy consumption. The direct use of energy at the source, or supplying users with unprocessed fuel.

Product and sectoral standards. Rules specifying the minimum standards for certain products (e.g., appliances) or sectors (industry, transport, etc.) for increasing energy efficiency.

Production tax credit. A tax incentive that provides the investor or owner of a qualifying property or facility with a tax credit based on the amount of renewable energy (electricity, heat or biofuel) generated by that facility.

Productive use of energy. Often used in the context of distributed renewables for energy access to refer to activities that use energy to generate income, increase productivity, enhance diversity and create economic value. Productive uses of energy may include local activities such as agriculture, livestock and fishing; light mechanical works such as welding, carpentry and water pumping; small retail and commercial activities such as tailoring, printing, catering and entertainment; and small and medium-scale production such as agro-processing (grinding, milling and husking), refrigeration and cold storage, drying, preserving and smoking.

Property Assessed Clean Energy (PACE) financing. Provides access to low-interest loans for renewable energy and energy efficiency improvements that can be repaid through increases on property taxes. It was originally conceived of in the United States but has been expanding worldwide.

Prosumer. An individual, household or small business that not only consumes energy but also produces it. Prosumers may play an active role in energy storage and demand-side management.

Public financing. A type of financial support mechanism whereby governments provide assistance, often in the form of grants or loans, to support the development or deployment of renewable energy technologies.

Pumped storage. Plants that pump water from a lower reservoir to a higher storage basin using surplus electricity, and that reverse the flow to generate electricity when needed. They are not energy sources but means of energy storage and can have overall system efficiencies of around 80-90%.

Regulatory policy. A rule to guide or control the conduct of those to whom it applies. In the renewable energy context, examples include mandates or quotas such as renewable portfolio standards, feed-in tariffs and technology/fuel-specific obligations.

Renewable energy certificate (REC). A certificate awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also less commonly of heat). In systems based on RECs, certificates can be accumulated to meet renewable energy obligations and also provide a tool for trading among consumers and/or producers. They also are a means of enabling purchases of voluntary green energy.

Renewable hydrogen. Hydrogen produced from renewable energy, most commonly through the use of renewable electricity to split water into hydrogen and oxygen in an electrolyser. The vast majority of hydrogen is still produced from fossil fuels, and the majority of policies and programmes focused on hydrogen do not include a focus on renewables-based production.

Renewable natural gas (RNG). Gas that is produced through the anaerobic digestion of organic matter and processed to remove the carbon dioxide and other gases, leaving methane that meets a high specification and that can be interchangeable with conventional natural gas. See Biomethane.

Renewable portfolio standard (RPS). An obligation placed by a government on a utility company, group of companies or consumers to provide or use a predetermined minimum targeted renewable share of installed capacity, or of electricity or heat generated or sold. A penalty may or may not exist for non-compliance. These policies also are known as "renewable electricity standards", "renewable obligations" and "mandated market shares", depending on the jurisdiction.

Reverse auction. See Tendering.

Sector integration (also called sector coupling). The integration of energy supply and demand across electricity, thermal and transport applications, which may occur via co-production, combined use, conversion and substitution.

Smart energy system. An energy system that aims to optimise the overall efficiency and balance of a range of interconnected energy technologies and processes, both electrical and non-electrical (including heat, gas and fuels). This is achieved through dynamic demand- and supply-side management; enhanced monitoring of electrical, thermal and fuel-based system assets; control and optimisation of consumer equipment, appliances and services; better integration of distributed energy (on both the macro and micro scales); and cost minimisation for both suppliers and consumers.

Smart grid. Electrical grid that uses information and communications technology to co-ordinate the needs and capabilities of the generators, grid operators, end-users and electricity market stakeholders in a system, with the aim of operating all parts as efficiently as possible, minimising costs and environmental impacts and maximising system reliability, resilience and stability.

Smart grid technology. Advanced information and control technology that is required for improved systems integration and resource optimisation on the grid.

Smart inverter. An inverter with robust software that is capable of rapid, bidirectional communications, which utilities can control remotely to help with issues such as voltage and frequency fluctuations in order to stabilise the grid during disruptive events.

Solar collector. A device used for converting solar energy to thermal energy (heat), typically used for domestic water heating but also used for space heating, for industrial process heat or to drive thermal cooling machines. Evacuated tube and flat plate collectors that operate with water or a water/glycol mixture as the heat-transfer medium are the most common solar thermal collectors used worldwide. These are referred to as glazed water collectors because irradiation from the sun first hits a glazing (for thermal insulation) before the energy is converted to heat and transported away by the heat transfer medium. Unglazed water collectors, often referred to as swimming pool absorbers, are simple collectors made of plastics and used for lower-temperature applications. Unglazed and glazed air collectors use air rather than water as the heat-transfer medium to heat indoor spaces or to pre-heat drying air or combustion air for agriculture and industry purposes.

Solar cooker. A cooking device for household and institutional applications that converts sunlight to heat energy that is retained for cooking. There are several types of solar cookers, including box cookers, panel cookers, parabolic cookers, evacuated tube cookers and trough cookers.

Solar home system. A stand-alone system composed of a relatively low-power photovoltaic module, a battery and sometimes a charge controller that can provide modest amounts of electricity for home lighting, communications and appliances, usually in rural or remote regions that are not connected to the electricity grid. The term solar home system kit is also used to define systems that usually are branded and have components that are easy for users to install and use.

Solar photovoltaics (PV). A technology used for converting light directly into electricity. Solar PV cells are constructed from semiconducting materials that use sunlight to separate electrons from atoms to create an electric current. Modules are formed by interconnecting individual cells. Building-integrated PV (BIPV) generates electricity and replaces conventional materials in parts of a building envelope, such as the roof or facade.

Solar photovoltaic-thermal (PV-T). A solar PV-thermal hybrid system that includes solar thermal collectors mounted beneath PV modules to convert solar radiation into electrical and thermal energy. The solar thermal collector removes waste heat from the PV module, enabling it to operate more efficiently.

Solar-plus-storage. A hybrid technology of solar PV with battery storage. Other types of renewable energy-plus-storage plants also exist.

Solar water heater. An entire system consisting of a solar collector, storage tank, water pipes and other components. There are two types of solar water heaters: pumped solar water heaters use mechanical pumps to circulate a heat transfer fluid through the collector loop (active systems), whereas thermosyphon solar water heaters make use of buoyancy forces caused by natural convection (passive systems).

Storage battery. A type of battery that can be given a new charge by passing an electric current through it. A lithium-ion battery uses a liquid lithium-based material for one of its electrodes. A lead-acid battery uses plates made of pure lead or lead oxide for the electrodes and sulphuric acid for the electrolyte, and remains common for off-grid installations. A flow battery uses two chemical components dissolved in liquids contained within the system and most commonly separated by a membrane. Flow batteries can be recharged almost instantly by replacing the electrolyte liquid, while simultaneously recovering the spent material for re-energisation.

Sustainable aviation fuel. According to the International Civil Aviation Organization, such fuels are produced from three families of bio-feedstock: the family of oils and fats (or triglycerides), the family of sugars and the family of lignocellulosic feedstock.

Target. An official commitment, plan or goal set by a government (at the local, state, national or regional level) to achieve a certain amount of renewable energy or energy efficiency by a future date. Targets may be backed by specific compliance mechanisms or policy support measures. Some targets are legislated, while others are set by regulatory agencies, ministries or public officials.

Tender (also called auction / reverse auction or tender). A procurement mechanism by which renewable energy supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Thermal energy storage. Technology that allows the transfer and storage of thermal energy. (See Molten salt.)

Torrefied wood. Solid fuel, often in the form of pellets, produced by heating wood to 200-300°C in restricted air conditions. It has useful characteristics for a solid fuel including relatively high energy density, good grindability into pulverised fuel and water repellency.

Transmission grid. The portion of the electrical supply distribution network that carries bulk electricity from power plants to sub-stations, where voltage is stepped down for further distribution. High-voltage transmission lines can carry electricity between regional grids in order to balance supply and demand.

Variable renewable energy (VRE). A renewable energy source that fluctuates within a relatively short time frame, such as wind and solar energy, which vary within daily, hourly and even sub-hourly time frames. By contrast, resources and technologies that are variable on an annual or seasonal basis due to environmental changes, such as hydropower (due to changes in rainfall) and thermal power plants (due to changes in temperature of ambient air and cooling water), do not fall into this category.

Vehicle fuel standard. A rule specifying the minimum fuel economy of automobiles.

Vehicle-to-grid (V2G). A system in which electric vehicles – whether battery electric or plug-in hybrid – communicate with the grid in order to sell response services by returning electricity from the vehicles to the electric grid or by altering the rate of charging.

Virtual net metering. Virtual (or group) net metering allows electricity utility consumers to share the output of a renewable power project. By receiving "energy credits" based on project output and their ownership share of the project, consumers are able to offset costs on their electricity utility bill.

Virtual power plant (VPP). A network of decentralised, independently owned and operated power generating units combined with flexible demand units and possibly also with storage facilities. A central control station monitors operation, forecasts demand and supply, and dispatches the networked units as if they were a single power plant. The aim is to smoothly integrate a high number of renewable energy units into existing energy systems; VPPs also enable the trading or selling of power into wholesale markets.

Virtual power purchase agreement (PPA). A contract under which the developer sells its electricity in the spot market. The developer and the corporate off-taker then settle the difference between the variable market price and the strike price, and the off-taker receives the electricity certificates that are generated. This is in contrast to more traditional PPAs, under which the developer sells electricity to the off-taker directly.

Voltage and frequency control. The process of maintaining grid voltage and frequency stable within a narrow band through management of system resources.

Watt. A unit of power that measures the rate of energy conversion or transfer. A kilowatt is equal to 1 thousand watts; a megawatt to 1 million watts; and so on. A megawatt-electrical (MWe) is used to refer to electric power, whereas a megawatt-thermal (MW_{th}) refers to thermal/heat energy produced. Power is the rate at which energy is consumed or generated. A kilowatt-hour is the amount of energy equivalent to steady power of 1 kW operating for one hour.

LIST OF ABBREVIATIONS

AC	Alternating current
AfDB	African Development Bank
AUD	Australian dollar
BEV	Battery electric vehicle
BloombergNEF	Bloomberg New Energy Finance
CCA	Community choice aggregation
CHP	Combined heat and power
CNY	Chinese yuan
CO_2	Carbon dioxide
COP	Conference of the Parties
CSP	Concentrating solar thermal power
DC	Direct current
DFI	Development finance institution
DHC	District heating and cooling
DOE	US Department of Energy
DRE	Distributed renewable energy
DREA	Distributed renewables for energy access
EC	European Commission
ECOWAS	Economic Community of West African States
EGS	Enhanced (or engineered) geothermal systems
EIA	Environmental impact assessment
EJ	Exajoule
ESCO	Energy service company
EU	European Union (specifically the EU-27)
EUR	Euro
EV	Electric vehicle
FAME	Fatty acid methyl esters
FCEV	Fuel cell electric vehicle
FIT	Feed-in tariff
FS	Frankfurt School
G20	Group of Twenty
GDP	Gross domestic product
GO	Guarantee of origin
GOGLA	Global association for the off-grid solar energy industry
GNI	Gross national income
GSR	Global Status Report
GW/GWh	Gigawatt/gigawatt-hour
GW_{th}	Gigawatt-thermal
GWEC	Global Wind Energy Council
HEFA	Hydrotreated esters and fatty acids
HJT	Heterojunction cell technology
HVAC	Heating, ventilation, and air-conditioning
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IDCOL	Infrastructure Development Company Limited
IEC	International Electrotechnical Commission
IEA	International Energy Agency
IEA PVPS	IEA Photovoltaic Power Systems Programme
IEA SHC	IEA Solar Heating and Cooling Programme
IFC	International Finance Corporation
IHA	International Hydropower Association
IPP	Independent power producer
ISCC	Integrated solar combined-cycle
IRENA	International Renewable Energy Agency
ITC	Investment Tax Credit
ktoe	Kilotonne of oil equivalent
kW/kWh	Kilowatt/kilowatt-hour
kW_{th}	kilowatt-thermal
LBG	Liquefied biogas
LCOE	Levelised cost of energy (or electricity)
LPG	Liquefied petroleum gas
LNG	Liquefied natural gas
M&A	Mergers and acquisitions
m^2	Square metre
m^3	Cubic metre
MENA	Middle East and North Africa
MJ	Megajoule
MSW	Municipal solid waste
Mtoe	Megatonne of oil equivalent
MW/MWh	Megawatt/megawatt-hour
MW_{th}	Megawatt-thermal
NDC	Nationally Determined Contribution
O&M	Operations and maintenance
OECD	Organisation for Economic Co-operation and Development
OTEC	Ocean thermal energy conversion
P2G	Power-to-gas
PACE	Property Assessed Clean Energy
PAYGo	Pay-as-you-go
PERC	Passivated Emitter Rear Cell
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PPA	Power purchase agreement
PPP	Purchasing power parity
PTC	Production Tax Credit
PV	Photovoltaic
R&D	Research and development
REC	Renewable electricity certificate
RED	EU Renewable Energy Directive
RFS	US Renewable Fuel Standard
RNG	Renewable natural gas
RPS	Renewable portfolio standard
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SEK	Swedish krona
SHC	Solar heating and cooling
SHIP	Solar heat for industrial processes
SUV	Sport utility vehicle
TES	Thermal energy storage
TFC	Total final consumption
TFEC	Total final energy consumption
Toe	Tonne of oil equivalent
TW/TWh	Terawatt/terawatt-hour
UAE	United Arab Emirates
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
dUSD	United States dollar
V2G	Vehicle-to-grid
VAT	Value-added tax
VNM	Virtual net metering
VRE	Variable renewable electricity
W/Wh	Watt/watt-hour
Yieldco	Yield company
ZEV	Zero emission vehicle
USD	United States dollar
V2G	Vehicle-to-grid
VAT	Value-added tax
VC/PE	Venture capital and private equity
VNM	Virtual net metering
VRE	Variable renewable electricity
W/Wh	Watt/watt-hour
WTO	World Trade Organization
ZEV	Zero emission vehicle

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1 International Energy Agency (IEA), *Global Energy Review 2021* (Paris: 2021), https://www.iea.org/reports/global-energy-review-2021.

2 Ember, *Global Electricity Review 2021* (London: 2021), https://ember-climate.org/project/global-electricity-review-2021. For further discussion, see Power section in this chapter, and Market and Industry chapter.

3 IEA, "Electricity", in *Global Energy Review 2020* (Paris: April 2020), https://www.iea.org/reports/global-energy-review-2020/electricity.

4 See Power section in this chapter and related endnotes.

5 IEA, *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020; Organisation for Economic Co-operation and Development (OECD), "The impact of coronavirus (COVID-19) and the global oil price shock on the fiscal position of oil-exporting developing countries", 30 September 2020, https://www.oecd.org/coronavirus/policy-responses/the-impact-of-coronavirus-covid-19-and-the-global-oil-price-shock-on-the-fiscal-position-of-oil-exporting-developing-countries-8bafbd95.

6 International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2020* (Abu Dhabi: 2021); Lazard, *Lazard's Levelized Cost of Energy Analysis – Version 14.0* (New York: 2020), https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf; J. Hodges, "Wind, solar are cheapest power source in most places, BNEF says", BloombergNEF, 19 October 2020, https://www.bloomberg.com/news/articles/2020-10-19/wind-solar-are-cheapest-power-source-in-most-places-bnef-says; Global Wind Energy Council (GWEC), *Global Wind Report 2021* (London: 2021), https://gwec.net/wp-content/uploads/2021/03/GWEC-Global-Wind-Report-2021.pdf, p. 12; SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024* (Brussels: 2020), https://www.solarpowereurope.org/global-market-outlook-2020-2024.

7 Ibid, all sources.

8 Ibid, all sources.

9 See Transport section in this chapter.

10 Ibid.

11 Ibid.

12 IEA, "Renewable heat", in *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020/renewable-heat.

13 See Buildings, Industry and Transport sections in this chapter, and Policy chapter.

14 M. Rowling, "Powerless in a pandemic: Solar energy prescribed for off-grid healthcare", *Reuters*, 3 July 2020, https://www.reuters.com/article/us-health-coronavirus-energy-solar-featu-idUSKBN24414T. See also Distributed Renewables chapter.

15 EnDev, "COVID-19 Energy Access Industry Barometer – presentation of results in a webinar hosted by EnDev", 7 August 2020, https://endev.info/covid-19-energy-access-industry-barometer-presentation-of-results-in-a-webinar-hosted-by-endev.

16 Data are for affiliates of the Global Off-Grid Lighting Association (GOGLA). GOGLA, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July-December 2020* (Amsterdam: 2020), https://www.gogla.org/sites/default/files/resource_docs/global_off-grid_solar_market_report_h2_2020.pdf.

17 IEA, "Access to electricity", https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity#abstract, viewed 6 December 2020.

18 IEA, "The Covid-19 crisis is reversing progress on energy access in Africa", 20 November 2020, https://www.iea.org/articles/the-covid-19-crisis-is-reversing-progress-on-energy-access-in-africa.

19 See Distributed Renewables chapter.

20 S. Modi and R. Postaria, "How COVID-19 deepens the digital education divide in India", World Economic Forum, 5 October 2020, https://www.weforum.org/agenda/2020/10/how-covid-19-deepens-the-digital-education-divide-in-india; B. Rochelle Parry and E. Gordon, "The shadow pandemic: Inequitable gendered impacts of COVID-19 in South Africa", *Gender, Work & Organization*, vol. 28 (March 2021), https://onlinelibrary.wiley.com/doi/full/10.1111/gwao.12565.

21 IEA, *World Energy Investment 2020* (Paris: 2020), https://www.iea.org/reports/world-energy-investment-2020/power-sector#overview-of-power-investment.

22 Ibid.; BloombergNEF, *Energy Transition Investment Trends. Tracking Global Investment in the Low-carbon Energy Transition* (London: 2021), p. 1, https://assets.bbhub.io/professional/sites/24/EnergyTransition-Investment-Trends_Free-Summary_Jan2021.pdf; total investment from idem, slide 2.

23 IEA, "Global investment in the power sector by technology, 2017-2020", https://www.iea.org/data-and-statistics/charts/global-investment-in-the-power-sector-by-technology-2017-2020 (viewed 15 May 2021).

24 IEA, op. cit. note 21.

25 "Denmark set to end all new oil and gas exploration", *BBC News*, 4 December 2020, https://www.bbc.com/news/business-55184580; I. Slav, "Denmark to end oil production in 2050", Oilprice.com, 4 December 2020, https://oilprice.com/Latest-Energy-News/World-News/Denmark-To-End-Oil-Production-In-2050.html.

26 C. Nugent, "U.K. says it will end support for overseas oil, gas and coal projects with 'very limited exceptions'", Time, 11 December 2020, https://time.com/5920475/u-k-fossil-fuels-overseas; Government of the UK, "PM announces the UK will end support for fossil fuel sector overseas", press release (London: 12 December 2020), https://www.gov.uk/government/news/pm-announces-the-uk-will-end-support-for-fossil-fuel-sector-overseas; T. Helm and R. McKie, "UK urged to follow Denmark in ending North Sea oil and gas exploration", *The Guardian* (UK), 6 December 2020, https://www.theguardian.com/environment/2020/dec/06/uk-urged-to-follow-denmark-in-ending-north-sea-oil-and-gas-exploration; World Oil, "UK projects up to 20 billion barrels of oil remain to be found offshore", 14 September 2020, https://www.worldoil.com/news/2020/9/14/uk-projects-up-to-20-billion-barrels-of-oil-remain-to-be-found-offshore.

27 Nikkei Asia, "Japan looks to end support for overseas coal power projects", 29 March 2021, https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Japan-looks-to-end-support-for-overseas-coal-power-projects.

28 Energy Policy Tracker, "Multilateral Development Banks Analysis", https://www.energypolicytracker.org/institution_analysis/mdbs, viewed 21 March 2021.

29 See, for example: S. Kiderlin, "HSBC will end all funding for the coal industry by 2040, narrowly avoiding revolt among climate conscious-investors", Business Insider France, 11 March 2021, https://www.businessinsider.fr/us/hsbc-stop-funding-coal-industry-following-investor-pressure-2021-3; T. Sims and S. Jessop, "Deutsche Bank tightens fossil fuel lending policies", *Reuters*, 27 July 2020,https://www.reuters.com/article/us-deutsche-bank-coal-idUSKCN24S17G; A. Ellfeldt, "America's biggest banks promise to fight climate change", *Scientific American*, 9 March 2021, https://www.scientificamerican.com/article/americas-biggest-banks-promise-to-fight-climate-change; A. Frangoul, "Swedish pension fund with billions of assets under management to stop fossil fuel investments", CNBC, 17 March 2020, https://www.cnbc.com/2020/03/17/swedish-pension-fund-to-stop-fossil-fuel-investments.html; G. Readfearn, "Insurance giant Suncorp to end coverage and finance for oil and gas industry", *The Guardian* (UK), 21 August 2020, https://www.theguardian.com/environment/2020/aug/21/insurance-giant-suncorp-to-end-coverage-and-finance-for-oil-and-gas-industry. For other examples going back to mid-December 2019, see J. Axelrod, "The energy shift approaches as fossil finance dries up", Natural Resources Defense Council, 27 February 2020, https://www.nrdc.org/experts/josh-axelrod/fossil-finance-drying-energy-shift-finally-coming.

30 BloombergNEF, "Corporate clean energy buying grew 18% in 2020, despite mountain of adversity", 26 February 2021, https://about.bnef.com/blog/corporate-clean-energy-buying-grew-18-in-2020-despite-mountain-of-adversity.

31 Ibid.

32 Current membership from RE100, "RE100 members", https://www.there100.org/re100-members, viewed 6 May 2020; 2019 members from idem, viewed 20 May 2019; RE100, "235 RE100 companies have made a commitment to go '100% renewable'. Read about the actions they are taking and why", http://there100.org/companies, viewed 26 March 2021.

33 As with RE100, at least 126 corporations had joined EP100 (up from 123 in 2019), committing to improving their energy productivity to lower emissions, while at least 108 had joined EV100 (up from 67 in early 2020), committing to transitioning their vehicle fleets to EVs. RE100, op. cit. note 32; The Climate Group, "EP100 members", https://www.theclimategroup.org/ep100-members, viewed 21 May 2021; The Climate Group, "EV100 members", https://www.theclimategroup.org/ev100-members, viewed 21 May 2021; The Climate Group, "SteelZero FAQs", https://www.theclimategroup.org/media/6841/download, viewed 21 May 2021.

34 See Feature chapter and Policy Landscape chapter.

35 Race to Zero, https://racetozero.unfccc.int, viewed 24 May 2021; New Climate Institute and Data-Driven EnviroLab, *Navigating the Nuances of Net-Zero Targets* (Berlin and Singapore: October 2020), https://newclimate.org/wp-content/uploads/2020/10/NewClimate_NetZeroReport_October2020.pdf; J. Baker, "How not to commit to 'net zero': 5 common carbon strategy mistakes", *Forbes*, 3 March 2021, https://www.forbes.com/sites/jessibaker/2021/03/03/how-not-to-commit-to-net-zero-5-common-carbon-strategy-mistakes.

36 M. Willuhn, "Shell and Total join fossil fuel companies bidding for a piece of Europe's PV renaissance", pv magazine, 28 February 2020, https://www.pv-magazine.com/2020/02/28/shell-and-total-join-fossil-fuel-companies-bidding-for-a-piece-of-europes-pv-renaissance; "Equinor to invest nearly $550 million in floating wind power off Norway", *Reuters*, 11 October 2020, https://www.reuters.com/article/us-equinor-windfarm/equinor-to-invest-nearly-550-million-in-floating-wind-power-off-norway-idUSKBN1WQ0DZ.

37 J. Ambrose, "Oil and gas companies undermining climate goals, says report", *The Guardian* (UK), 6 September 2020, https://www.theguardian.com/environment/2020/sep/06/oil-and-gas-companies-undermining-climate-goals-says-report; J. Ambrose and J. Jolly, "Royal Dutch Shell may fail to reach green energy targets", *The Guardian* (UK), 3 January 2021, https://www.theguardian.com/business/2021/jan/03/royal-dutch-shell-may-fail-to-reach-green-energy-targets; J. Murray, "How the six major oil companies have invested in renewable energy projects", NS Energy, 16 January 2021, https://www.nsenergybusiness.com/features/oil-companies-renewable-energy. **Sidebar 1** based on the following: Ibid., all sources; D. Monzon, R. Guzman and A. Guichard, "Weathering the perfect storm: COVID-19 and the future of the oil & gas industry", Arthur D. Little Global, May 2020, https://www.adlittle.com/en/weathering-perfect-storm; J. Crider, "COVID-19 bankrupts 19 energy (oil & gas) companies", CleanTechnica, 5 August 2020, https://cleantechnica.com/2020/08/05/covid-19-bankrupts-19-energy-oil-gas-companies; Save Lamu, "ICBC withdraws financing from the Lamu Coal Plant", November 2020, https://www.savelamu.org/wp-content/uploads/2020/11/Press-release-on-ICBC-withdrawal-from-financing-coal..-1.pdf; "Germany: Climate activists occupy coal mine, power plants", DW, 26 September 2020, https://www.dw.com/en/germany-climate-activists-occupy-coal-mine-power-plants/a-55063482; Energy Voice, "Oil giant targeted in climate protest", 17 January 2021, https://www.energyvoice.com/oilandgas/north-sea/218708/oil-giant-targeted-in-climate-protest; M. Green, "Climate activists stage protest at oilfield in southern England", *Reuters*, 1 June 2020, https://www.reuters.com/article/us-climate-change-britain-protests/climate-activists-stage-protest-at-oilfield-in-southern-england-idUSKBN2381K3; N. Cunningham, "Canada rocked by anti-pipeline protests", Oilprice.com, 15 February 2020, https://oilprice.com/Energy/Energy-General/Canada-Rocked-By-Anti-Pipeline-Protests.html; D. Holger, "Norway's biggest private money manager exits from Exxon, Chevron over climate change",*Wall Street Journal*, 24 August 2020, https://www.wsj.com/articles/norways-biggest-private-money-manager-exits-from-exxon-chevron-over-climate-change-11598294780; L. Fink, "A fundamental reshaping of finance", BlackRock, 2020, https://www.blackrock.com/us/individual/larry-fink-ceo-letter; IRENA, *Oil Companies and the Energy Transition* (Abu Dhabi: February 2021), https://www.irena.org/publications/2021/Feb/Oil-companies-and-the-energy-transition; "French gas giant GDF Suez changes name to Engie", *Reuters*, 24 April 2015, https://www.reuters.com/article/gdfsuez-name-idUSL5N0XL1XS20150424; Ørsted, "Ørsted – the new name for DONG Energy", https://orsted.co.uk/about-us/our-company/our-name-change, viewed 15 May 2021; J. Dagenborg and N. Adomaitis, "Statoil to rebrand as Equinor in green energy push", *Reuters*, 15 March 2018, https://www.reuters.com/article/us-statoil-name-equinor-idUSKCN1GR0K2; Equinor, "About our name change", https://www.equinor.com/en/about-us/about-our-name-change.html, viewed 15 May 2021; Naturgy, "'Naturgy' to replace 'Gas Natural Fenosa' as the energy company's brand to face new challenges", 27 June 2018,https://www.naturgy.com/en/press_room/press_releases/2018_en/%E2%80%98naturgy%E2%80%99_to_replace_%E2%80%98gas_natural_fenosa%E2%80%99_as_the_energy_company%E2%80%99s_brand_to_face_new_challenges; "French oil giant Total rebrands in shift to renewables", BBC News, 28 May 2021, https://www.bbc.com/news/business-57282008; D. Sheppard and A. Raval, "Oil producers face their 'life or death' question", *Financial Times*, 19 June 2018, https://www.ft.com/content/a41df112-7080-11e8-92d3-6c13e5c92914; Ørsted, *Our Green Business Transformation* (Fredericia: April 2021), https://orstedcdn.azureedge.net/-/media/www/docs/corp/com/about-us/whitepaper/our-green-business-transformation---what-we-did-and-lessons-learned.ashx; M. Farmer, "How Ørsted's energy transition led the way for oil and gas companies", Offshore Technology, 6 May 2020, https://www.offshore-technology.com/features/how-orsteds-energy-transition-led-the-way-for-oil-and-gas-companies; J. Murray, "Which major oil companies have set net-zero emissions targets?" NS Energy, 16 December 2020, https://www.nsenergybusiness.com/features/oil-companies-net-zero; Eni, "Boosting our transformation; Eni strategic plan 2021-2024: towards zero emissions", 19 February 2021, https://eni.iwebcasting.it/strategy-2021/assets/docs/press_release.pdf; Royal Dutch Shell, "Shell accelerates drive for net-zero emissions with customer-first strategy", 11 February 2021, https://www.shell.com/media/news-and-media-releases/2021/shell-accelerates-drive-for-net-zero-emissions-with-customer-first-strategy.html; BP, "From international oil company to integrated energy company: BP sets out strategy for decade of delivery towards net zero ambition", 4 August 2020, https://www.bp.com/en/global/corporate/news-and-insights/press-releases/from-international-oil-company-to-integrated-energy-company-bp-sets-out-strategy-for-decade-of-delivery-towards-net-zero-ambition.html; Oil Change International, "Oil Change International response to BP's new commitment to major cuts in extraction by 2030", 4 August 2020, http://priceofoil.org/2020/08/04/statement-in-response-to-bps-new-commitment-to-major-cuts-in-extraction-by-2030; S. Reed, C. Moses, "A Dutch court rules that Shell must step up its climate change efforts", *New York Times*, 26 May 2021, https://www.nytimes.com/2021/05/26/business/royal-dutch-shell-climate-change.html; J. Scully, "Repsol targets 15 GW of renewables capacity by 2030", PV-Tech, 27 November 2020, https://www.pv-tech.org/repsol-targets-15gw-of-renewables-capacity-by-2030; Repsol, "Repsol will be a net zero emissions company by 2050", 2 December 2019, https://www.repsol.com/en/press-room/press-releases/2019/repsol-will-be-a-net-zero-emissions-company-by-2050.cshtml; Royal Dutch Shell, "Executive remuneration", *Shell Sustainability Report 2019* (The Hague: 2019), https://reports.shell.com/sustainability-report/2019/introduction/our-approach-to-sustainability/executive-remuneration.html; F. D. Beaupuy, "Total ties customers' emissions reductions to executive bonuses", Bloomberg, 18 March 2021, https://www.bloomberg.com/news/articles/2021-03-18/total-ties-customers-emissions-reductions-to-executive-bonuses; Total, *Getting to Net Zero* (Paris: September 2020), https://www.total.com/sites/g/files/nytnzq111/files/documents/2020-10/total-climate-report-2020.pdf; Chevron, *Climate Change Resilience: Advancing a Lower Carbon Future* (San Ramon: 2021), https://www.chevron.com/-/media/chevron/sustainability/documents/climate-change-resilience-report.pdf; ExxonMobil, "ExxonMobil announces emission reduction plans; expects to meet 2020 goals", 14 December 2020, https://corporate.exxonmobil.com/News/Newsroom/News-releases/2020/1214_ExxonMobil-announces-2025-emissions-reductions_expects-to-meet-2020-plan; C. Krauss, "U.S. and European oil giants go different ways on climate change", *New York Times*, updated 11 December 2020, https://www.nytimes.com/2020/09/21/business/energy-environment/oil-climate-change-us-europe.html; S. Reed, "Europe's big oil companies are turning electric", *New York Times*, 17 August 2020, https://www.nytimes.com/2020/08/17/business/energy-environment/oil-companies-europe-electric.html; L. Hook and J. Politi, "US to propose emissions cut of at least 50% by end of decade", *Financial Times*, 22 April 2021, https://www.ft.com/content/32f5e2cd-4689-4434-9da0-d97d46673eaf; "Shareholders are pushing ExxonMobil to go green", *The Economist*, 6 February 2021, https://www.economist.com/business/2021/02/06/shareholders-are-pushing-exxonmobil-to-go-green; "Chevron investors back proposal for more emissions cuts", *Reuters*, 26 May 2021, https://www.reuters.com/business/energy/chevron-shareholders-approve-proposal-cut-customer-emissions-2021-05-26; J. Hiller, S. Herbst-bayliss, "Exxon loses board seats to activist hedge fund in landmark climate vote", *Reuters*, 27 May 2021, https://www.reuters.com/business/sustainable-business/shareholder-activism-reaches-milestone-exxon-board-vote-nears-end-2021-05-26; A. Filbert, "Shell strikes deal for 300 MW solar energy", Energy Watch, 18 January 2021, https://energywatch.eu/EnergyNews/Renewables/article12695415.ece; B. Beetz, "UK: Shell signs 5 year private PPA with BSR for 69.8 MW solar project – comment", pv magazine, 18 January 2018,

https://www.pv-magazine.com/2018/01/18/uk-shell-signs-5-year-ppa-with-bsr-for-69-8-mw-solar-project-comment; C. Martin and K. Crowley, "Exxon will use wind, solar to produce crude oil in Texas", Industry Week, 30 November 2018, https://www.industryweek.com/leadership/companies-executives/article/22026765/exxon-will-use-wind-solar-to-produce-crude-oil-in-texas; SunPower, "SunPower building new 35-megawatt DC solar project to supply renewable energy to Chevron's Lost Hills Oil Field", 29 October 2019, https://newsroom.sunpower.com/2019-10-29-SunPower-Building-New-35-Megawatt-DC-Solar-Project-to-Supply-Renewable-Energy-to-Chevrons-Lost-Hills-Oil-Field; T. Tsanova, "Chevron to get wind power for Permian operations", Renewables Now, 23 August 2019, https://renewablesnow.com/news/chevron-to-get-wind-power-for-permian-operations-666287; Chevron, "Investing in low-carbon technologies to enable commercial solutions", https://www.chevron.com/sustainability/environment/innovation, viewed 15 May 2021; "Chevron launches $300 million fund for energy transition technology", Hart Energy, 26 February 2021, https://www.hartenergy.com/exclusives/chevron-launches-300-million-fund-energy-transition-technology-192622; ExxonMobil, "ExxonMobil invests $1 billion per year in energy research, emerging technologies", 18 September 2018, https://corporate.exxonmobil.com/Energy-and-innovation/University-and-National-Labs-partnerships/ExxonMobil-invests-1-billion-per-year-in-energy-research-emerging-technologies; M. DiLallo, "ExxonMobil to create a new low-carbon business unit", The Motley Fool, 2 February 2021, https://www.fool.com/investing/2021/02/02/exxonmobil-to-create-a-new-low-carbon-business-uni; A. Raval, "Oil majors switch on to a future in power generation", *Financial Times*, 13 November 2018, https://www.ft.com/content/699584f4-e36e-11e8-a6e5-792428919cee; Total, "Total et Sunpower créent un nouveau leader mondial de l'industrie solaire", 15 June 2011,https://www.total.com/media/news/press-releases/total-et-sunpower-creent-un-nouveau-leader-mondial-de-lindustrie-solaire; R. Bousso and S. Twidale, "BP returns to solar with investment in Lightsource", *Reuters*, 15 December 2017, https://www.reuters.com/article/us-lightsource-bp-stake-idUSKBN1E90H9; "BP to increase stake in Lightsource BP to 50%", NS Energy, 6 December 2019, https://www.nsenergybusiness.com/news/bp-lightsource-bp; R. Bousso and S. Twidale, "Shell goes green as it rebrands UK household power supplier", *Reuters*, 24 March 2019, https://www.reuters.com/article/us-shell-power-idUSKCN1R50ON; J. Pyper, "Shell takes a major stake in US solar developer Silicon Ranch", Greentech Media, 15 January 2018, https://www.greentechmedia.com/articles/read/shell-takes-major-stake-in-us-solar-developer; J. Deign, "Shell Technology Ventures leads $20 million investment in minigrid specialist Husk", Greentech Media, 18 January 2018, https://www.greentechmedia.com/articles/read/shell-ventures-leads-20-million-investment-in-minigrid-specialist-husk. Accounting for currently contracted renewable capacity, the share of oil and gas majors in total renewable capacity is expected to reach 2.1% by 2025 from 0.3% in 2020. ", IEA, "Installed and contracted renewable capacity by major oil and gas companies, 2018-2025", https://www.iea.org/data-and-statistics/charts/installed-and-contracted-renewable-capacity-by-major-oil-and-gas-companies-2018-2025, updated 9 November 2020; M. J. Coren, "This is the year oil companies finally invest in geothermal", Quartz, 19 January 2021, https://qz.com/1958041/oil-companies-may-finally-invest-in-geothermal-in-2021; L. Collins, "Oil giants BP and Chevron become part-owners of 'world-changing' deep-geothermal innovator Eavor", Recharge News, 18 February 2021, https://www.rechargenews.com/technology/oil-giants-bp-and-chevron-become-part-owners-of-world-changing-deep-geothermal-innovator-eavor/2-1-963275; P. Lee, "Unocal's geothermal projects are gaining steam", *Los Angeles Times*, 23 October 1989, https://www.latimes.com/archives/la-xpm-1989-10-23-fi-379-story.html; "Oil majors are driving wind energy revolution", RT, 14 February 2021, https://www.rt.com/business/515529-oil-majors-wind-enrgy-revolution; S. Reed, "Oil giants win offshore wind leases in Britain", *New York Times*, 8 February 2021, https://www.nytimes.com/2021/02/08/business/oil-companies-offshore-wind-britain.html; J. St. John, "New York's latest clean energy push includes 2.5GW of offshore wind contracts for Equinor and BP", Greentech Media, 13 January 2021, https://www.greentechmedia.com/articles/read/new-yorks-new-green-push-includes-2.5gw-of-offshore-wind-contracts-for-equinor-and-bp; BP, "BP and Equinor form strategic partnership to develop offshore wind energy in US", 10 September 2020, https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-and-equinor-form-strategic-partnership-to-develop-offshore-wind-energy-in-us.html; IEA, *The Oil and Gas Industry in Energy Transitions* (Paris: January 2020), https://www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions; L. Carter, Z. Boren and A. Kaufman, "Revealed: BP and Shell back anti-climate lobby groups despite pledges", Unearthed, 28 September 2020, https://unearthed.greenpeace.org/2020/09/28/bp-shell-climate-lobby-groups; "How some international treaties threaten the environment", *The Economist*, 5 October 2020, https://www.economist.com/finance-and-economics/2020/10/05/how-some-international-treaties-threaten-the-environment; K. Taylor, "Energy Charter Treaty strikes again as Uniper sues Netherlands over coal phase-out", EURACTIV, 20 April 2021, https://www.euractiv.com/section/energy/news/energy-charter-treaty-strikes-again-as-uniper-sues-netherlands-over-coal-phase-out; K. Taylor, "Germany's RWE uses Energy Charter Treaty to challenge Dutch coal phase-out", EURACTIV, 5 February 2021, https://www.euractiv.com/section/energy/news/germanys-rwe-uses-energy-charter-treaty-to-challenge-dutch-coal-phase-out; F. Simon, "France puts EU withdrawal from Energy Charter Treaty on the table", EURACTIV, 3 February 2021, https://www.euractiv.com/section/energy/news/france-puts-eu-withdrawal-from-energy-charter-treaty-on-the-table; K. Taylor, "EU pushes for fossil fuel phase-out in 'last chance' energy charter treaty talks", EURACTIV, 18 February 2021, https://www.euractiv.com/section/energy/news/eu-pushes-for-fossil-fuel-phase-out-in-last-chance-energy-charter-treaty-talks; ODI, "G20 governments have committed USD 151 billion to fossil fuels in COVID-19 recovery packages", 15 July 2020, https://www.odi.org/news/17179-g20-governments-have-committed-usd-151-billion-fossil-fuels-covid-19-recovery-packages. Note on **Figure 5**: For all companies except Eni, the amount spent on renewables is difficult to isolate. Oil and gas companies do not explicitly report on renewable energy spending in their financial statements. Of the companies represented in the figure, Eni was the only one that provided this number, under "Business of increasing renewable installed capacity" for 2020. Equinor's spending was calculated based on its self-reported 4% share of "Renewables and low carbon solutions" in its gross capital expenditure. ExxonMobil and Chevron reported on "Environmental capital expenditures" without clarifying what is included in this spending category. BP's renewables spending was reported under "non-oil and gas expenditure", which may conflate a range of spending categories including electric mobility. Shell reported on "Renewables and energy solutions", which includes power generation, trading and supply; hydrogen; and nature-based solutions. Total reported on renewables under "Integrated gas, renewables and power", both of which include spending on fossil gas for power generation. **Figure 5** based on the following sources: Eni, *2020 Annual Report on Form 20F* (Rome: 2021), pp. 2 and 120, https://www.eni.com/assets/documents/eng/reports/2020/Annual-Report-On-Form-20-F-2020.pdf; Equinor total capital expenditure from Equinor, *2020 Annual Report on Form 20F* (Stavanger: 2021), p. 88, https://www.equinor.com/en/investors/our-dividend/annual-reports-archive.html; spending on low-carbon solutions calculated based on self-reported share of "Renewables and low carbon solutions" in gross capital expenditure, from Equinor, "Equinor annual and sustainability reports for 2020", 19 March 2021, https://www.equinor.com/en/news/20210319-annual-sustainability-reports-2020.html; Chevron, *2020 Annual Report* (San Ramon: 2021), pp. 40, 69, https://www.chevron.com/-/media/chevron/annual-report/2020/documents/2020-Annual-Report.pdf; BP, *2020 Annual Report on Form 20F* (London: 2021), pp. 22, 46, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2020.pdf, Royal Dutch Shell, *2020 Form 20-F* (The Hague: 2021), pp. 26, 34, https://www.shell.com/about-us/annual-publications/annual-reports-download-centre/_jcr_content/par/tabbedcontent_f645/tab_7bf9_copy/textimage_d83f.stream/1615464115245/a1e527c87e9d548f6e5e0b760ec92c12464b8b94/royal-dutch-shell-form-20-f-2020.pdf; ExxonMobil, *2020 Annual Report* (Irving: 2021), pp. 52, 54, https://corporate.exxonmobil.com/-/media/Global/Files/investor-relations/annual-meeting-materials/annual-report-summaries/2020-Annual-Report.pdf; Total, *2020 Form 20-F* (Paris: 2021), pp. 1, 4, https://www.total.com/system/files/documents/2021-03/2020-total-form-20-f.pdf.

38 H. L. Brumberg, "AAP policy: Ambient air pollution a preventable risk factor in pediatric health concerns", AAP News, 17 May 2021, https://www.aappublications.org/news/2021/05/17/air-pollution-child-health-policy-051721; COBENEFITS, "Why co-benefits?", https://www.cobenefits.info/our-work/project, viewed 27 May 2021. **Sidebar 2** from the following sources: IRENA, *The Post-COVID Recovery: An Agenda for Resilience, Development and Equality* (Abu Dhabi: 2020), www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Post-COVID_Recovery_2020.pdf;

Solar Foundation, *11th Annual National Solar Jobs Census 2020* (Washington, DC: May 2021), https://www.thesolarfoundation.org/wp-content/uploads/2021/05/National-Solar-Jobs-Census-2020-FINAL.pdf; 2019 off-grid solar jobs estimate from GOGLA and Vivid Economics, *Employment Opportunities in an Evolving Market* (Utrecht: 2018), www.gogla.org/resources/employment-opportunities-in-an-evolving-market-off-grid-solar-creating-high-value; 2020 off-grid solar jobs estimated using sales trend data from GOGLA, op. cit. note 16; Ministry of Labour and Employment of Brazil, "Annual list of social information: Database including active and inactive employments for sugarcane cultivation and alcohol manufacture", in *Relação Anual de Informações Sociais (Annual Report of Social Information)* (Brasilia: 2020); in-person sales and solar industry job losses from E. F. Merchant, "The highs and lows for solar in 2020", Greentech Media, 30 December 2020, https://www.greentechmedia.com/articles/read/the-highs-and-lows-for-solar-in-2020, and from E. F. Merchant, "A new response to coronavirus: Giving solar away for free", Greentech Media, 23 April 2020, https://www.greentechmedia.com/articles/read/one-response-to-the-coronavirus-giving-solar-away-for-free; off-grid finances from Sustainable Energy for All (SEforALL), *Energizing Finance: Understanding the Landscape 2020* (Washington, DC: 2020), https://www.seforall.org/publications/energizing-finance-understanding-the-landscape-2020; balsa shortages from E. Ng, "China turbine makers winded after Ecuador lockdown leaves them without blades", *South China Morning Post*, 16 April 2020, https://www.scmp.com/business/article/3080227/china-turbine-makers-winded-after-ecuador-lockdown-leaves-them-without.

39 S. Dixon-Fyle et al., "Diversity wins: How inclusion matters", McKinsey & Company, 19 May 2020, https://www.mckinsey.com/featured-insights/diversity-and-inclusion/diversity-wins-how-inclusion-matters; Global Women's Network for the Energy Transition, "News resources", https://www.globalwomennet.org/news/resources, viewed 26 May 2021; Energy Voice, "Renewables 'early advantage' in gender equality could disappear, warns software firm", 5 May 2021, https://www.energyvoice.com/renewables-energy-transition/320188/renewables-gender-diversity; J. Davenport, "Here's how to fix renewable energy's diversity problem", *Forbes*, 4 May 2021, https://www.forbes.com/sites/julietdavenport/2021/05/04/heres-how-to-fix-renewable-energys-diversity-problem.

40 For example, Enel and Clir Renewables joined in early 2021, from Enel, "Enel joins Equal by 30 Campaign, confirming its commitments on gender equality", press release (Rome: 19 February 2021), https://www.enel.com/media/explore/search-press-releases/press/2021/02/enel-joins-equal-by-30-campaign-confirming-its-commitments-on-gender-equality-, and from CLIR, "Commitments are key for gender equality in the renewables industry", pv magazine, 4 May 2021, https://www.pv-magazine.com/press-releases/commitments-are-key-for-gender-equality-in-the-renewables-industry. See also: Clean Energy Ministerial, "Equal by 30", http://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/equal-30, viewed 27 May 2021; Equal by 30, "About the campaign", https://www.equalby30.org/en/content/about-campaign, viewed 27 May 2021.

41 Equal by 30, "Equal by 30: Countries commitments", https://www.equalby30.org/en/countries-commitments, viewed 27 May 2021.

42 For country details, see **Table 4** in Policy Landscape chapter, and GSR 2021 Data Pack. As of 20 May 2021, 121 countries had joined the Climate Ambition Alliance, from Global Climate Action, "Climate Ambition Alliance: Net Zero 2050", https://climateaction.unfccc.int/views/cooperative-initiative-details.html?id=94, viewed 24 May 2021. E. Kosolapova, "77 countries, 100+ cities commit to net zero carbon emissions by 2050 at Climate Summit", International Institute for Sustainable Development (IISD) SDG Knowledge Hub, 24 September 2020, http://sdg.iisd.org/news/77-countries-100-cities-commit-to-net-zero-carbon-emissions-by-2050-at-climate-summit; IISD, "European Commission launches green deal to reset economic growth for carbon neutrality", 19 December 2020, https://sdg.iisd.org/news/european-commission-launches-green-deal-to-reset-economic-growth-for-carbon-neutrality; "EU carbon neutrality: Leaders agree 2050 target without Poland", BBC News, 13 December 2020, https://www.bbc.com/news/world-europe-50778001. A key principle to decarbonising the EU energy system is to prioritise energy efficiency and develop a power sector based on renewable energy, from European Commission (EC), *Clean Energy: The European Green Deal* (Brussels: December 2020), https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6723. The IEA net zero scenario specifies "no additional new final investment decisions should be taken for new unabated coal plants, the least efficient coal plants are phased out by 2030, and the remaining coal plants still in use by 2040 are retrofitted", from IEA, *Net Zero by 2050: A Roadmap for the Global Energy Sector* (Paris: May 2021), pp. 18-19, https://www.iea.org/reports/net-zero-by-2050.

43 United Nations Framework Convention on Climate Change (UNFCCC), "The Race to Zero", https://racetozero.unfccc.int/what-is-the-race-to-zero, viewed 13 November 2020; Global Covenant of Mayors for Climate & Energy, https://www.globalcovenantofmayors.org, viewed 3 November 2020; New Climate Institute and Data-Driven EnviroLab, op. cit. note 35; UNFCCC, "Net-zero double in less than a year", press release (Bonn: 21 September 2020), https://unfccc.int/news/commitments-to-net-zero-double-in-less-than-a-year; Renewable Energy Policy Network for the 21st Century (REN21), *Renewables in Cities 2021 Global Status Report* (Paris: 2021), https://www.ren21.net/reports/cities-global-status-report. **Box 2** from REC 2021 Data Pack, available at www.ren21.net/cities/datapack. Data are compiled by REN21 and based on CDP-ICLEI Unified Reporting System, CDP Open Data, The Global 100% Renewable Energy Platform, Climate Action Network, C40, ICLEI, IRENA, Sierra Club, UK100 and REN21 data collection. Some research is based on voluntary reporting and may not be exhaustive.

44 IEA, op. cit. note 1.

45 IEA, "Monthly evolution of global CO_2 emissions, 2020 relative to 2019", in "Global Energy Review: CO_2 emissions in 2020", 2 March 2021, https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020; National Oceanic and Atmospheric Administration, "Despite pandemic shutdowns, carbon dioxide and methane surged in 2020", 7 April 2021, https://research.noaa.gov/article/ArtMID/587/ArticleID/2742/Despite-pandemic-shutdowns-carbon-dioxide-and-methane-surged-in-2020.

46 Ibid. Previously, a flattening in emissions was due mainly to declines in emissions from the power sector in some countries, which were related mostly to improvements in energy efficiency and to rising shares of renewable energy, but also to some extent to fuel switching from coal to gas, as well as to higher nuclear power output. From IEA, "Global CO_2 emissions in 2019", 11 February 2020, https://www.iea.org/articles/global-co2-emissions-in-2019.

47 Share of renewable energy in total final energy consumption in Brazil, Canada, Turkey, Argentina, India, Australia, China, Mexico, Indonesia, Japan and South Africa based on IEA, "World Energy Balances 2021 – Summary energy balances" (Paris: 2021), https://www.iea.org/data-and-statistics/data-product/world-energy-balances#energy-balances; European countries and EU-27 from Eurostat, "Share of renewable energy in gross final energy consumption", https://ec.europa.eu/eurostat/databrowser/view/t2020_31/default/table, viewed 21 May 2021; Russian Federation and Saudi Arabia based on data from IEA, *World Energy Balances 2020* (Paris: 2020), https://www.iea.org/data-and-statistics/data-product/world-energy-balances. All rights reserved; as modified by REN21. Targets for renewable energy by end-2020 from the following sources: IRENA, "Energy Profile: Canada", https://www.irena.org/IRENADocuments/Statistical_Profiles/North%20America/Canada_North%20America_RE_SP.pdf, updated 30 September 2020; EU-27, Italy, Germany and France from Eurostat, "News release: Share of renewable energy in the EU up to 18.0%", 23 January 2020, https://ec.europa.eu/eurostat/documents/2995521/10335438/8-23012020-AP-EN.pdf/292cf2e5-8870-4525-7ad7-188864ba0c29?t=1579770240000; IRENA, "Energy Profile: Turkey", https://www.irena.org/IRENADocuments/Statistical_Profiles/Eurasia/Turkey_Eurasia_RE_SP.pdf, updated 30 September 2020; IRENA, "Energy Profile: Mexico", https://www.irena.org/IRENADocuments/Statistical_Profiles/North%20America/Mexico_North%20America_RE_SP.pdf, updated 30 September 2020.

48 Ibid. **Figure 1** based on idem.

49 **Box 3** based on the following sources: L. Bennun et al., *Mitigating Biodiversity Impacts Associated with Solar and Wind Energy Development* (Gland, Switzerland: IUCN, 2021), https://portals.iucn.org/library/sites/library/files/documents/2021-004-En.pdf; S. Spillias et al., "Renewable energy targets may undermine their sustainability", *Nature Climate Change*, vol. 10 (2020), https://www.nature.com/articles/s41558-020-00939-x.

50 Estimated shares based on the following sources: total final energy consumption in 2019 (estimated at 381.1 exajoules, EJ) is based on 377.7 EJ for 2018, from IEA, *World Energy Balances 2020*, op. cit. note 47, and escalated by the 0.91% increase in estimated global total final consumption (including non-energy use) from 2018 to 2019, derived from IEA, *World Energy Outlook 2020* (Paris: 2020). Estimate of traditional biomass from idem. Modern bioenergy for heat and geothermal heat based on 2018 values from IEA, *World Energy Balances*, op. cit. note 47, and escalated to 2019 based on combined annual average growth rates from 2008 to 2018. Biofuels used in transport in 2019 from IEA, op. cit. note 5. Solar thermal heating and cooling from M. Spörk-Dür, AEE-Institute for Sustainable Technologies (AEE INTEC), Gleisdorf, Austria, personal communication with REN21, April 2021, and from W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market and Development Trends in 2020, Detailed Market Figures 2019* (Paris: IEA Solar Heating and Cooling Programme, 2021), http://www.iea-shc.org/solar-heat-worldwide. Nuclear power final consumption based on generation of 2,701.4 TWh, from US Energy Information Administration (EIA) international data browser, https://www.eia.gov/international/data/world, viewed 14 April 2021, and global average electricity losses and estimated industry own-use of nuclear power in 2019 based on IEA, *World Energy Balances 2020*, op. cit. note 47. Electricity consumption from renewable sources based on estimates of 2018 generation from IEA, op. cit. note 5 and global average electricity losses and estimated technology-specific industry own-use of electricity from renewable sources in 2019, based on IEA, *World Energy Balances 2020*, op. cit. note 47. Estimates of industry own-use of electricity are differentiated by technology based on explicit technology-specific own-use (such as pumping at hydropower facilities) as well as apportioning of various categories of own-use by technology as deemed appropriate. For example, industry own-use of electricity at coal mines and oil refineries are attributed to fossil fuel generation. Industry own-use includes the difference between gross and net generation at thermal power plants (the difference lies in the power consumption of various internal loads, such as fans, pumps and pollution controls at thermal plants), and other uses such as electricity use in coal mining and fossil fuel refining. Differentiated own-use by technology, combined with global average losses, are as follows: solar PV, ocean energy and wind power (8.2%); hydropower (10.1%); CSP and geothermal (14.2%); and biopower (15.2%). See Methodological Notes. **Figure 2** based on Ibid., all sources.

51 Ibid., all sources.

52 Ibid.

53 Ibid.

54 Ibid.

55 **Figure 3** based on sources in endnote 47.

56 See Energy Efficiency chapter and IEA, *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020.

57 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

58 Based on Ibid.

59 Ibid.

60 Ibid.

61 **Figure 4** based on Ibid.

62 For information on technological innovation in industry and transport, see IRENA, *Reaching Zero With Renewables* (Abu Dhabi: 2020), https://www.irena.org/publications/2020/Sep/Reaching-Zero-with-Renewables, and S. Madeddu et al., "The CO_2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat)", *Environmental Research Letters*, vol. 15, no. 12 (25 November 2020), https://iopscience.iop.org/article/10.1088/1748-9326/abbd02.

63 IEA, *Electricity Security 2021* (Paris: 2021), https://www.iea.org/reports/electricity-security-2021; S. Teske, *Citizen Power for Grids* (Paris: REN21, 2021), https://www.ren21.net/2021-citizen-power-for-grids. See also Systems Integration chapter.

64 However, Asia (where coal remains cheaper) is estimated to see renewables becoming competitive by 2030 or earlier. Wood Mackenzie, "Renewables in most of Asia Pacific to be cheaper than coal power by 2030", 26 November 2020, https://www.woodmac.com/press-releases/renewables-in-most-of-asia-pacific-to-be-cheaper-than-coal-power-by-2030.

65 See **Table 4** in Policy Landscape chapter.

66 UNFCCC, "Nationally determined contributions under the Paris Agreement", 26 February 2021, https://unfccc.int/sites/default/files/resource/cma2021_02E.pdf; UNFCCC, "NDC Synthesis Report", 26 February 2021, https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report; UNFCCC, "NDC Registry", https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx, viewed 21 May 2021.

67 Excluding recovery packages. REN21 Policy Database; see GSR 2021 Data Pack at www.ren21.net/gsr-2021.

68 Austria from Klimaaktiv, "E-Mobilitätsoffensive 2021", https://www.klimaaktiv.at/mobilitaet/elektromobilitaet/foerderaktion_emob2021.html, viewed 21 May 2021; Germany from BMVI, "500 Millionen Euro zusätzlich für Ladeinfrastruktur – 6. Förderaufruf abgeschlossen", https://www.bmvi.de/SharedDocs/DE/Artikel/G/infopapier-sechster-foerderaufruf-ladeinfrastruktur.html, viewed 21 May 2021; "Japan to offer up to ¥800,000 in subsidies for electric vehicles", Japan Times, 25 November 2020, https://www.japantimes.co.jp/news/2020/11/25/business/subsidies-electric-vehicles. Previously, a policy linking renewables and EVs was in place in Luxembourg, but it was no longer in place as of 2017. IRENA, *Energy Subsidies. Evolution in the Global Energy Transformation to 2050* (Abu Dhabi: 2020), https://www.irena.org/publications/2020/Apr/Energy-Subsidies-2020; OECD, "Governments should use Covid-19 recovery efforts as an opportunity to phase out support for fossil fuels, say OECD and IEA", 5 June 2020, https://www.oecd.org/environment/governments-should-use-covid-19-recovery-efforts-as-an-opportunity-to-phase-out-support-for-fossil-fuels-say-oecd-and-iea.htm; F. Birol, "Put clean energy at the heart of stimulus plans to counter the coronavirus crisis", IEA, 14 March 2020, https://www.iea.org/commentaries/put-clean-energy-at-the-heart-of-stimulus-plans-to-counter-the-coronavirus-crisis; CarbonBrief, "Leading economists: Green coronavirus recovery also better for economy", 5 May 2020,https://www.carbonbrief.org/leading-economists-green-coronavirus-recovery-also-better-for-economy; M. Holder, "Boris Johnson: 'We owe it to future generations to build back better'", Business Green, 28 May 2020, https://www.businessgreen.com/news/4015783/boris-johnson-owe-future-generations-build; Climate Action Network, "CAN position: Who should pay the bill for covid-19 recovery measures?" April 2021, https://climatenetwork.org/resource/can-position-who-should-pay-the-bill-for-covid-19-recovery-measures; United Nations Environment Programme Finance Initiative, "Position on the coronavirus recovery", 2021, https://www.unepfi.org/wordpress/wp-content/uploads/2021/01/AoA-position-on-the-coronavirus-recovery-21.pdf.

69 In 2019, fossil fuel subsidies totalled more than USD 478 billion, down from USD 582 billion in 2018, due mainly to lower international oil prices and thus lower costs to governments for subsidising energy for end-users. However, direct and indirect subsidies for fossil fuel production increased 38% in 2019 based on analysis of 77 countries, with a rise also estimated for 2020, nearly triple the support for renewable electricity generation and biofuels. OECD, op. cit. note 68; IRENA, op. cit. note 68, p. 8. In **Europe**, coal subsidies decreased 9% between 2015 and 2018, while natural gas subsidies increased 4%, from EC, "Annex to the 2020 report on the State of the Energy Union pursuant to Regulation (EU) 2018/1999 on Governance of the Energy Union and Climate Action" (Brussels: 14 October 2020), p. 7, https://ec.europa.eu/energy/sites/ener/files/progress_on_energy_subsidies_in_particular_for_fossil_fuels.pdf.

70 The **United States** saw a net decrease in utility-scale coal-fired power capacity of over 10 GW in 2020, while more than 20 GW was planned for decommissioning in the EU and the **United Kingdom** during 2020. The US 2020 decommissioned capacity amounted to the fourth highest annual total since 2009, while total US coal capacity declined 25% between 2010 and 2019, from B. Storrow, "With mega-emitters closed, coal's 'cleaner fleet' persists", E&E News, 9 December 2020, https://www.eenews.net/stories/1063720241. US net decrease from US EIA, "Electric Power Monthly with Data for December 2020", February 2021, https://www.eia.gov/electricity/monthly/archive/February2021.pdf; EU and United Kingdom from IEA, "2020 Global overview: Capacity, supply and emissions", in *Electricity Market Report* (Paris: December 2020), https://www.iea.org/reports/electricity-market-report-december-2020/2020-global-overview-capacity-supply-and-emissions; CarbonBrief, "Global coal power", https://www.carbonbrief.org/mapped-worlds-coal-power-plants, viewed 26 March 2021. In Europe, operation began at the new unit 6 (660 MW) Ledvice Power Station in the **Czech Republic** on 1 January 2020, from Ministry of the Environment of the Czech Republic, "Změna povolení", https://www.mzp.cz/ippc/ippc4.nsf/$pid/

MZPPRHECJJZW, viewed 24 May 2021, and at Unit 4 of the Datteln Power Station in **Germany** on 30 May 2020, from "Climate activists protest Germany's new Datteln 4 coal power plant", DW, 30 May 2020, https://www.dw.com/en/climate-activists-protest-germanys-new-datteln-4-coal-power-plant/a-53632887.

71 CarbonBrief, op. cit. note 70. An estimated 46 GW of a new coal capacity came into service in 2020, while 28 GW of coal capacity was retired; for natural gas, 50 GW was added and 20 GW was retired; and for nuclear, some 5 GW came online but 10 GW was retired, all from Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and BloombergNEF, *Global Trends in Renewable Energy Investment* (Frankfurt: 2020), https://wedocs.unep.org/bitstream/handle/20.500.11822/32700/GTR20.pdf; China added by far the most capacity during the year, commissioning an estimated 38.4 GW.

72 Global Energy Monitor, "Global Coal Plant Tracker", https://globalenergymonitor.org/projects/global-coal-plant-tracker, viewed 12 March 2021; J. Purtill, "World is now shutting down coal plants faster than it's opening them", ABC, 4 August 2020, https://www.abc.net.au/triplej/programs/hack/world-global-coal-power-capacity-has-fell-in-2020/12523904.

73 Global Energy Monitor, *Boom and Bust: Tracking the Global Coal Plant Pipeline* (London: 2021), p. 3, https://globalenergymonitor.org/wp-content/uploads/2021/04/BoomAndBust_2021_final.pdf; Many countries – notably in Asia – have reconsidered their view of coal going forward, driven by several factors including lower electricity demand during the Covid-19 crisis, lower costs for renewable energy, low natural gas prices, reducing air pollution, financing difficulties, and rising international pressure, from IEA, op. cit. note 70. Conversely, natural gas-fired power plant capacity continued to expand globally during the year, as more than 40 GW was estimated to be commissioned in 2020 driven mainly by the Middle East, the United States and China, from idem.

74 End Coal, "Global Coal Public Finance Tracker", https://endcoal.org/finance-tracker, viewed 6 March 2021; IEA, *Chinese Companies Energy Activities in Emerging Asia* (Paris: April 2019), https://www.iea.org/reports/chinese-companies-energy-activities-in-emerging-asia.

75 Rainforest Action Network, *Banking on Climate Change Fossil Fuel Financial Report* (San Francisco: March 2020), https://www.ran.org/wp-content/uploads/2020/03/Banking_on_Climate_Change__2020_vF.pdf.

76 Energy Policy Tracker, Recovery package database, www.energypolicytracker.org, viewed on multiple occasions in March and April 2021.

77 The remaining billions are considered "Other" in the database. "Governments" include all levels. Energy Policy Tracker, op. cit. note 76.

78 E. Gündüzyeli and J. Flisowska, "Poland goes all out on coal rescue against EU's higher climate goal", EURACTIV, 23 December 2020, https://www.euractiv.com/section/energy/opinion/poland-goes-all-out-on-coal-rescue-against-eus-higher-climate-goal.

79 Sectoral energy share based on IEA, *World Energy Balances 2020*, op. cit. note 47.

80 Calculations based on Ibid. See Methodological Notes and GSR 2021 Data Pack.

81 Ibid.

82 Ibid. Renewable contribution to cooling from IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Abu Dhabi and Paris: 2020), p. 49, https://www.ren21.net/wp-content/uploads/2019/05/IRENA_IEA_REN21-Policies_HC_2020_Full_Report.pdf.

83 IEA, "Context: A world in lockdown", in *Global Energy Review 2020* (Paris: 2020), https://www.iea.org/reports/global-energy-review-2020/context-a-world-in-lockdown.

84 IEA, *Global Energy Review 2020* (Paris: 2020), https://www.iea.org/reports/global-energy-review-2020.

85 IEA, "Buildings", in *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020/buildings; D. Crow and A. Millot, "Working from home can save energy and reduce emissions. But how much?" IEA, 12 June 2020 https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much.

86 Sectoral energy share based on IEA, *World Energy Balances 2020*, op. cit. note 47. Emissions include both direct and indirect emissions, such as power generation for electricity, and exclude the estimated portion of overall industry devoted to manufacturing building construction materials such as steel, cement and glass, from Global Alliance for Buildings and Construction (GlobalABC), IEA and UNEP, *2020 Global Status Report for Buildings and Construction* (Paris: 2020), p. 12, https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf.

87 Ibid, pp. 20, 23.

88 Ibid, p. 18.

89 Ibid, p. 18. These are global trends, but large variations exist in different regions where decoupling has been observed. See, for example, Architecture 2030, "An unprecedented achievement", February 2020, https://architecture2030.org/unprecedented-a-way-forward.

90 GlobalABC, IEA and UNEP, op. cit. note 86, p. 18.

91 See Energy Efficiency chapter.

92 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

93 Ibid.

94 Ibid.

95 Ibid.

96 T. Abergel and C. Delmastro, "Is cooling the future of heating?" IEA, 13 December 2020, https://www.iea.org/commentaries/is-cooling-the-future-of-heating.

97 Ibid.

98 Ibid.; IEA, *The Future of Cooling* (Paris: 2018), p. 45, https://www.iea.org/reports/the-future-of-cooling.

99 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

100 R. Lowes et al., "Hot stuff: Research and policy principles for heat decarbonisation through smart electrification", *Energy Research and Social Science*, vol. 70 (December 2020), https://www.sciencedirect.com/science/article/pii/S2214629620303108; Regulatory Assistance Project, *Beneficial Electrification of Space Heating* (Brussels: 2018), https://www.raponline.org/knowledge-center/beneficial-electrification-of-space-heating.

101 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

102 Ibid.

103 Ibid.

104 **Figure 6** based on Ibid.

105 Eurostat, "Share of energy from renewable sources", https://ec.europa.eu/eurostat/data/database, viewed 12 March 2021. The definition of "renewable heating and cooling" in the EU also includes waste heat (or "derived" heat) and thermal energy supplied by aerothermal, hydrothermal or geothermal heat pumps.

106 Government of Iceland, "Energy", https://www.government.is/topics/business-and-industry/energy, viewed 12 May 2021; Eurostat, op. cit. note 105.

107 Abergel and Delmastro, op. cit. note 96.

108 Ibid.

109 IRENA, IEA and REN21, op. cit. note 82, p. 49.

110 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

111 See Bioenergy section in Market and Industry chapter.

112 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

113 Ibid.

114 Ibid.

115 See Solar Thermal Heating section in Market and Industry chapter.

116 See Market and Industry chapter.

117 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

118 Ibid.

119 Ibid.

120 IEA, op. cit. note 5.

121 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

122 See Heat Pumps section in Systems Integration chapter.

123 See Heat Pumps section in Systems Integration chapter, and **Table 6** in Policy chapter. The **United Kingdom** made a commitment to install 600,000 heat pumps yearly by 2028, a 17-fold increase compared the level of installations in 2019. R. Lowes, J. Rosenow and P. Guertler, *Getting On Track to Net Zero: A Policy Package for a Heat Pump Mass Market in the UK* (Brussels: 2021), https://www.raponline.org/wp-content/uploads/2021/03/RAP-Heat-Pump-Policy-0324212.pdf; Heat Pump Association, "UK heat pump market set to almost double

this year", https://www.heatpumps.org.uk/uk-heat-pump-market-set-to-almost-double-this-year, viewed 12 March 2021. However, the United Kingdom's Green Homes Grant programme, which supported the installation of heat pumps, was cancelled in March 2021, six months after its launch, from F. Harvey,"UK government scraps green homes grant after six months", *The Guardian* (UK), 27 March 2021, https://www.theguardian.com/environment/2021/mar/27/uk-government-scraps-green-homes-grant-after-six-months. International Energy Research Centre, *Best Practices and Policy Solutions for Ireland's 2030 Heat Pump Target* (Dublin: 2020), http://www.ierc.ie/wp-content/uploads/2020/11/Best-Practices-and-Policy-Solutions-for-Irelands-2030-Heat-Pump-Target-1.pdf.

124 T. Gruenwald and M. Lee, "2020: Watt a year for building electrification!" RMI, 16 December 2020, https://rmi.org/2020-watt-a-year-for-building-electrification. See also: J. Meyers, *Building Electrification: How Cities and Counties Are Implementing Electrification Policies* (Boulder: 2020), https://swenergy.org/pubs/building_electrification; T. DiChristopher, "'Banning' natural gas is out; electrifying buildings is in", S&P Global, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/banning-natural-gas-is-out-electrifying-buildings-is-in-59285807; REN21, op. cit. note 43. RMI was also awarded USD 8 million from the Bezos Fund to work with local governments and develop policies and plans to renovate their building stock to be all-electric, from K. Kroh and J. Mandel, "RMI awarded $8 million to accelerate carbon-free US buildings", RMI, 16 November 2020, https://rmi.org/rmi-awarded-8-million-to-accelerate-carbon-free-us-buildings.

125 Ibid, all references.

126 M. Mazengarb, "ACT Greens pledge to build first zero-emissions, all-electric business district", One Step Off the Grid, 23 September 2020, https://onestepoffthegrid.com.au/act-greens-pledge-to-build-first-zero-emissions-all-electric-business-district.

127 M. Mace, "North of England homes to pilot hydrogen heating", EURACTIV, 6 January 2021, https://www.euractiv.com/section/energy/news/north-of-england-homes-to-pilot-hydrogen-heating; T. Seskus, "Hydrogen-injected natural gas to heat homes in Alberta city next year", CBC News, 21 July 2020, https://www.cbc.ca/news/canada/calgary/alberta-hydrogen-home-heating-1.5657736.

128 EC, *A Hydrogen Strategy for a Climate-Neutral Europe* (Brussels: 2020), p. 6, https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

129 Fraunhofer Institute for Energy Economics and Energy System Technology, *Hydrogen in the Energy System of the Future: Focus on Heat in Buildings* (Hannover: 2020),https://www.iee.fraunhofer.de/content/dam/iee/energiesystemtechnik/en/documents/Studies-Reports/FraunhoferIEE_Study_H2_Heat_in_Buildings_final_EN_20200619.pdf; C. Baldino et al., *Hydrogen for Heating? Decarbonization Options for Households in the European Union in 2050* (Brussels: International Council on Clean Transportation, 2021), https://theicct.org/publications/hydrogen-heating-eu-feb2021; Agora Energiewende, *No-Regret Hydrogen: Charting Early Steps for H2 Infrastructure in Europe* (Berlin: 2021), https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf; E3G, *E3G Hydrogen Factsheet: Building Heat* (Brussels: 2021), https://9tj4025ol53byww26jdkao0x-wpengine.netdna-ssl.com/wp-content/uploads/E3G_2021_Hydrogen-Factsheet_Heat.pdf; E. Godsen, "Switching all boilers to hydrogen 'is impractical'", *The Times*, 7 December 2020, https://www.thetimes.co.uk/article/switching-all-boilers-to-hydrogen-is-impractical-zw00f3v9l.

130 European Alliance to Save Energy, "Broad coalition calls on EU not to rely on hydrogen to decarbonise buildings", 21 January 2021, https://euase.net/broad-coalition-calls-eu-not-to-rely-on-hydrogen-buildings.

131 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

132 Ibid.

133 The top European countries in 2017 and their respective shares of renewable district heat in final heat demand were Iceland (89.2%), Denmark (38.6%), Lithuania (38.5%), Sweden (36.6), Finland (15.4%) and Norway (3.7%); in Norway, renewable electricity represented 60% of the heat market, all from Euroheat & Power, *Country by Country 2019* (Brussels: 2019), https://www.euroheat.org/cbc_publications/cbc-2019.

134 See Solar Thermal Heating section in Market and Industry chapter.

135 World Health Organization, "Household air pollution", 8 May 2018, https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health.

136 Energy Sector Management Assistance Program (ESMAP), *The State of Access to Modern Cooking Energy Services* (Washington, DC: 2020), p. 39, http://documents.worldbank.org/curated/en/937141600195758792/The-State-of-Access-to-Modern-Energy-Cooking-Services.

137 Ibid.

138 Solar Cookers International, "Distribution of solar cookers", https://www.solarcookers.org/partners/distribution-solar-cookers, viewed 31 March 2021.

139 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

140 IEA, op. cit. note 63; IEA, *Power Systems in Transition* (Paris: 2020), https://www.iea.org/reports/power-systems-in-transition.

141 IEA, op. cit. note 5.

142 See Power section in this chapter. Ember, op. cit. note 1.

143 See Distributed Renewables chapter.

144 GOGLA, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January-June 2020*, (Amsterdam: 2020), https://www.gogla.org/sites/default/files/resource_docs/global_off_grid_solar_market_report_h1_2020.pdf.

145 Mini-Grids Partnership, *State of the Global Mini-Grids Market 2020* (BloombergNEF and SEforALL: 1 July 2020), https://minigrids.org/market-report-2020.

146 See Policy Landscape chapter, pp. 69-71.

147 Ibid.

148 REN21, op. cit. note 43, pp. 58-59.

149 Ibid. pp. 58-59.

150 See Heating and Cooling section in Policy Landscape chapter. The commitments and bans vary by fuel (e.g., coal, oil or fossil gas), by building type (e.g., new vs. existing) and by year they will come into force. The seven national governments were Austria, Denmark, France, Germany, the Netherlands, Norway, Poland and the United Kingdom. In 2020, the United Kingdom announced a future ban of gas boilers in newly built homes. The previous target year was 2023, and is now expected to be 2025, from R. Lowes, University of Exeter, personal communication with REN21, 26 April 2021. France also banned the use of gas heating in new homes by mid-2021, with multi-dwelling buildings targeted for 2024, from M. Chauvot, S. Wajsbrot and V. Collen, "Le chauffage au gaz bientôt proscrit des logements neufs", Les Echos, 24 November 2020,https://www.lesechos.fr/industrie-services/immobilier-btp/exclusif-immobilier-le-chauffage-au-gaz-proscrit-des-maisons-neuves-des-2021-1267599#xtor=CS1-3046; "Réglementation: le chauffage au gaz interdit dès l'été 2021 pour les maisons neuves", *Journal du bâtiment et des TP*, 1 December 2020, https://www.journal-du-btp.com/reglementation-le-chauffage-au-gaz-interdit-des-l-ete-2021-pour-les-maisons-neuves-2265.html. New buildings in the Netherlands are increasingly using electricity (heat pumps) for space and water heating following the country's declaration of a gas phaseout in 2018, from C. Lyon, "Heating the Netherlands: The future's all-electric. Or is it? Delta-EE's top 10 facts to demystify the Dutch heating market", Delta Energy & Environment, 18 June 2020, https://www.delta-ee.com/delta-ee-blog/heating-the-netherlands-the-future-s-all-electric-or-is-it-delta-ee-s-top-10-facts-to-demystify-the-dutch-heating-market-1.html;B. Webster, S. Swinford and A. Ellson, "Gas boiler ban for new homes in three years under green deal", *The Times*, 19 November 2020, https://www.thetimes.co.uk/article/gas-boiler-ban-for-new-homes-in-three-years-under-green-deal-sc85v00rn. See also REN21, op. cit. note 43, p. 68, and J. Rosenow and R. Lowes, "Heating without the hot air: Principles for smart heat electrification" (Brussels: 2020), p. 22, https://www.raponline.org/knowledge-center/heating-without-hot-air-principles-smart-heat-electrification.

151 REN21, op. cit. note 43, p. 68; M. Gough, "San Francisco, San Jose, and Oakland bring electrification this holiday season", Sierra Club, 3 December 2020, https://www.sierraclub.org/articles/2020/12/san-francisco-san-jose-and-oakland-bring-electrification-holiday-season. The European Commission is considering revising its energy labelling and downgrading fossil gas boilers to the lowest efficiency standard to encourage consumers to opt for cleaner options, from ECOS and CoolProducts, *Five Years Left: How Ecodesign and Energy Labelling Can Decarbonise Heating* (Brussels: 2020), https://ecostandard.org/wp-content/

uploads/2020/12/Five-Years-Left-How-ecodesign-and-energy-labelling-Coolproducts-report.pdf. Further examples of such bans in Rosenow and Lowes, op. cit. note 150, p. 22.

152 Most European countries still provided subsidies for fossil fuel boilers at end-2020, often at levels superior to financial policies that incentivise the use of renewable energy for heating, from F. Tognetti, *Analysis of Existing Incentives in Europe for Heating Powered by Fossil Fuels and Renewable Sources* (Brussels: 2021), https://www.coolproducts.eu/wp-content/uploads/2020/12/Analysis-of-Fossil-Fuel-Incentives-in-Europe_FINAL_.pdf. For example, Italy provides a tax rebate for 110% of the cost of an electric heat pump, yet a similar subsidy is also available for highly efficient gas boilers under certain conditions, from idem. The US state of New York also still has laws that subsidise the expansion of its gas network, from E. Pontecorvo, "He wanted to get his home off fossil fuels. There was just one problem.", Grist, 18 March 2021, https://grist.org/buildings/he-wanted-to-get-his-home-off-fossil-fuels-there-was-just-one-problem.

153 R. Leber, "How the fossil fuel industry convinced Americans to love gas stoves", *Mother Jones*, 11 February 2021, https://www.motherjones.com/environment/2021/02/how-the-fossil-fuel-industry-convinced-americans-to-love-gas-stoves; K. Joshi, "The gas war part 1: The American electrification battlegrounds", Medium, 13 November 2020, https://medium.com/lobbywatch/the-gas-war-part-1-the-american-electrification-battlegrounds-3494ac71d100; R. Lowes, B. Woodman and J. Speirs, "Heating in Great Britain: An incumbent discourse coalition resists an electrifying future", *Environmental Innovation and Societal Transitions*, vol. 37 (December 2020), pp. 1-17, https://www.sciencedirect.com/science/article/pii/S2210422420300964?via%3Dihub; Global Witness, *Pipe Down: How Gas Companies Influence EU Policy and Have Pocketed €4 Billion of Taxpayers' Money* (London: 2020),https://www.globalwitness.org/en/campaigns/oil-gas-and-mining/pipe-down.

154 D. Drugmand, "Unplugged: How the gas industry is fighting efforts to electrify buildings", DeSmog Blog, 22 July 2020, https://www.desmogblog.com/2020/07/22/unplugged-how-gas-industry-fighting-efforts-electrify-buildings; T. DiChristopher, "AGA takes steps to counter gas bans, state opposition to pipelines", S&P Global, 27 January 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/aga-takes-steps-to-counter-gas-bans-state-opposition-to-pipelines-56763558; S. Cagle, "US gas utility funds 'front' consumer group to fight natural gas bans", *The Guardian* (UK), 26 July 2019, https://www.theguardian.com/us-news/2019/jul/26/us-natural-gas-ban-socalgas-berkeley.

155 S. Roth, "SoCalGas should be fined $255 million for fighting climate action, watchdog says", *Los Angeles Times*, 6 November 2020, https://www.latimes.com/environment/story/2020-11-06/southern-california-gas-company-climate-fine-recommended; T. Trimming, "Public Advocates Office opening brief on SoCalGas", 5 November 2020, https://www.documentcloud.org/documents/20402546-public-advocates-office-opening-brief-on-socalgas. The state government of Massachusetts blocked a local policy that banned fossil gas in new buildings and renovations. As of early 2021 as many as nine US states had introduced bills to stop cities from banning natural gas hook-ups in buildings. Arizona was the first state in the country to pass such legislation in 2020. See T. DiChristopher, "Mass. attorney general blocks 1st East Coast gas ban", S&P Global, 21 July 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/mass-attorney-general-blocks-1st-east-coast-gas-ban-59524958; T. DiChristopher, "Gas Ban Monitor: States launch anti-ban blitz as electrification efforts grow", S&P Global Market Intelligence, 29 January 2021, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/gas-ban-monitor-states-launch-anti-ban-blitz-as-electrification-efforts-grow-62336952; N. Groom and R. Valdmanis, "As climate fight intensifies, U.S. states seek to block local natural-gas bans", *Reuters*, 5 March 2020, https://www.reuters.com/article/us-usa-climatechange-naturalgas-idUSKBN20S1G8.

156 D. Ürge-Vorsatz et al., "Advances toward a net-zero global building sector", *Annual Reviews*, vol. 45 (October 2020), pp. 227-69, https://www.annualreviews.org/doi/abs/10.1146/annurev-environ-012420-045843.

157 World Green Building Council (WGBC), "WorldGBC announces 18 new signatories to the Net Zero Carbon Buildings Commitment", 11 December 2020, https://www.worldgbc.org/news-media/worldgbc-announces-18-new-signatories-net-zero-carbon-buildings-commitment; WGBC, "The Net Zero Carbon Buildings Commitment", https://worldgbc.org/thecommitment, viewed 22 March 2021.

158 EC, *A Renovation Wave for Europe – Greening Our Buildings, Creating Jobs, Improving Lives* (Brussels: 2020), https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf; L. Sunderland and M. Santini, "Filling the policy gap: Minimum energy performance standards for European buildings" (Brussels: 2020), https://www.raponline.org/knowledge-center/filling-the-policy-gap-minimum-energy-performance-standards-for-european-buildings.

159 S. Nadel and A. Hinge, *Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals* (Washington, DC: 2020), https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf; Z. Hart, "Behind-the-scenes: Montgomery County's journey to building energy performance standards", Institute for Market Transformation (IMT), 21 April 2021, https://www.imt.org/behind-the-scenes-montgomery-countys-journey-to-building-energy-performance-standards; IMT, *Comparison of U.S. Building Performance Standards* (Washington, DC: 2021), https://www.imt.org/wp-content/uploads/2021/01/IMT-Comparison-of-Building-Performance-Policies-January-2021.pdf.

160 See Policy Landscape chapter. The International Code Council in the 2021 International Energy Code added two voluntary appendices (residential and commercial) that require renewable energy for 100% of the building's energy use; see Zero Code, "Renewable energy portions of the Zero Code added to the 2021 International Energy Conservation Code", July 2020, http://zero-code.org/new-model-building-code-empowers-local-jurisdictions-to-require-zero-net-carbon-operations. In California, new building standards came into force on 1 January that require on-site renewable electricity generation with some allowance for off-site equivalence; see California Energy Commission, "Energy Commission adopts standards requiring solar systems for new homes, first in nation", 9 May 2018, https://www.energy.ca.gov/news/2018-05/energy-commission-adopts-standards-requiring-solar-systems-new-homes-first.

161 IEA, *World Energy Balances 2020*, op. cit. note 47.

162 Ibid.

163 Ibid.; J. Friedmann, Z. Fan and K. Tang, *Low-carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today* (New York: October 2019), https://energypolicy.columbia.edu/sites/default/files/file-uploads/LowCarbonHeat-CGEP_Report_100219-2_0.pdf.

164 IEA, *World Energy Balances 2020*, op. cit. note 47; Friedmann, Fan and Tang, op. cit. note 163.

165 Our World in Data, "Emissions by sector", https://ourworldindata.org/emissions-by-sector, viewed 17 May 2021.

166 The curtailment of economic activity due to the pandemic is forecast to reduce heat consumption in industry by 4.2% in 2020. IEA, *The Covid-19 Crisis and Clean Energy Progress* (Paris: June 2020), https://www.iea.org/reports/the-covid-19-crisis-and-clean-energy-progress/industry#abstract; IEA, op. cit. note 5.

167 The United States is expected to record the largest drop in industrial bioenergy consumption, followed by Brazil and the EU. IEA, op. cit. note 5.

168 IEA, *World Energy Balances 2020*, op. cit. note 47.

169 IRENA Coalition for Action, *Companies in Transition Towards 100% Renewables: Focus on Heating and Cooling* (Abu Dhabi: 2021) https://coalition.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_Coalition_Companies_in_Transition_towards_100_2021.pdf.

170 IEA, *Renewable Energy Market Update: Outlook for 2020 and 2021* (Paris: May 2020), https://www.iea.org/reports/renewable-energy-market-update/technology-summaries#renewable-heat.

171 See Bioenergy section in Market and Industry chapter.

172 IEA. op. cit. note 5. China is also an important user of biomass for heating in both buildings and industry, but this is not reflected in current statistics due to data collection and reporting challenges. See Bioenergy section in Market and Industry chapter.

173 IEA, *Tracking Industry 2020* (Paris: June 2020), https://www.iea.org/reports/tracking-industry-2020; IEA, op. cit. note 5.

174 IRENA Coalition for Action, op. cit. note 169.

175 Ibid.; IEA, *Tracking Industry 2020*, op. cit. note 173.

176 J. W. Lund and A. N. Toth, "Direct utilization of geothermal energy 2020 worldwide review", *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland, April 26-May 2, 2020, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01018.pdf.

177 Ibid.

178 IEA Solar Heating & Cooling Programme, *Solar Heat Worldwide 2020* (Gleisdorf, Austria: 2020), https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2020.pdf.

179 Ibid.

180 BloombergNEF, *BNEF Executive Factbook; Power, Transport, Buildings and Industry, Commodities, Food and Agriculture, Capital* (London: 22 April 2020), https://data.bloomberglp.com/promo/sites/12/678001-BNEF_2020-04-22-ExecutiveFactbook.pdf; IEA, *Pulp and Paper Tracking Report 2020* (Paris: 2020), https://www.iea.org/reports/pulp-and-paper#tracking-progress.

181 IEA, op. cit. note 5.

182 K. Ericsson and L. J. Nilsson, *Climate Innovations in the Paper Industry: Prospects for Decarbonisation*, Reinvent Decarbonisation, 30 September 2018, https://static1.squarespace.com/static/59f0cb986957da5faf64971e/t/5dc1acfb29bc520c15c858fc/1572973823092/%28updated%29D2.4+Climate+innovations+in+the+paper+industry.pdf.

183 S. Matthis, "New biomass boiler inaugurated at Navigator's Figueira da Foz industrial complex", Pulp and Paper News, 21 December 2020, https://www.pulpapernews.com/20201221/12096/new-biomass-boiler-inaugurated-navigators-figueira-da-foz-industrial-complex.

184 Ericsson and Nilsson, op. cit. note 182.

185 S. Matthis, "DS Smith Paper switches to green electrical power in Croatia", Pulp and Paper News, 13 November 2020, https://www.pulpapernews.com/20201113/11961/ds-smith-paper-switches-green-electrical-power-croatia.

186 BloombergNEF, op. cit. note 180.

187 IRENA Coalition for Action, op. cit. note 169; BloombergNEF, op. cit. note 180.

188 Protarget Solar Power Systems, "Orange juice from Cyprus, produced with lots of sun and solar generated steam using Protarget's Concentrating Solar Thermal (CST) technology", https://protarget-ag.com/en/1138, viewed 17 May 2021; "Sunny prospects for Cyprus", CSP Focus, 26 May 2020, http://www.cspfocus.cn/en/market/detail_3033.htm.

189 McCain Foods, "McCain Foods unveils Australia's largest 'behind-the-meter' renewable energy system", 14 July 2020, https://www.mccain.com/information-centre/news/mccain-foods-unveils-australia-s-largest-behind-the-meter-renewable-energy-system.

190 U. Gupta, "SunAlpha installs 12 MW rooftop solar for food processing", pv magazine, 13 October 2020, https://www.pv-magazine-india.com/2020/10/13/sunalpha-installs-12-mw-rooftop-solar-for-food-processing.

191 Two Birds, *Renewables for Mining in Africa* (London: 2020), https://www.twobirds.com/~/media/pdfs/expertise/energy-and-utilities/2020/renewables-for-mining-in-africa.pdf; A. Fawthrop, "Why the mining industry must continue to embrace renewable energy", NS Energy, 20 March 2020, https://www.nsenergybusiness.com/features/renewable-energy-mining-bnef.

192 Two Birds, op. cit. note 191.

193 N. Maennling and P. Toledano, *The Renewable Power of the Mine* (New York: Columbia Center on Sustainable Investment: December 2018), p. 17, https://rue.bmz.de/includes/downloads/CCSI_2018_-_The_Renewable_Power_of_The_Mine__mr_.pdf.

194 "Mining & Renewable energy – a greener way forward", Renewables Now, 24 November 2020, https://renewablesnow.com/news/mining-renewable-energy-a-greener-way-forward-721937.

195 D. Benton, "Chile's Zaldivar mine to operate with 100% renewable energy", Mining Global, 17 May 2020, https://miningglobal.com/sustainability-1/chiles-zaldivar-mine-operate-100-renewable-energy; Two Birds, op. cit. note 191; L. Cornish, "Renewable energy uptake in mining gathers momentum", Mining Review Africa, 22 May 2020, https://www.miningreview.com/energy/renewable-energy-uptake-in-mining-gathers-momentum; Rio Tinto, "Rio Tinto to build first solar plant in Western Australia to power iron ore mine", 16 February 2020, https://www.riotinto.com/news/releases/2020/Rio-Tinto-to-build-first-solar-plant-in-Western-Australia-to-power-iron-ore-mine; D. Mavrokefalidis, "Australian gold mine to be decarbonised by 56MW hybrid renewable project", 26 May 2020, https://www.energylivenews.com/2020/05/26/australian-gold-mine-to-be-decarbonised-by-56mw-hybrid-renewable-project; R. Warrier, "Finland's Wärtsilä to equip 44MW solar plant at Saudi gold mine", Construction Week, 9 April 2020, https://www.constructionweekonline.com/projects-and-tenders/264350-finlands-wartsila-to-equip-44mw-solar-plant-at-saudi-gold-mine.

196 G. Parkinson, "Fortescue leads 'stampede' into green energy with stunning plans for 235 gigawatts of wind and solar", RenewEconomy, 12 November 2020, https://reneweconomy.com.au/fortescue-leads-stampede-into-green-energy-with-stunning-plans-for-235-gigawatts-of-wind-and-solar-27936.

197 IEA, *Energy Technology Perspectives 2020* (Paris: September 2020), https://www.iea.org/reports/energy-technology-perspectives-2020.

198 IEA, *World Energy Balances 2020*, op. cit. note 47. Renewables accounted for 0.68% of the total energy consumption in iron and steel, chemicals and petrochemicals, and non-metallic minerals (chemicals) together, as of 2018.

199 IEA, op. cit. note 197.

200 T. K. Blank and P. Molly, *Hydrogen's Decarbonization Impact for Industry: Near-term Challenges and Long-term Potential* (Basalt, CO: RMI, January 2020), https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf; A. Griffin, "Hydrogen, enabling decarbonisation in heavy industry", HSBC, 22 April 2020, https://www.sustainablefinance.hsbc.com/carbon-transition/hydrogen-enabling-decarbonisation-in-heavy-industry; IRENA, op. cit. note 62.

201 Climate Champions, "Green Hydrogen Catapult", https://racetozero.unfccc.int/green-hydrogen-catapult, viewed 17 May 2021

202 IRENA, op. cit. note 62.

203 Ibid.

204 Ibid.

205 Ibid.

206 Australian Renewable Energy Agency, *ENGIE-YARA Renewable Hydrogen and Ammonia Deployment in Pilbara* (Canberra: October 2020), https://arena.gov.au/assets/2020/11/engie-yara-renewable-hydrogen-and-ammonia-deployment-in-pilbara.pdf.

207 Green Car Congress, "Nouryon-led consortium wins €11M EU backing for green hydrogen project", 23 January 2020, https://www.greencarcongress.com/2020/01/20200123-nouryon.html.

208 "BioBTX takes significant step towards a commercial plant", Bioplastics Magazine, 21 January 2020, https://www.bioplasticsmagazine.com/en/news/meldungen/20200121-BioBTX-takes-significant-step-towards-a-commercial-plant.php.

209 IRENA, op. cit. note 62.

210 Ibid.

211 Ibid.

212 World Steel Association, *2020 World Steel in Figures*, 30 April 2020, https://www.worldsteel.org/en/dam/jcr:f7982217-cfde-4fdc-8ba0-795ed807f513/World%2520Steel%2520in%2520Figures%25202020i.pdf.

213 M. Pooler, "'Green steel': the race to clean up one of the world's dirtiest industries", *Financial Times*, 15 February 2021, https://www.ft.com/content/46d4727c-761d-43ee-8084-ee46edba491a; Bocconi Students Investment Club, "Green steel – the next largest industrial investment?" https://bsic.it/green-steel-the-next-largest-industrial-investment, viewed 17 May 2021.

214 "Sweden's HYBRIT starts operations at pilot plant for fossil-free steel", *Reuters*, 31 August 2020, https://www.reuters.com/article/us-sweden-steel-hydrogen-idUSKBN25R1PI.

215 LKAB, "LKAB produces the world's first iron ore pellets with fossil-free fuels", 2 November 2020, https://www.lkab.com/en/news-room/news/lkab-produces-the-worlds-first-iron-ore-pellets-with-fossil-free-fuels.

216 L. Paulsson, J. Starn and E. Spence, "Spotify billionaire Ek among investors in green steel startup", Bloomberg, 23 February 2021, https://www.bloomberg.com/news/articles/2021-02-23/hydrogen-to-power-large-green-steel-plant-in-sweden-from-2024.

217 L. Varriale, "Germany's Thyssenkrupp to build DRI plant run on hydrogen for green steel production", S&P Global Platts, 28 August 2020, https://www.spglobal.com/platts/en/market-insights/latest-news/metals/082820-germanys-thyssenkrupp-to-build-dri-plant-run-on-hydrogen-for-green-steel-production.

218 IRENA, op. cit. note 62.

219 Ibid.

220 Ibid.

221 Ibid.

222 M. Mace, "Manufacturers aim for carbon-neutral cement by 2050", Edie, 1 September 2020, https://www.edie.net/news/6/Manufacturers-aim-for-carbon-neutral-cement-by-2050; "UK concrete and cement industry claims it can 'go beyond net-zero' by 2050", Edie, 6 October 2020, https://www.edie.net/news/6/UK-concrete-and-cement-industry-claims-it-can--go-beyond-net-zero--by-2050; "Dominican Republic cement industry targets 33% carbon reduction by 2030", Cemnet, 2 December 2020, https://www.cemnet.com/News/story/169963/dominican-republic-cement-industry-targets-33-carbon-reduction-by-2030.html; CEMBUREAU, "2050 Carbon Neutrality Roadmap", 12 May 2020, https://cembureau.eu/library/reports/2050-carbon-neutrality-roadmap.

223 R. Leese, "Putting our energies into carbon-cutting research", MPA UK Concrete, 2 April 2020, https://www.thisisukconcrete.co.uk/Perspectives/Putting-our-energies-into-carbon-cutting-research.aspx.

224 S. George, "Major renewable hydrogen demo project comes online at Welsh cement plant", Industrial News, 11 February 2021, https://industrialnews.co.uk/major-renewable-hydrogen-demo-project-comes-online-at-welsh-cement-plant.

225 A. Gillod, Climate Chance, presentation at "Mobilités durables – Accélérer et réussir" conference, 15 January 2021.

226 International Civil Aviation Organization (ICAO), "2020 passenger totals drop 60 percent as COVID-19 assault on international mobility continues", 15 January 2021, https://www.icao.int/Newsroom/Pages/2020-passenger-totals-drop-60-percent-as-COVID19-assault-on-international-mobility-continues.aspx; rail from IEA, "Long-distance transport", in *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020/long-distance-transport; United Nations Conference on Trade and Development, "COVID-19 cuts global maritime trade, transforms industry", 12 November 2020, https://unctad.org/news/covid-19-cuts-global-maritime-trade-transforms-industry.

227 Gillod, op. cit. note 225; IEA, "Urban transport", in *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020/urban-transport#abstract. In many parts of Asia, especially China, public transport was more or less back to normal by the second half of 2020, from SLOCAT Partnership on Sustainable, Low Carbon, "COVID-19 and mobility – an updated analysis of regional impacts", 28 October 2020, https://slocat.net/covid-19-and-mobility-update.

228 IEA, *Global EV Outlook 2021* (Paris: 2021), https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf; 14% from L. Cozzi and A. Petropoulos, "Carbon emissions fell across all sectors in 2020 except for one – SUVs", IEA, 15 January 2021, https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs. Also, many car dealerships closed in major markets such as China, Europe and the United States, from T. Furcher et al., "How consumers' behavior in car buying and mobility is changing amid COVID-19", McKinsey & Company, 22 September 2020, https://www.mckinsey.com/business-functions/marketing-and-sales/our-insights/how-consumers-behavior-in-car-buying-and-mobility-changes-amid-covid-19. See also: ZSW, "Data Service Renewable Energies", https://www.zsw-bw.de/en/media-center/data-service.html, viewed 27 May 2021; R. Irle, "Global plug-in vehicle sales reached over 3,2 million in 2020", EV-Volumes, www.ev-volumes.com, viewed 27 May 2021.

229 As of 2020, around 25% of all two-wheelers on the road were electric, over 95% of which were in China, and most of the rest were in India and South-East Asian countries. Sales of electric two-/three-wheelers increased 30% in Europe in 2020. IEA, op. cit. note 228; IEA, *Electric Vehicles* (Paris: 2020), https://www.iea.org/reports/electric-vehicles.

230 On average, SUVs consume over 20% more energy than a mid-sized passenger car for the same distance travelled. Cozzi and Petropoulos, op. cit. note 228.

231 Demand fell particularly during the second quarter of 2020, as the sector was heavily impacted by mobility restrictions linked to Covid-19. It had nearly rebounded to pre-pandemic levels by mid-2021, and is expected to return to 2019 levels by the end of 2021. IEA, "Oil", in *Global Energy Review 2021* (Paris: 2021), https://www.iea.org/reports/global-energy-review-2021/oil.

232 Ibid.

233 Based on IEA, *World Energy Balances 2020*, op. cit. note 47

234 Ibid.

235 Numbers may not add up to 100% due to rounding. IEA, *World Energy Balances 2020*, op. cit. note 47; IEA, "Transport", in *Renewables 2019* (Paris: 2019), https://www.iea.org/reports/renewables-2019/transport.

236 Based on IEA, *World Energy Balances 2020*, op. cit. note 47

237 Larger size of vehicles leads to higher energy consumption and emissions, from International Transport Forum (ITF), *Lightening Up: How Less Heavy Vehicles Can Help Cut CO_2 Emissions* (Paris: 2017), p. 7, https://www.itf-oecd.org/sites/default/files/docs/less-heavy-vehicles-cut-co2-emissions.pdf. See also: L. Cozzi and A. Petropoulos, "Growing preference for SUVs challenges emissions reductions in passenger car markets", IEA, 15 October 2020, https://www.iea.org/commentaries/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-market; IEA, "Energy Efficiency Indicators database (2020 edition) – extended version" (Paris: 2020), http://data.iea.org/payment/products/120-energy-efficiency-indicators-2018-edition.aspx; IEA, *World Energy Balances 2020*, op. cit. note 47; IEA, *Energy Efficiency 2019: Analysis and Outlook to 2040* (Paris: 2019), https://www.iea.org/efficiency2019.

238 SLOCAT, "Transport and Climate Change Global Status Report (TCC-GSR): Tracking transport emissions trends, raising transport policy ambition", December 2018, https://slocat.net/2011-2; SLOCAT, *Transport and Climate Change Global Status Report 2018* (Brussels: 2018), p. 2, http://www.slocat.net/wp-content/uploads/legacy/slocat_transport-and-climate-change-2018-web.pdf.

239 Energy intensity has not decreased as much for freight due to vehicle attributes, payloads and lack of supportive policy frameworks to incentivise improvements. SLOCAT, *Transport and Climate Change Global Status Report 2018*, op. cit. note 238, p. 2.

240 This global increase has occurred even as transport emissions in some regions (such as the EU and the United States) have fallen. Whereas total CO_2 emissions in the EU decreased 20% between 1990 and 2017, emissions from the transport sector increased 27%, from ITF, "Is low-carbon road freight possible?" 6 December 2018, https://www.itf-oecd.org/low-carbon-road-freight. Similarly, US transport sector emissions surpassed those of the power sector in 2017, from J. Runyon, "6 key trends in sustainable and renewable energy", Renewable Energy World, 15 February 2019, https://www.renewableenergyworld.com/baseload/6-key-trends-in-sustainable-and-renewable-energy/#gref. L. Cozzi and A. Petropoulos, op. cit. note 228. 2018 emissions and 2020 emissions drop estimate from: ITF, *ITF Transport Outlook 2021* (Paris: 2021), p. 24, https://read.oecd-ilibrary.org/transport/itf-transport-outlook-2021_16826a30-en#page24.

241 Numbers may not add up to 100% due to rounding. Another 2% is attributed to pipeline and non-specified transport. IEA, "Transport sector CO_2 emissions by mode in the Sustainable Development Scenario, 2000-2030", 22 November 2019, https://www.iea.org/data-and-statistics/charts/transport-sector-co2-emissions-by-mode-in-the-sustainable-development-scenario-2000-2030.

242 Plug-in hybrids differ from simple hybrid vehicles, as the latter use electric energy produced only by braking or through the vehicle's internal combustion engine. Therefore, only plug-in hybrid EVs allow for the use of electricity from renewable sources. Although not an avenue for increased penetration of renewable electricity, hybrid vehicles contribute to reduced fuel demand and remain far more numerous than EVs. Electro-fuels, also known as e-fuels, are synthetic fuels that do not chemically differ from conventional fuels such as diesel or petrol, generated in procedures known as power-to-liquids and power-to-gas. Renewable electro-fuels are generated exclusively from electricity from renewable sources. See Verband der Automobilindustrie, "Synthetic fuels – power for the future", https://www.vda.de/en/topics/environment-and-climate/e-fuels/synthetic-fuels.html, viewed 1 May 2019, and N. Aldag, "Role for e-fuels in EU transport?" Sunfire, 12 January 2018, https://www.transportenvironment.org/sites/te/files/Industry%20perspectives%20on%20the%20future%20development%20of%20electrofuels%2C%20Nils%20Aldag.pdf. See also IRENA, IEA and REN21, op. cit. note 83, Figure 3.4, p. 41.

243 See Bioenergy section in Market and Industry chapter. Based on national biofuels data as referenced below; biofuels supplemented by data from IEA, *Oil 2021* (Paris: March 2021), https://www.iea.org/reports/oil-2021.

244 Ibid.

245 Renewable diesel is also called hydrogenated vegetable oil (HVO) or hydrogenated esters of fatty acids (HEFA). This is produced by taking vegetable oils and other bio-based oils and liquids, including waste materials such as used cooking oil, and treating them with hydrogen, which removes the oxygen and produces a hydrocarbon which can be refined to a product which has fuel qualities equivalent to fossil-based diesel. The refining process also produced bio-based LPG and can be tuned to produce other fuels including biojet. Renewable diesel can be used mixed in any proportion with fossil diesel or on its own. Production estimate is based on analysis of existing and new capacity as shown in Biofuels Digest, "50 renewable diesel projects and the technologies behind them", 8 February 2021, https://www.biofuelsdigest.com/bdigest/2021/02/08/50-renewable-diesel-projects-and-the-technologies-behind-them, and research on specific plant outputs. See Bioenergy industry section in Market and Industry chapter for more detailed information.

246 IEA, *World Energy Balances 2020*, op. cit. note 47.

247 For example, in the EU where the renewable share of electricity is higher than in other most regions, EV emissions over the entire vehicle life cycle were estimated to be 17-30% lower than those of petrol or diesel vehicles, from European Environment Agency, "EEA report confirms: Electric cars are better for climate and air quality", 22 November 2018, https://www.eea.europa.eu/highlights/eea-report-confirms-electric-cars.

248 The estimation of EVs being more efficient than conventional vehicles can be attributed in part to the fact that the energy losses of converting primary energy to electricity (as well as transport and distribution losses) are often underestimated, from IEA, *Global EV Outlook 2020* (Paris: 2020), https://www.iea.org/reports/global-ev-outlook-2020.

249 See, for example: T. Casey, "100% renewable energy for 2,700 new EV fast charging stations in USA", CleanTechnica, 31 July 2020, https://cleantechnica.com/2020/07/31/100-renewable-energy-for-2700-new-ev-fast-charging-stations-in-usa; K. Silverstein, "Solar-powered electric vehicle charging stations are just around the corner", *Forbes*, 10 February 2020, https://www.forbes.com/sites/kensilverstein/2020/02/10/solar-powered-electric-vehicle-charging-stations-are-just-around-the-corner; J. Butler, "New electric boat charging stations and networks for Norway, Venice", Plugboats, 27 April 2021, https://plugboats.com/new-electric-boat-charging-networks-norway-venice.

250 IEA, *Hydrogen* (Paris: 2021), https://www.iea.org/reports/hydrogen; Argus, "China's Sinopec outlines hydrogen aspirations", 24 February 2021, https://www.argusmedia.com/en/news/2189848-chinas-sinopec-outlines-hydrogen-aspirations; J. Jolly, "Hydrogen fuel bubbles up the agenda as investments rocket", *The Guardian* (UK), 28 June 2020, https://www.theguardian.com/environment/2020/jun/28/hydrogen-fuel-bubbles-up-the-agenda-as-investments-rocket; IEA, "Hydrogen", https://www.iea.org/fuels-and-technologies/hydrogen, viewed 24 May 2021.

251 Sustainable Mobility for All, *Global Roadmap of Action: Toward Sustainable Mobility* (2019). http://pubdocs.worldbank.org/en/350451571411004650/Global-Roadmap-of-Action-Toward-Sustainable-Mobility.pdf; IRENA, *NDCs in 2020: Advancing Renewables in the Power Sector and Beyond* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_NDCs_in_2020.pdf; IEA, Tracking Transport (Paris: 2020), https://www.iea.org/reports/tracking-transport-2020; *Transport and Environment, Draft National Energy and Climate Plans Transport Ranking* (Brussels: 2019), https://www.transportenvironment.org/sites/te/files/publications/2020_06_Draft_NECP_transport_analysis_final.pdf.

252 Based on first-generation NDCs. ITF, "How transport CO_2 reduction pledges fall short", 20 November 2018, https://www.itf-oecd.org/co2-reduction-pledges.

253 Based on REN21 research on NDCs, from REN21 Policy Database. See GSR 2021 Data Pack, available at www.ren21.net/gsr-2021.

254 REN21 op. cit. note 43.

255 Despite the necessary role that renewable energy would play in decarbonising the transport sector, many adaptations of the ASI framework have failed to include renewables or to mention the source of energy under the improve section, focusing only on energy efficiency. See improved ASI framework: Figure 60 in REN21, *Renewables 2020 Global Status Report* (Paris: 2020), https://www.ren21.net/gsr-2020/chapters/chapter_07/chapter_07; Figure 2.1 in REN21 and FIA Foundation, *Renewable Energy Pathways in Road Transport* (London: November 2020), p. 17, https://www.ren21.net/wp-content/uploads/2019/05/REN21_FIA-Fdn_Renewable-Energy-Pathways_FINAL.pdf; H.E. Murdock, "Decarbonising the transport sector with renewables requires urgent action", 18 November 2020, https://www.ren21.net/decarbonise-transport-sector-2020; SLOCAT, *Transport and Climate Change Global Status Report 2018*, op. cit. note 238.

256 LDVs represent about 88.7% of the transport energy demand among passenger vehicles (excluding freight), the remainder from buses (8%) and 2- and 3-wheelers (3.3%). US EIA, "Transportation sector passenger transport and energy consumption by region and mode", in *International Energy Outlook 2019* (Washington, DC: 2019), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=50-IEO2019&region=0-0&cases=Reference&start=2010&end=2020&f=A&linechart=Reference-d080819.2-50-IEO2019&sourcekey=0.

257 Data from 2018 (latest available). IEA, *World Energy Balances 2020*, op. cit. note 47.

258 See Policy Landscape chapter, and **Reference Table R8** in GSR 2021 Data Pack, www.ren21.net/gsr-2021.

259 C. Huizenga, personal communication with REN21, 13 April 2020.

260 Irle, op. cit. note 228; M. Gorner and L. Paoli, "How global electric car sales defied Covid-19 in 2020", IEA, 28 January 2021, https://www.iea.org/commentaries/how-global-electric-car-sales-defied-covid-19-in-2020.

261 Austria and Japan provide incentives to EV owners when they use renewable electricity for charging, while Germany offers support for charging infrastructure using renewable electricity. Klimaaktiv, op. cit. note 68; BMVI, op. cit. note 68; "Japan to offer up to ¥800,000 in subsidies for electric vehicles", op. cit. note 68. Previously, a policy linking renewables and EVs was in place in Luxembourg, but it was no longer in place as of 2017.

262 See Policy Landscape chapter, and data for **Figure 15** in GSR 2021 Data Pack, www.ren21.net/gsr-2021.

263 See Policy Landscape chapter, and **Reference Table R8** in GSR 2021 Data Pack, www.ren21.net/gsr-2021. These targets primarily incentivise increased EV uptake. However, while not a full ban on internal combustion engine vehicles, restrictions on vehicles using fossil fuels also have the potential to stimulate interest in biogas vehicles that result in fewer emissions, as well as interest in increased biofuel use in hybrid vehicles, as a major part of a transition towards complete electrification where bans on internal combustion engine vehicles are envisioned. For example, hybrid vehicles are still allowed to enter the city centre of Madrid (Spain), which has put in place bans on petrol and diesel cars registered before 2000 and 2006, respectively, from J. Porter, "Madrid's ban on polluting vehicles cuts traffic by nearly 32 percent in some areas", The Verge, 3 December 2018, https://www.theverge.com/2018/12/3/18123561/vehicle-emissions-pollution-ban-madrid-spain-traffic-decrease. Increased interest in biogas, for example in the UK, from K. Dickinson, "Waitrose to run HGV fleet on biomethane", Resource, 30 July 2018, https://resource.co/article/waitrose-run-hgv-fleet-biomethane-12768; A. Sherrard, "Biomethane reaches 91% share in expansive Swedish vehicle gas market", Bioenergy International, 22 February 2019, https://bioenergyinternational.com/markets-finance/biomethane-reaches-91-share-in-expansive-swedish-vehicle-gas-market; biofuels in hybrid vehicles from R. Ocone, "Does the 2040 ban on new petrol and diesel cars mean the death of biofuels?" The Conversation, 30 July 2017, https://theconversation.com/does-the-2040-ban-on-new-petrol-and-diesel-cars-mean-the-death-of-biofuels-81765.

264 However, in many cases, low-emission zones mainly affect older diesel vehicles rather than entirely banning fossil fuel vehicles. REN21, op. cit. note 43.

265 **General Motors** has committed to phase out gas and diesel vehicles worldwide by 2035 and plans to become carbon-neutral by 2040, from E. Hannon, "General Motors says it will stop making gas-powered vehicles by 2035", Slate, 29 January 2021, https://slate.com/news-and-politics/2021/01/general-motors-gm-zero-emission-gas-powered-vehicles.html, and from "General Motors announces plan for all-electric lineup by 2035", *The Guardian* (UK), 28 January 2021, https://www.theguardian.com/environment/2021/jan/28/gm-electric-vehicles-cars-gas-diesel. Nissan aims for all new vehicles to be electric in key markets by early 2030s, from **Nissan**, "Nissan sets carbon neutral goal for 2050", 27 January 2021, https://global.nissannews.com/en/releases/

release-18e8181d3a7c563be5e62225a70c61b2-nissan-sets-carbon-neutral-goal-for-2050. **Ford** aims for all car sales in Europe to be electric by 2030 and will double investments in electric development until 2025, to USD 22 billion, from C. Isidore, "Ford is investing $1 billion in Germany as it goes electric in Europe", CNN, 17 February 2021, https://edition.cnn.com/2021/02/17/business/ford-europe-electric-vehicles/index.html. **Volvo and Daimler** announced a new joint venture aimed at developing, producing and commercialising hydrogen fuel cells for the heavy-duty vehicle industry, from J. S. Hill, "Volvo and Daimler to develop fuel cell systems for heavy vehicles", The Driven, 22 April 2020, https://thedriven.io/2020/04/22/volvo-and-daimler-to-develop-and-fuel-cell-systems-for-heavy-vehicles. **Isuzu**, while not committing to EV targets, announced a target for net zero greenhouse gases across the entire lifecycle of Isuzu Group products and from Isuzu Group operations by 2050 as well as 100% recycling of waste and end-of-use vehicles by 2050, from Isuzu, "Isuzu announces formulation of Isuzu Environmental Vision 2050", 2 March 2020, https://www.isuzu.co.jp/world/press/2020/3_2.html.

266 Challenges include a lack of charging infrastructure, a lack of battery-swapping stations in many areas, a lack of standardisation of charging infrastructure, and the potential environmental and social impacts of sourcing raw materials for battery production. See, for example, the following: Chargepoint, "An employer's guide to EV charging in the workplace", https://incisive.cvtr.io/lp/chargepoint-bg1?wp=2291&locale=1&msgid=577553-f0bac4483b40ec99, viewed 15 April 2019; Alternative Fuels Observatory, "Fuel map", https://www.eafo.eu/fuel-map, viewed 14 March 2019; Runyon, op. cit. note 240; J. Ward and A. Upadhyay, "India's rickshaw revolution leaves China in the dust", Bloomberg, 25 October 2018, https://www.bloomberg.com/news/features/2019-10-25/india-s-rickshaws-outnumber-china-s-electric-vehicles. Standardisation of charging infrastructure from S. Bajaj, "New EV charging station guidelines announced", Mercom India, 18 December 2018, https://mercomindia.com/ev-charging-station-guidelines-announced; potential environmental and social impacts from SLOCAT, *Transport and Climate Change Global Status Report 2018*, op. cit. note 238, p. 92; V2G from, for example, J. Spector, "EMotorWerks is using its network of 10,000 EV chargers to bid into wholesale markets", Greentech Media, 25 September 2018, https://www.greentechmedia.com/articles/read/emotorwerks-wholesale-markets-ev-charger-network.

267 L. Collins, "Engie and Fiat-Chrysler join forces to build world's largest vehicle-to-grid project", Recharge, 26 May 2020, https://www.rechargenews.com/transition/engie-and-fiat-chrysler-join-forces-to-build-worlds-largest-vehicle-to-grid-project/2-1-814744; PEI, "France to kickstart Europe rollout of ABB vehicle-to-grid solution", 15 October 2020, https://www.powerengineeringint.com/smart-grid-td/ev-infrastructure/abbs-new-v2g-tech-selected-for-rollout-by-edf-subsidiary; EDF, "Flexitanie, l'énergie devient plus flexible grâce au V2G en Occitanie", 22 October 2020, https://www.edf.fr/collectivites/le-mag/le-mag-collectivites/territoires-realisations/flexitanie-l-energie-devient-plus-flexible-grace-au-v2g-en-occitanie; T. Hill, "From parking to power: Major vehicle to grid electricity trial ready for take off", Business Green, 7 August 2020, https://www.businessgreen.com/news/4018725/parking-power-major-vehicle-grid-electricity-trial-ready; M. Lempriere, "World's largest V2G project dubbed Bus2Grid launched in London", Current News, 13 August 2020, https://www.current-news.co.uk/news/worlds-largest-v2g-project-dubbed-bus2grid-launched-in-london; M. Lempriere, "V2G project launched at London's Islington Town Hall by Honda and Moixa", Energy Storage News, 17 January 2020, https://www.energy-storage.news/news/v2g-project-launched-at-islington-town-hall-by-moixa-and-honda; Automotive World, "Nissan LEAF to light up Australia: Industry-first vehicle-to-grid charging technology launched at Realising Electric Vehicles Services (REVS) in ACT", 7 July 2020, https://www.automotiveworld.com/news-releases/nissan-leaf-to-light-up-australia-industry-first-vehicle-to-grid-charging-technology-launched-at-realising-electric-vehicles-services-revs-in-act.

268 Collins, op. cit. note 267.

269 ITF, "Towards road freight decarbonisation", 5 December 2018, https://www.itf-oecd.org/towards-road-freight-decarbonisation.

270 "Why automakers are driving for uniform fuel efficiency standards", University of Pennsylvania – Knowledge @ Wharton, 14 June 2019, https://knowledge.wharton.upenn.edu/article/end-california-emissions-standards.

271 ITF, op. cit. note 240.

272 EC, "Reducing CO_2 emissions from heavy-duty vehicles", https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en, viewed 27 May 2021.

273 Although not all from renewable sources, many alternative fuels are already commercially viable, and technological development continues. Alternative fuels for heavy-duty vehicles refer to alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine and are not exclusively from renewable sources. Alternative fuels include biofuels, synfuels or low-carbon liquid fuels produced from agriculture crops or waste, liquefied natural gas (LNG) or compressed natural gas (CNG), and biomethane. Other propulsion systems that are reaching commercial viability include hydrogen fuel cells, battery electric and hybrid vehicles, and electric roads (electric-powered vehicles where the energy source is external, for example through overhead wires). Other options under development are vehicle-integrated solar PV and the use of solar PV for road surfaces to charge vehicles while they are in motion. ITF, op. cit. note 269.

274 M. Bates, "CARB adopts rule requiring state transition from diesel trucks", NGT News, 26 June 2020, https://ngtnews.com/carb-adopts-rule-requiring-state-transition-from-diesel-trucks.

275 W. Owen, "Gasum expands its LNG filling station network", LNG Industry, 15 June 2020, https://www.lngindustry.com/liquid-natural-gas/15062020/gasum-expands-its-lng-filling-station-network.

276 Bioenergy Insight, "Volvo Trucks reports increased interest in LNG and bio-LNG", 23 September 2020, https://www.bioenergy-news.com/news/volvo-trucks-reports-increased-interest-in-lng-and-bio-lng; Bioenergy Insight, "Finnish freight firm Posti invests in biogas truck fleet", 28 October 2020, https://www.bioenergy-news.com/news/finnish-freight-firm-posti-invests-in-biogas-truck-fleet.

277 For more on biofuels and EV efforts in cities, see REN21, op. cit. note 43. Sustainable Bus, "Electric bus, main fleets and projects around the world", 19 May 2020, https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world. An example of renewable energy charging stations is the bus charging station in Jinjiang's Binjiang Business District (Fujian Province, China), which was charging its electric buses using solar power as of end-2019. CNESA, "2019 sees new solar-storage-charging stations launched across China", 29 November 2019, http://en.cnesa.org/latest-news/2019/11/29/et8hrtqdeblp7knrz3rjl6bg4ohjlt. Many other charging stations that use solar EV and energy storage have been developed in China since 2017. Also, to incentivise increased public transport use, some cities have made public transport free. In 2018, Luxembourg became the first country to pledge to make all of its public transport free for users by 2020, although these initiatives are often mainly to decrease congestion and local pollution, from D. Boffey, "Luxembourg to become first country to make all public transport free", *The Guardian* (UK), 5 December 2018, http://www.theguardian.com/world/2019/dec/05/luxembourg-to-become-first-country-to-make-all-public-transport-free.

278 See, for example: "963 railway stations solarised, 550 more to get rooftop solar panels soon: Indian Railways", *Economic Times*, 31 August 2020, https://economictimes.indiatimes.com/industry/transportation/railways/963-railway-stations-solarised-550-more-to-get-rooftop-solar-panels-soon-indian-railways/articleshow/77853689.cms; Biofuels International, "18 new biodiesel fuelled trains coming to the Netherlands", 13 July 2017, https://biofuels-news.com/news/18-new-biodiesel-fuelled-trains-coming-to-the-netherlands.

279 India's rail electrification target includes also advancing plans to integrate rising amounts of renewable power capacity (among other sustainability improvements). "Indian Railways gears up to become 'Green Railway' by 2030", *Economic Times*, 13 July 2020, https://energy.economictimes.indiatimes.com/news/power/indian-railways-gears-up-to-become-green-railway-by-2030/76938990. France's national railway company committed to meeting a portion of its electricity needs using renewable electricity and signed a renewable electricity PPA for 2% of the electricity consumption of all national passenger trains. C. Rollet, "French railway operator buys 40 MW of power through solar PPA", pv magazine, 18 June 2020, https://www.pv-magazine.com/2020/06/18/french-railway-operator-buys-40-mw-of-power-through-solar-ppa.

280 Around three-quarters of passenger rail transport, and nearly half of freight rail transport globally, is electric, from IEA, *The Future of*

Rail (Paris, 2019), https://www.iea.org/reports/the-future-of-rail. Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

281 Based on IEA, *World Energy Balances 2020*, op. cit. note 47.

282 See, for example: "Dutch electric trains become 100% powered by wind energy", *Agence France-Presse*, 10 January 2017, https://www.theguardian.com/world/2018/jan/10/dutch-trains-100-percent-wind-powered-ns; the Swiss railway company SBB CFF FFS sources 75% of its power from hydropower, from International Union of Railways (UIC), *Railway Statistics: Synopsis* (Paris: 2017), https://uic.org/IMG/pdf/uic-statistics-synopsis-2017.pdf.

283 O. Cuenca, "Indian Railways targets net zero emissions by 2030", International Railway Journal, 16 July 2020, https://www.railjournal.com/technology/indian-railways-to-achieve-net-zero-emissions-by-2030; Carbon Intelligence, "Network Rail", https://carbon.ci/case-studies/network-rail-becomes-the-first-railway-organisation-to-set-science-based-targets-aligned-to-1-5-degrees, viewed 10 May 2021.

284 IEA, *World Energy Balances 2020*, op. cit. note 47. Emissions as of 2018 (latest data) from International Maritime Organization (IMO), *Fourth IMO Greenhouse Gas Study* (Geneva: 2020), p. 1, https://wwwcdn.imo.org/localresources/en/MediaCentre/Documents/Fourth%20IMO%20GHG%20Study%202020%20Executive%20Summary.pdf.

285 Biofuels International,"Netherlands examines biofuels' law changes to meet RED II targets", 11 December 2020, https://biofuels-news.com/news/netherlands-examines-biofuels-law-changes-to-meet-red-ii-targets.

286 Energie zukunft, "Schifffahrtsbranche will sich grünen Anstrich geben", https://www.energiezukunft.eu/mobilitaet/schifffahrtsbranche-will-sich-gruenen-anstrich-geben, viewed 26 January 2021.

287 N. Chestney, "IMO agrees on stricter efficiency targets for some ships", *Reuters*, 17 May 2020, https://www.reuters.com/article/us-imo-shipping-efficiency/imo-agrees-on-stricter-efficiency-targets-for-some-ships-idUSKCN1SN2BV; International Shipping News, "New fuel, emission standards for shipping from January", Hellenic Shipping, 30 December 2020, https://www.hellenicshippingnews.com/new-fuel-emission-standards-for-shipping-from-january; Euronews, "Shipping industry plans speed limit reductions to cut emissions", 13 May 2020, https://www.euronews.com/2020/05/13/shipping-industry-plans-speed-limit-reductions-to-cut-emissions; M. Wingrove, "IMO sets new emissions-cutting goals for ship-port interfaces", Riviera, 22 May 2020, https://www.rivieramm.com/news-content-hub/news-content-hub/imo-sets-new-maritime-emissions-cutting-goals---though-technology-59494. Previously, in 2019, the IMO had adopted energy efficiency standards for international shipping, targeting a 40% reduction in total carbon intensity by 2030 and a 50% reduction in overall greenhouse gas emissions for the sector by 2050, relative to 2008 levels, from IMO, "UN body adopts climate change strategy for shipping", 13 April 2019, http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx.

288 For an example using wind, see M. Schaus, "Greening our shipping: Wind-powered cargo ships can change future of freight cutting emissions by 90%", Good News Network, 24 October 2020, https://www.goodnewsnetwork.org/oceanbird-prototype-cuts-cargo-ship-emissions-by-90pt.

289 For example: 100% renewably fuelled ferry fleet, from Biofuel Express, "Take the ferry to the Copenhagen Opera with Neste MY Renewable Diesel HVO", https://www.biofuel-express.com/en/take-the-ferry-to-the-copenhagen-opera-with-neste-my-renewable-diesel-hvo, viewed 27 May 2021; hybrid ferry fleet with storage but fossil fuel-based from Wärtsilä, "Three new Finnlines ships to go green with Wärtsilä Hybrid Systems", 5 February 2020, https://www.wartsila.com/media/news/05-02-2020-three-new-finnlines-ships-to-go-green-with-wartsila-hybrid-systems-2632097.

290 Bioenergy Insight, "Finnish firms testing liquefied biogas as shipping fuel", 12 June 2020, https://www.bioenergy-news.com/news/finnish-firms-testing-liquefied-biogas-as-shipping-fuel. In 2019, some shipping companies in Scandinavia entered into agreements to use LBG, from Scandinavia: "Preem signs agreement for renewable maritime fuel", Renewable Energy Magazine, 25 March 2020, https://www.renewableenergymagazine.com/biogas/preem-signs-agreement-for-renewable-maritime-fuel-20210325; "Hurtigruten buys fish-based fuel for its future fleet", The Maritime Executive, 24 May 2019, https://www.maritime-executive.com/article/hurtigruten-buys-fish-based-fuel-for-its-future-fleet.

291 Green Car Congress, "Wärtsilä launches first combustion trials with ammonia", 26 March 2021, https://www.greencarcongress.com/2021/03/20210326-wartsila.html.

292 See, for example: Fuel Cells Works, "Irish islands look to ferry services with hydrogen fuel cells", 23 November 2020, https://fuelcellsworks.com/news/irish-islands-look-to-ferry-services-with-hydrogen-fuel-cells; M. Lewis, "Denmark, Norway to build world's largest green hydrogen ferry", Electrek, 8 December 2020, https://electrek.co/2020/12/08/denmark-norway-worlds-largest-green-hydrogen-ferry; J. Saul and N. Chestney, "The path to zero: First wave of ships explore green hydrogen", Maritime Logistics Professional, 30 October 2020, https://www.maritimeprofessional.com/news/path-zero-first-wave-ships-362805.

293 IEA, "Ordinance (2017: 1317) on grants to private individuals for the purchase of electric bikes, mopeds, motorcycles and outboard motors", 4 November 2019, https://www.iea.org/policies/7159-ordinance-2017-1317-on-grants-to-private-individuals-for-the-purchase-of-electric-bikes-mopeds-motorcycles-and-outboard-motors; Mobility Foresights, "Global Marine Outboard Engine Market 2019-2025", https://mobilityforesights.com/product/marine-outboard-engine-market; Torqueedo, "Torqeedo Solar pannel 45 W", http://www.torqeedo-belux.com/Solaire/Torqeedo%20solar%20pannel%2045%20W.htm, viewed 27 May 2021; Global Market Insights, "Electric outboard engines market size by power (below 25kW, 25 to 50 kW, 50 to 150 kW), by control (tiller, remote), by application (commercial, recreational, military), industry analysis report, regional outlook, application growth potential, price trends, competitive landscape & forecast, 2021-2027", 2020, https://www.gminsights.com/industry-analysis/electric-outboard-engine-market.

294 AJOT, "Valenciaport joins the club of the 12 largest ports in the world that lead the decarbonization and reduction of emissions", 4 January 2021, https://www.ajot.com/news/valenciaport-joins-the-club-of-the-12-largest-ports-in-the-world-that-lead-the-decarbonization-and-reduction-of-emissions. The programme was established in 2017 led by the Port of Rotterdam (Netherlands) along with Antwerp (Belgium), Barcelona (Spain), Hamburg (Germany), Long Beach and Los Angeles (US) and Vancouver (Canada). New additions from 2019 include Amsterdam (Netherlands), Le Havre (France), Gothenburg (Sweden), and New York and New Jersey (US). Greenport, "Climate action congress plans underway", 6 September 2019, https://www.greenport.com/news101/Projects-and-Initiatives/climate-action-congress-plans-underway; E. Lopez, "From Los Angeles to Hamburg, 7 ports team up to fight climate change", Supply Chain Dive, 15 September 2018, https://www.supplychaindive.com/news/World-Ports-Climate-Action-Program-launch/532431.

295 S. Djunisic, "Port of Valencia plans to add 8.5 MW of PV for own operations", Renewables Now, 22 April 2020, https://renewablesnow.com/news/port-of-valencia-plans-to-add-85-mw-of-pv-for-own-operations-695937.

296 E. Bellini, "Portuguese green hydrogen for the Port of Rotterdam", pv magazine, 24 September 2020,,https://www.pv-magazine.com/2020/09/24/portuguese-green-hydrogen-for-the-port-of-rotterdam. In 2016, industrial activities in the Port of Rotterdam accounted for 19% of total CO_2 emissions in the Netherlands, from C. Schneider, S. Lechtenböhmer and S. Samadi, "Risks and opportunities associated with decarbonizing Rotterdam's industrial cluster", *Environmental Innovation and Societal Transitions*, vol. 35 (2020), pp. 414-28, https://epub.wupperinst.org/frontdoor/index/index/start/4/rows/10/sortfield/year_sort/sortorder/desc/searchtype/simple/query/Rotterdam/yearfq/2020/docId/7334.

297 IEA, World Energy Balances 2020, op. cit. note 47; H. Ritchie, "Climate change and flying: What share of global CO_2 emissions come from aviation?", Our World in Data, 22 October 2020, https://ourworldindata.org/co2-emissions-from-aviation.

298 Ritchie, op. cit. note 297; D. Habtemariam, "Global air traffic growth outpaced capacity growth in 2018", Business Travel News, 7 February 2019, https://www.businesstravelnews.com/Global/Global-Air-Traffic-Growth-Outpaced-Capacity-Growth-in-2018; International Airport Review, "IATA announces 50 per cent decrease in carbon emissions per passenger", 16 December 2019, https://www.internationalairportreview.com/news/109066/iata-50-per-cent-decrease-carbon-emissions-per-passenger; H. Tabuchi, "'Worse than anyone expected': Air travel emissions vastly outpace predictions", *New York Times*, 20 September 2019, https://www.nytimes.com/2019/09/19/climate/air-travel-emissions.html.

299 Seating capacity fell by around 50%, while flights decreased from 38.9 million in 2019 to 16.4 million in 2020. "Air travel down 60 per cent, as airline industry losses top $370 billion: ICAO", UN News, 15 January 2021, https://news.un.org/en/story/2021/01/1082302; E. Mazareanu, "Global air traffic – number of flights 2004-2021", Statista, 11 May 2020, https://www.statista.com/statistics/564769/airline-industry-number-of-flights.

300 ICAO, "Climate change: State action plans and assistance", https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx, viewed 12 March 2021; ICAO, "Environment", https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx, viewed 12 March 2021.

301 ICAO, "Environment", op. cit. note 300.

302 Mazareanu, op. cit. note 299.

303 Airports with regular distribution saw the addition of San Francisco Airport (US), while those with batch deliveries decreased from 14 the year before as San Francisco Airport began regular distribution. ICAO, "Environment", op. cit. note 300.

304 However, some limitations (related to costs and availability of sufficient sustainable feedstocks) continue to hinder significant biofuel use in aviation. See Bioenergy section in Market and Industry chapter.

305 See, for example: B. Cogley, "World's first commercial electric plane takes off near Vancouver", Dezeen, 17 December 2019, https://www.dezeen.com/2019/12/17/worlds-first-commercial-electric-plane-canada-seaplane; Green Car Congress, "Wright Electric begins motor development program for 186-seat electric aircraft; 1.5MW motor, 3 kV inverter", 31 January 2020, https://www.greencarcongress.com/2020/01/20200131-wright.html. In 2018, Norway became the first country (and as of early 2021, still the only country) to see its airports announce a target for electric air travel, with a goal of having all short-haul domestic flights run on electricity by 2040, from "Norway aims for all short-haul flights 100% electric by 2040", Tech Xplore, 17 January 2018, https://techxplore.com/news/2018-01-norway-aims-short-haul-flights-electric.html.

306 GCCA+, "Reducing aviation emissions from the ground up on the island of Trinidad", 12 August 2019, https://www.gcca.eu/stories/reducing-aviation-emissions-ground-island-trinidad; Jamaica from ICAO, "Solar-at-gate. Pilot project", https://www.icao.int/environmental-protection/Documents/UNDP%20Leaflets/ICAO%20ENV%20Solar-F%20WEB.pdf, viewed 27 May 2021, and from ICAO, "New Jamaica 'solar-at-gate' pilot project a big step toward more sustainable aircraft gate power solutions for small island states", 25 April 2018, https://www.icao.int/Newsroom/Pages/New-Jamaica-solar-at-gate-pilot-project-big-step-toward-sustainable-aircraft-gate-power-solutions-for-small-island-states.aspx; Green Ari, "ICAO launches two African airport solar-at-gate projects to reduce aircraft ground emissions", 25 January 2019, https://www.greenaironline.com/news.php?viewStory=2557.

307 J. M. Takouleu, "Ghana: Government to power airports with solar energy", Afrik21, 6 April 2020, https://www.afrik21.africa/en/ghana-government-to-power-airports-with-solar-energy; International Airport Review, "EIA introduces the world's-largest airport solar farm", 8 July 2020, https://www.internationalairportreview.com/news/120379/solar-farm-edmonton-international-airport; L. Butcher, "Solar power for Australian airport", Passenger Terminal Today, 6 August 2020, https://www.passengerterminaltoday.com/news/airport/solar-power-for-australian-airport.html; Aviation Pros, "New York State's largest solar power canopy storage system at JFK Airport authorized to begin development, furthering Port Authority's commitment to the Paris Climate Agreement", 17 December 2020, https://www.aviationpros.com/airports/press-release/21203148/the-port-authority-of-new-york-new-jersey-new-york-states-largest-solar-power-canopy-storage-system-at-jfk-airport-authorized-to-begin-development-furthering-port-authoritys-commitment-to-the-paris-climate-agreement; E. Bellini, "21-year solar PPA for three French airports", pv magazine, 6 February 2020, https://www.pv-magazine.com/2020/02/06/21-year-solar-ppa-for-three-french-airports.

308 See Market and Industry chapter. See also L. Stoker, "New solar investment falls 12% as COVID-19 dents H1 2020 figures: BNEF", pv magazine, 13 July 2020, https://www.pv-tech.org/new-solar-investment-falls-12-as-covid-19-dents-h1-2020-figures-bnef, and IEA, *Renewable Energy Market Update 2021* (Paris: 2021), https://www.iea.org/reports/renewable-energy-market-update-2021. Auctions were cancelled for solar PV and wind, as well as hydropower in Brazil, from L. Morais, "Brazil officially cancels 2020 auctions, posts schedule for 2021-2023", Renewables Now, 8 December 2020, https://renewablesnow.com/news/brazil-officially-cancels-2020-auctions-posts-schedule-for-2021-2023-723763.

309 GWEC, *Global Wind Report 2020* (Brussels: 2020), p. 46, https://gwec.net/global-offshore-wind-report-2020; IEA, op. cit. note 5, p. 11. See Market and Industry chapter for more information.

310 Additions of 256.6 GW consisted of 139.4 GW solar PV, 93.0 GW wind power, 19.4 GW hydropower, 4.6 GW biopower, 0.1 GW geothermal power, 0.1 GW CSP and ~0 GW ocean power. **Hydropower** from International Hydropower Association (IHA), *Hydropower Status Report 2021* (London: May 2021), https://www.hydropower.org/publications/2021-hydropower-status-report, and from IHA, personal communication with REN21, 25 May 2020; **wind power** from GWEC, op. cit. note 6; **solar PV** collected in direct current and from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2021* (Paris: 2021), https://iea-pvps.org/snapshot-reports/snapshot-2021; **bio-power** from IEA, op. cit. note 5, and from US Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for December 2020" (Washington, DC: 2020), https://www.ferc.gov/legal/staff-reports/2019/dec-energy-infrastructure.pdf; German Federal Ministry for Economic Affairs and Energy (BMWi) and AGEE Stat, "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2020", Table 4, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, updated March 2021; UK Department for Business, Energy and Industrial Strategy (BEIS), "Energy Trends: Renewables", Table 6.1, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, updated 13 May 2021; Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements) for 2019 and 2020", https://mnre.gov.in/physical-progress-achievements, viewed 14 February 2021; data for other countries based on forecast 2020 capacity figures from IEA, op. cit. this note, datafiles. **Geothermal** from the following sources: IEA, op. cit. this note; US EIA, op. cit. note 70, Table 6.2.B; BMWi, op. cit. this note; Turkey from endnote 1 in Geothermal section of Market and Industry chapter. **CSP** capacity was limited to 14 countries; for data and references, see CSP section of Market and Industry chapter. **Ocean power** capacity was negligible worldwide and had no effect on capacity rankings or whether or not a certain country exceeded 10 GW of capacity. Where national data were unavailable from previously referenced sources, gaps were filled from IRENA, "Renewable electricity capacity and generation statistics", http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54, viewed on multiple occasions in April and May 2021. For "rebound", see Market and Industry chapter and IEA, op. cit. note 308.

311 Total capacity and growth based on sources in endnote 310, on data provided throughout this report and on data from past GSRs. See Market and Industry chapter, **Reference Table R1** in GSR 2021 Data Pack, and related endnotes for sources and details. **Figure 7** based on idem. For more on renewable power capacity in 2020, see **Reference Table R1** in GSR 2021 Data Pack, technology sections in Market and Industry chapter, and related endnotes.

312 Fossil fuel and nuclear power sector progress from IEA, *Global Energy Review 2021* (Paris: 2021), https://www.iea.org/reports/global-energy-review-2021; share of 83% from IRENA, "Renewable capacity highlights", 31 March 2021, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_-RE_Capacity_Highlights_2021.pdf; renewable power capacity from idem; non-renewable power capacity provided by A. Whiteman, IRENA, personal communication with REN21, April 2021. **Figure 8** based on sources in this note.

313 Based on capacity additions reported in endnote 310 and throughout this report.

314 Ibid.

315 46% share from China's additions of 119.3 GW over a global total of 256.8 GW, from Ibid.

316 Ibid.

317 Based on capacity additions reported in endnote 310 and in Market and Industry section.

318 Based on capacity additions reported in endnote 310.

319 Ibid.; 20 countries in 2010 from IRENA, op. cit. note 312.

320 Estimate of 19 countries in 2020 from sources in endnote 310; 5 countries in 2010 from IRENA, op. cit. note 312.

321 Ranking for top countries per capita for based on sources throughout this chapter and population data from World Bank, "Population, total", https://data.worldbank.org/indicator/SP.POP.TOTL, viewed March 2021.

322 See Policy Landscape chapter, Wind Power section and Solar PV section in Market and Industry chapter and IEA, "January to June renewable electricity capacity additions", https://www.iea.org/reports/renewables-2020/covid-19-and-the-resilience-of-renewables, viewed 13 May 2021. See also IEA, op. cit. note 308.

323 IEA PVPS, op. cit. note 310, p. 12. See sources throughout Market and Industry chapter and endnote 308.

324 Ibid, all references.

325 IHA, *Hydropower Status Report 2021*, op. cit. note 310. See Hydropower section in Market and Industry chapter for more information.

326 Each technology only installed 100 MW of new capacity, with nearly all geothermal additions in Turkey and only CSP project coming only in China during the year. See Market and Industry chapter for more information.

327 See Ocean Power section in Market and Industry chapter. Capacity targets from EC, *Offshore Renewable Energy Strategy* (Brussels: 2020), https://ec.europa.eu/energy/sites/ener/files/offshore_renewable_energy_strategy.pdf.

328 See **Figure 16** in Policy Landscape chapter and related endnotes.

329 IEA, op. cit. note 5, p. 19.

330 Countries holding tenders for the first time in 2020 included Bhutan, Croatia, Mozambique, Myanmar and the Slovak Republic. Europe is included in this total. From REN21 Policy Database. See Policy Landscape chapter for more discussion.

331 IRENA Coalition for Action, *Stimulating Investment in Community Energy* (Abu Dhabi: 2020), p. 13, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/IRENA_Coalition_Stimulating_Investment_in_Community_Energy_2020.pdf.

332 **Solar PV** from E. Bellini, "Portugal's second PV auction draws world record low bid of $0.0132/kWh", pv magazine, 24 August 2020, https://www.pv-magazine.com/2020/08/24/portugals-second-pv-auction-draws-world-record-low-bid-of-0-0132-kwh, and from "Bundesnetzagentur awards 100.55 MW under first solar PV auction of 2020 in Germany with average Wwnning bid coming in at €0.0501/kWh", TaiyangNews, 21 February 2020, http://taiyangnews.info/markets/record-low-e0-0355-winning-bid-in-german-auction. **Wind** from the following sources: C. Richard, "Greece momentum continues with record onshore prices", Wind Power, 9 April 2020, https://www.windpowermonthly.com/article/1679862/greece-momentum-continues-record-onshore-prices; N. Weekes, "Onshore wind dominates latest Italian energy tender", Wind Power, 2 June 2020, https://www.windpowermonthly.com/article/1684954/onshore-wind-dominates-latest-italian-energy-tender; C. Richard, "Prices hit new low in French onshore", Wind Power, 2 April 2020, https://www.windpowermonthly.com/article/1679192/prices-hit-new-low-french-onshore; C. Richard, "Shell advances hydrogen plan with Eneco deal", Wind Power, 7 May 2020, https://www.windpowermonthly.com/article/1682629/shell-advances-hydrogen-plan-eneco-deal; C. Richard, "Subsidy-free wind farm wins first Lithuanian tender", Wind Power, 16 January 2020, https://www.windpowermonthly.com/article/1671089/subsidy-free-wind-farm-wins-first-lithuanian-tender; I. Todorović, "Greece awards nearly all wind, solar capacity at auction as prices drop", Balkan Green Energy News, 28 July 2020, https://balkangreenenergynews.com/greece-awards-nearly-all-wind-solar-capacity-at-auction-as-prices-drop; A. Franke, "France awards 1.7 GW renewables projects, adjusts 2020 auction schedule", S&P Global, 3 April 2020, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/040320-france-awards-17-gw-renewables-projects-adjusts-2020-auction-schedule. See Market and Industry chapter for further examples and discussion.

333 IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), pp. 13-16, https://www.irena.org/publications/2019/Dec/Renewable-energy-auctions-Status-and-trends-beyond-price; E. Vartiainen et al., "Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity", EU PVSEC, 29 August 2019, https://doi.org/10.1002/pip.3189.

334 BloombergNEF, op. cit. note 31. See Feature chapter for further discussion.

335 Ibid.

336 A. Niklaus, Pexpark, cited in M. Nicholls, "Dynamism and innovation in a post-subsidy renewables market", EnergyMonitor, 8 March 2021, https://energymonitor.ai/finance/sustainable-finance/dynamism-and-innovation-in-a-post-subsidy-renewables-market.

337 IEA, "2020 Global overview: The Covid-19 pandemic", in *Electricity Market Report* (Paris: 2020), https://www.iea.org/reports/electricity-market-report-december-2020/2020-global-overview-the-covid-19-pandemic#abstract.

338 Ibid.

339 See, for example, GWEC, op. cit. note 6; IEA, op. cit. note 5.

340 Ember, op. cit. note 2.

341 Decline of electricity production from fossil fuels of 16,233 TWh in 2018 to 16,114 TWh in 2019 and 15,757 TWh in 2020, from Ember, op. cit. note 2.

342 Share of generation in 2020 based on estimated total global electricity generation of 25,850 TWh and total renewable generation of 7,493 TWh, from Ember, op. cit. note 2. Global totals for 2020 were estimated by summing total electricity generation and electricity generation per energy source in 36 countries where 2020 national sources (including official government data and utility data) were available, comprising 90% of global generation. See Ember, "Methodology", https://ember-climate.org/global-electricity-review-2021/methodology, viewed 7 April 2021. **Figure 7** based on previous year's generation from idem.

343 Ember, *EU Power Sector in 2020* (London and Berlin: 2021), https://ember-climate.org/project/eu-power-sector-2020.

344 Ibid.

345 UK BEIS, op. cit. note 310.

346 US EIA, "Table 7.2b – Electricity Net Generation", in *Monthly Energy Review April 2021* (Washington, DC: 2021), https://www.eia.gov/totalenergy/data/monthly/pdf/sec7_6.pdf.

347 Clean Energy Council, *Clean Energy Australia 2021* (Sydney: 2021), p. 7, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf.

348 Based on total electricity production in 2020 of 7,623,600 GWh, solar energy production of 261,100 GWh, hydropower production of 1,355,200 GWh and wind energy production of 466,500 GWh (based on grid-connected capacity), and total electricity production in 2019 of 7,326,900 GWh, solar energy production of 224,000, hydropower production of 1,302,100 GWh and wind energy production of 405,300 GWh, from China Energy Portal, "2020 electricity & other energy statistics (preliminary)", 22 January 2021, https://chinaenergyportal.org/en/2020-electricity-other-energy-statistics-preliminary.

349 Total global share from Ember, op. cit. note 2. Remaining countries from the following: **Denmark** share of net generation based on net generation data of 16,353 GWh from wind power, 1,181 GWh from solar PV, and total net production of 27,907 GWh, from Danish Energy Agency, "Månedlig elstatistik. Oversigtstabeller", in Electricity Supply, https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics, viewed 15 April 2021; **Uruguay** share of wind generation of 5,437.7 GWh, solar generation 525.5 GWh and total 13,470.5 GWh, from Ministerio de Industria, Energía y Minería, "Balance Preliminar 2020", https://ben.miem.gub.uy/preliminar.php; **Ireland** share of wind as percentage of demand, based on provisional 2020 data (to be confirmed in May 2021) from EIRGRID, "System & renewable summary report", https://www.eirgridgroup.com/how-the-grid-works/renewables, viewed 16 April 2021; **Germany** share of gross electricity production of wind onshore 103,66 TWh, wind offshore 27,303 TWh (total wind: 130,963 TWh), solar gross electricity production 50,6 TWh, and total gross electricity production 558 TWh, from BMWi and AGEE Stat, op. cit. note 310; **Greece** share of wind production of 9,323 GWh, Solar PV production 3,898 GWh, solar rooftop PV 494 GWh, and total 42,229.90 GWh, from Dapeep, "Μηνιαίο Δελτίο Ειδικού Λογαριασμού ΑΠΕ & ΣΗΘΥΑ", 2020, https://www.dapeep.gr/wp-content/uploads/ELAPE/2020/08_DEC_2020_DELTIO_ELAPE_v1.0_21.03.2021.pdf, viewed April 2021, all in Greek and provided by I. Tsipouridis, REDPro Consultants, Athens, personal communication with REN21, 12 April 2021; **Spain** share of demand coverage of wind 22.2%, and solar 6.1%, from Red Eléctrica de España (REE), *The Spanish Electricity System – Preliminary Report 2020* (Madrid: February 2021), with estimated data as of

13 January 2021, p. 15, https://www.ree.es/sites/default/files/publication/2021/03/downloadable/avance_ISE_2020_EN.pdf; **United Kingdom** share of electricity generation of wind onshore 34.95 TWh, wind offshore 40.66 TWh, solar PV 12.8 TWh, and total electricity generation 312.76 TWh, from UK BEIS, "Fuel used in electricity generation and electricity supplied", March 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972781/ET_5.1_MAR_21.xls; **Portugal** share of 12,067 GWh of wind production and 1,269 GWh of solar PV, and total production of 49,342 GWh, from REN, "Dados Tecnicos / Technical Data 20", p. 9, https://www.centrodeinformacao.ren.pt/PT/InformacaoTecnica/DadosTecnicos/AFnet_RENPRO%20Brochura%20Dados%20T%C3%A9cnicos%202020.pdf; **Australia** share of wind of 22,196 GWh and solar PV of 22,288 GWh, and total generation of 221,957 GWh from OpenNEM, "Western Australia (SWIS)", https://opennem.org.au/energy/wem/?range=all&interval=1y, viewed 23 April 2021; **The Netherlands** provisional data for net production of wind onshore 9,785 TWh and offshore 5,484 TWh, solar 8,056 TWh and total net production of 118,920 TWh, from CBS StatLine, "Electricity balance sheet; supply and consumption", https://opendata.cbs.nl/statline/#/CBS/en/dataset/84575ENG/table?ts=1619216097037, viewed 3 May 2021; **Honduras** power generation data on the National Interconnected Electrical System – Energía Eléctrica Generada en el Sistema Inteconectado Nacional, based on net generation of wind of 707,202.8 MWh, solar of 1,044,775.9 MWh, and total 9,292,817.3 MWh, from Empresa Nacional de Energía Eléctrica (ENEE), *Boletines Estadísticos Año 2020 – Diciembre*, http://www.enee.hn/index.php/planificacionicono/182-boletines-estadisticos; **Sweden** share of wind of 27,589 GWh, solar 805 GWh, and total 159,635 GWh, from Statistics Sweden, "Elproduktion i Sverige efter produktionsslag. Månad 2017M01 – 2021M02", https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__EN__EN0108/Elprod; **Belgium** share of wind onshore generation of 4.1 TWh and offshore 6.7 TWh, and solar generation of 4.3 TWh, from Elia Group, "Belgium's electricity mix in 2020: Renewable generation up 31% in a year marked by the COVID-19 crisis", 7 January 2021, https://www.elia.be/-/media/project/elia/shared/documents/press-releases/2021/20210107-mix-electrique-2020_en.pdf; **Chile** wind generation of 5,537 GWh, and solar of 7,638 GWh, from Generadoras de Chile, Generación Eléctrica en Chile, http://generadoras.cl/generacion-electrica-en-chile; **Nicaragua** share of wind net generation of 538,826 MWh and solar of 22,688 MWh, and total generation of 3,379,530 MWh, from Instituto Nicaragüense de Energía, Ente Regulador, Generación Neta Sistema Eléctrico Nacional Año 2020, https://www.ine.gob.ni/DGE/estadisticas/2020/generacion_neta_dic20_actfeb21.pdf; **Italy** share of wind generation of 18,547 GWh, solar generation of 25,549 GWh, and total 273,108 GWh, from Terna, *Rapporto mensile sul Sistema Elettrico*, https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202020_8d8b615dca4dafe.pdf.

350 For examples, see Systems Integration chapter and Teske, op. cit. note 63.

351 See Wind Power section and Solar PV section in Market and Industry chapter.

352 See Policy Landscape chapter.

353 W. Gorman et al., "Motivations and options for deploying hybrid generator-plus-battery projects within the bulk power system", *The Electricity Journal*, June 2020, https://www.sciencedirect.com/science/article/pii/S1040619020300312?via%3Dihub; N. Lee et al., "Hybrid floating solar photovoltaics-hydropower systems: Benefits and global assessment of technical potential", *Renewable Energy*, vol. 162 (December 2020), pp. 1415-27, https://www.sciencedirect.com/science/article/pii/S0960148120313252. Pairing technologies not only side-by-side but at the same interconnection reduces costs of equipment, siting, grid connection, financing as well as operations and maintenance compared to separate projects while also increasing capacity factor.

354 In addition, 13 provinces in China introduced policies requiring a specific amount of energy storage be included in the development of solar PV and wind power projects, from Polaris Solar Photovoltaic Network, "Zhongguang Nuclear 5.7GW, China Resources 5GW... 3 months more than 45GW, photovoltaic project filing blowout!" https://mp.weixin.qq.com/s/kdGGc6N2iJS9QGwG_oY_QA, viewed 17 May 2021 (using Google Translate); B. Matich, "WA govt approves 15 GW Asian Renewable Energy Hub, whole project now expanded to 26 GW", pv magazine, 20 October 2020, https://www.pv-magazine.com/2020/10/20/wa-govt-approves-15-gw-asian-renewable-energy-hub-whole-project-now-expanded-to-26-gw; J. M. Takouleu, "Gabon: Ausar Energy and CDC launch the Ndjolé hybrid power plant construction", Afrik21, 5 February 2020, https://www.afrik21.africa/en/gabon-ausar-energy-and-cdc-launch-the-ndjole-hybrid-power-plant-construction; GE, "GE Renewable Energy to integrate UK's first DC-coupled battery energy storage system at Wykes's Chelveston Renewable Energy Wind-Solar Park", 27 August 2020, https://www.ge.com/news/press-releases/ge-renewable-energy-integrate-uks-first-dc-coupled-battery-energy-storage-system; E. Hancock, "Construction starts on Australia's 'largest' hybrid solar and battery energy storage system", PV-Tech, 22 March 2021, https://www.pv-tech.org/construction-starts-on-australias-largest-hybrid-solar-and-battery-energy-storage-system; C. Keating, "Iberdrola teams up with DP Energy for 320MW Aussie wind-solar hybrid", PV-Tech, 15 January 2020, https://www.pv-tech.org/iberdrola-partners-with-dp-energy-for-maiden-australian-project; Z. Shahan, "Largest renewable energy project in world will be 30 gigawatt solar–wind project in India", CleanTechnica, 17 December 2020, https://cleantechnica.com/2020/12/17/largest-renewable-energy-project-in-world-will-be-30-gigawatt-solar-wind-project-in-india; The Wire, "'World's largest renewable energy park' opens in Kutch", 15 December 2020, https://thewire.in/politics/worlds-largest-renewable-energy-park-opens-in-kutch; PR Newswire, "JA Solar supplies modules for the largest solar-wind hybrid project in South Korea", 26 August 2020, https://www.prnewswire.com/ae/news-releases/ja-solar-supplies-modules-for-the-largest-solar-wind-hybrid-project-in-south-korea-829837442.html; P. Hannen, "New solar PPA, hybrid PV-wind project in Germany", pv magazine, 27 August 2020, https://www.pv-magazine.com/2020/08/27/new-solar-ppa-hybrid-pv-wind-project-in-germany; A. Dimitrova, "Engie to develop GBP-8m hybrid renewables project for Keele Uni", Renewables Now, 11 December 2020, https://renewablesnow.com/news/engie-to-develop-gbp-8m-hybrid-renewables-project-for-keele-uni-724226; G. Parkinson, "BP looks to add 1.5GW wind and solar for huge renewable hydrogen project in W.A.", RenewEconomy, 13 May 2020, https://reneweconomy.com.au/bp-looks-to-add-1-5gw-wind-and-solar-for-huge-renewable-hydrogen-project-in-w-a-45931; "Goldwind to deliver turbines to Oz hybrid scheme", reNEWS, 5 August 2020, https://renews.biz/62225/goldwind-to-deliver-turbines-to-oz-hybrid-scheme; U. Gupta, "Renew Power wins 400 MW 'round-the-clock' renewables auction at Rs2.90/kWh", pv magazine, 09 May 2020, https://www.pv-magazine-india.com/2020/05/09/renew-power-wins-400-mw-round-the-clock-renewable-auction-at-rs-2-90-kwh; M. Maisch, "56 MW hybrid microgrid powers up at Western Australian gold mine", pv magazine, 19 May 2020, https://www.pv-magazine-australia.com/2020/05/19/56-mw-hybrid-microgrid-powers-up-at-western-australian-gold-mine; J. S. Hill, "Aurora project may still include solar thermal as 1414 signs with Vast Solar", RenewEconomy, 10 September 2020, https://reneweconomy.com.au/aurora-project-may-still-include-solar-thermal-as-1414-signs-with-vast-solar-65004; J. Scully, "Adani to develop 600MW solar-wind hybrid project following SECI auction success", PV-Tech, 4 January 2021, https://www.pv-tech.org/adani-to-develop-600mw-solar-wind-hybrid-project-following-seci-auction-success; L. Stoker, "Enel targets US multi-gigawatt solar, storage build-out as maiden hybrid breaks ground", PV-Tech, 22 July 2020, https://www.pv-tech.org/enel-sets-sights-on-1gw-of-us-energy-storage-as-it-co-locates-first-with-so; L. Collins, "World first for solid-state green hydrogen at hybrid solar project", Recharge, 11 March 2020, https://www.rechargenews.com/transition/world-first-for-solid-state-green-hydrogen-at-hybrid-solar-project/2-1-771319; E. Bellini, "Malian gold mine to be powered by 3.9 MW/2.6 MWh solar-plus-storage plant", pv magazine, 28 October 2020, https://www.pv-magazine.com/2020/10/28/malian-gold-mine-to-be-powered-by-3-9-mw-2-6-mwh-solar-plus-storage-plant; D. Mavrokefalidis, "Statkraft to manage 'UK's largest solar and battery storage project'", Energy News Live, 1 June 2020, https://www.energylivenews.com/2020/06/01/statkraft-to-manage-uks-largest-solar-and-battery-storage-project; A. Colthorpe, "California community energy group signs PPA for 400MW / 540MWh solar-plus-storage plant", Energy Storage News, 11 September 2020, https://www.energy-storage.news/news/california-community-energy-group-signs-ppa-for-400mw-540mwh-solar-plus-sto; J. Scully, "Australia's largest solar-plus-storage project edges forward as Elecnor wins EPC contract", PV-Tech, 2 October 2020, https://www.pv-tech.org/elecnor-secures-epc-contract-for-australias-largest-solar-plus-pstorage-project; S. Kraemer, "Morocco pioneers PV with thermal storage at 800 MW Midelt CSP project",

SolarPACES, 25 April 2020, https://www.solarpaces.org/morocco-pioneers-pv-to-thermal-storage-at-800-mw-midelt-csp-project; V. Godinho, "Dubai's Mohammed bin Rashid Al Maktoum Solar Park to have world's largest energy storage capacity", Gulf Business, 29 November 2020, https://gulfbusiness.com/dubais-mohammed-bin-rashid-al-maktoum-solar-park-to-have-worlds-largest-energy-storage-capacity; K. Pickerel, "Dept. of Interior approves plans for 690-MW Gemini solar project with 1,400-MWh battery", Solar Power World, 11 May 2020, https://www.solarpowerworldonline.com/2020/05/dept-of-interior-approves-plans-for-690-mw-gemini-solar-project-with-1400-mwh-battery; GE, "GE Renewable Energy to supply DC-coupled system to Convergent for 123 MWh hybrid solar plus storage project in upstate New York", 16 March 2021, https://www.ge.com/news/press-releases/ge-renewable-energy-to-supply-dc-coupled-system-to-convergent-for-123-mwh-hybrid-solar-storage-project-upstate-new-york.

355 T. Ramschak, AEE INTEC, Austria, personal communication with REN21, April 2021. See Solar Thermal Heating section in Market and Industry chapter.

POLICY LANDSCAPE

1 International Energy Agency (IEA), *Renewables 2020: Analysis and Forecast to 2025* (Paris: 2020), p. 146, https://www.iea.org/reports/renewables-2020/key-trends-to-watch.

2 This chapter is intended to be only indicative of the overall landscape of policy activity and is not a definitive reference. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. It is difficult to capture every policy change, so some policies may be unintentionally omitted or incorrectly listed. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it attempt to provide a comprehensive list of broader framework and strategic policies – all of which are still important to renewable energy progress. For the most part, this report also does not cover policies that are still under discussion or formulation, except to highlight overall trends. Information on policies comes from a wide variety of sources, including the IEA and International Renewable Energy Agency (IRENA) Global Renewable Energy Policies and Measures Database, the US Database of State Incentives for Renewables & Efficiency (DSIRE), press reports, submissions from REN21 regional- and country-specific contributors and a wide range of United Nations unpublished data. **Table 6** and **Figures 10-16** are based on numerous sources cited throughout this chapter.

3 "Global corporate clean energy purchasing up 18% in 2020", Renewable Energy World, 27 January 2021, https://www.renewableenergyworld.com/solar/global-corporate-clean-energy-purchasing-up-18-in-2020; IEA, op. cit. note 1, p. 146; IRENA, *Renewable Power Generation Costs in 2019* (Abu Dhabi: 2020), https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019; Institute for Energy Economics and Financial Analysis, "Study shows renewables cheaper than fossil fuels across Middle East, North Africa region", 28 April 2020, https://ieefa.org/study-shows-renewables-cheaper-than-fossil-fuels-across-middle-east-north-africa-region; Carbon Brief, "Solar is now 'cheapest electricity in history', confirms IEA", 13 October 2020, https://www.carbonbrief.org/solar-is-now-cheapest-electricity-in-history-confirms-iea.

4 Data in this paragraph are from the REN21 Policy Database and can be accessed in **Reference Tables R3-R8** in the GSR 2021 Data Pack, www.ren21.net/gsr-2021.

5 Energy Policy Tracker, https://www.energypolicytracker.org, updated 20 January 2021; T. Lei Win, "Reuters, G20 countries still backing fossil fuels through COVID-19 response", *Reuters*, 9 November 2020,,https://www.reuters.com/article/us-g20-climatechange-energy-trfn-idUSKBN27Q00Q. **Sidebar 3** based on the following sources: IEA, op. cit. note 1; Y. Dagnet and J. Jaeger, "Not enough climate action in stimulus plans", World Resources Institute (WRI) Blog, 15 September 2020, https://www.wri.org/blog/2020/09/coronavirus-green-economic-recovery; S. Kaplan and D. Grandoni, "Stimulus deal includes raft of provisions to fight climate change", *Washington Post*, 21 December 2020, https://www.washingtonpost.com/climate-solutions/2020/12/21/congress-climate-spending; Energy Policy Tracker, "G20 countries", https://www.energypolicytracker.org/region/g20, viewed 26 January 2021. The EU's recovery package includes EUR 91 billion (USD 112 billion) a year for green incentives like low-interest loans to drive sustainable building initiatives across the continent, including renewable heating systems, rooftop solar, batteries and energy efficiency measures. For renewable energy, the EU committed to tender 15 GW of new capacity over the coming two years, with expected investments of EUR 25 billion (USD 31 billion), focused particularly on large-scale solar and wind. The EU package also focuses on the production of hydrogen from renewable electricity, boosting funding for this to EUR 1.3 billion (USD 1.6 billion). For transport, the package provides EUR 20 billion (USD 25 billion) to drive the shift to electric and other zero-emission vehicles, including the installation of 1 million EV charging stations by 2025. The package also includes EUR 40-60 billion (USD 49-74 billion) of investments in zero-emission trains. S. Vorrath, "EU unveils 'green' Covid recovery plan, leaves Australia wallowing in coal dust", RenewEconomy, 28 May 2020, https://reneweconomy.com.au/eu-unveils-green-covid-recovery-plan-leaves-australia-wallowing-in-coal-dust-39319; IEA, op. cit. note 1, pp. 142-44; Clean Energy Canada, "Media brief: A summary of international clean stimulus efforts", 29 May 2020, https://cleanenergycanada.org/media-brief-a-summary-of-international-clean-stimulus-efforts; "Doosan Heavy I&C gets another $1bn, raising total state bailout to near $3 bn", Pulse, 2 June 2020, https://pulsenews.co.kr/view.php?year=2020&no=564186; "Green Stimulus Index: An assessment of the orientation of COVID-19 stimulus in relation to climate change, biodiversity and other environmental impacts", Vivid Economics, 3 June 2020, https://www.vivideconomics.com/wp-content/uploads/2020/06/200605-Green-Stimulus-Index-1.pdf; C. Farand, "India eyes private investment to open 41 new coal mines", Climate Home News, 19 June 2020, https://www.climatechangenews.com/2020/06/19/india-eyes-private-investment-open-41-new-coal-mines; fossil fuel support in India and the Republic of Korea from Energy Policy Tracker, https://www.energypolicytracker.org, viewed February 2021; fossil fuel support in Canada and the United Kingdom from Alberta, "Investing in Keystone XL pipeline", https://www.alberta.ca/investing-in-keystone-xl-pipeline.aspx, viewed February 2021, and from D. Barmes et al., *The Covid Corporate Financing Facility. Where Are the Conditions for the Billion £ Bailouts?* (London: PositiveMoney, July 2020), http://positivemoney.org/wp-content/uploads/2020/07/CCFF-Final-version.pdf; International Institute for Sustainable Development (IISD), "Sustainable recovery in Colombia: President underlines ambitions", 31 August 2020, https://www.iisd.org/sustainable-recovery/news/sustainable-recovery-in-colombia-president-underlines-ambitions; E. Bellini, "Israel's plan to recover from Covid-19 crisis includes 2 GW of New Solar", pv magazine, 29 April 2020, https://www.pv-magazine.com/2020/04/29/israels-plan-to-recover-from-covid-19-crisis-includes-2-gw-of-new-solar; Federal Republic of Nigeria, *Bouncing Back: Nigeria Economic Sustainability Plan* (Lagos: 2020), p. 22, https://nipc.gov.ng/wp-content/uploads/2020/09/NG-Economic-Sustainability-Plan-2020.pdf; C. Morehouse, "Federal stimulus includes wind, solar tax credit extensions, adds first US offshore wind tax credit", Utility Dive, 22 December 2020, https://www.utilitydive.com/news/federal-stimulus-includes-wind-solar-tax-credit-extensions-adds-first-us/592572; H. Cooper and P. Tingle, "COVID-19 stimulus bill includes key renewable energy tax credits", National Law Review, 28 December 2020, https://www.natlawreview.com/article/covid-19-stimulus-bill-includes-key-renewable-energy-tax-credits; Fredrikson & Byron PA, "New stimulus brings another extension for renewable energy tax credits", Lexology, 29 December 2020, https://www.lexology.com/library/detail.aspx?g=070f5f1a-4922-4b10-b10f-ea10f7331d2a; J. Cossardeaux, "Plan de relance: la transition ecologique se taille la part du lion", 3 September 2020, https://www.lesechos.fr/politique-societe/societe/plan-de-relance-la-transition-ecologique-se-taille-la-part-du-lion-1238889; A. Garric et al., "Le chantier sans fin de la rénovation thermique", *Le Monde*, 5 October 2020, https://www.lemonde.fr/economie/article/2020/10/05/le-chantier-sans-fin-de-la-renovation-thermique_6054748_3234.html; H. Shin and S. Cha, "The Republic of Korea to spend $95 billion on green projects to boost economy", *Reuters*, 14 July 2020, https://www.reuters.com/article/us-southkorea-president-newdeal/south-korea-to-spend-95-billion-on-green-projects-to-boost-economy-idUSKCN24F0GA; J. Spaes, "France devotes €30 billion to energy transition", pv magazine, 4 September 2020, https://www.pv-magazine.com/2020/09/04/france-devotes-e30-billion-to-energy-transition. However, actual spending will depend on the annual budget of the corresponding ministry. Government of Germany, "Policies, measures and actions on climate change and environmental protection in the context of COVID-19 recovery: Germany", https://platform2020redesign.org/countries/germany, updated 17 September 2020; D. Loy, Loy Energy Consulting, personal communication with REN21, 19 January 2021; S. Morgan, "Spain underpins car sector bailout with green goals", EURACTIV, 15 June 2020, https://www.euractiv.com/section/transport/news/spain-underpins-car-sector-bailout-with-green-goals; EUobserver, "Spain unveils €3.75bn rescue package for car industry", 16 June 2020, https://euobserver.com/tickers/148653; M. Planelles, "Spain to provide up to €4,000 in subsidies for purchase of a new car", *El Pais*, 16 June 2020, https://english.elpais.com/economy_and_business/2020-06-16/spain-to-provide-up-to-4000-in-subsidies-for-purchasing-a-new-car.html.

6 Based on information and sources used throughout this chapter.

7 **Box 4** based on the following sources: J. Spaes, "Mali exempts solar from VAT, import duties", pv magazine, 7 April 2020, https://www.pv-magazine.com/2020/04/07/mali-exempts-solar-from-vat-import-duties; N. Karume, "New energy policy

to promote solar and geothermal sectors in Uganda", PUMPS Africa, 17 January 2020, http://www.pumps-africa.com/new-energy-policy-to-promote-solar-and-geothermal-sectors-in-uganda-2; J. E. Rodriguez, Colibri Energy SAS, personal communication with REN21, 19 January 2021; J. M. Takouleu, "Senegal: Government exempts renewable energy equipment from VAT" Afrik21, 5 August 2020, https://www.afrik21.africa/en/senegal-government-exempts-renewable-energy-equipment-from-vat; C. Mwirigi, "Senegal introduces VAT exemption for off-grid solar products", pv magazine, 2 September 2020, https://www.pv-magazine.com/2020/09/02/senegal-introduces-vat-exemption-for-off-grid-solar-products; "Plan unveiled to increase local content in Saudi renewable energy industry chains", Asharq Al-Awsat, 12 January 2020, https://aawsat.com/english/home/article/2078831/plan-unveiled-increase-local-content-saudi-renewable-energy-industry-chains; U. Gupta, "PV imports to face 20-25% customs duty in India", pv magazine, 26 June 2020, https://www.pv-magazine.com/2020/06/26/pv-panel-imports-to-face-20-25-customs-duty-in-india-from-august; "Govt working on mega plan to triple solar manufacturing capacity", Economic Times, 4 July 2020, https://energy.economictimes.indiatimes.com/news/renewable/govt-working-on-mega-plan-to-triple-solar-manufacturing-capacity/76786536; S. Patel, "Trump ban on foreign bulk power equipment triggers new uncertainty", Power Magazine, 7 May 2020, https://www.powermag.com/trump-ban-on-foreign-bulk-power-equipment-triggers-new-uncertainty; B. Publicover, "Burkina Faso kicks off 'Solar Cluster' plan", pv magazine, 8 July 2020, https://www.pv-magazine.com/2020/07/08/burkina-faso-kicks-off-solar-cluster-plan; E. Bellini, "Turkey sets new rules for solar module imports", pv magazine, 15 April 2020, https://www.pv-magazine.com/2020/04/15/turkey-sets-new-rules-for-solar-module-imports; P. Sánchez Molina, "Brazil eliminates import duties for cells, modules, inverters and trackers", pv magazine, 2 July 2020, https://www.pv-magazine.com/2020/07/22/brazil-eliminates-import-duties-for-cells-modules-inverters-and-trackers; S. Islam, "Bangladesh opens €200m loan fund for eco-friendly imports", pv magazine, 27 April 2020, https://www.pv-magazine.com/2020/04/27/bangladesh-opens-e200m-loan-fund-for-eco-friendly-imports; "BB introduces €200m green transformation fund", Dhaka Tribune, 15 April 2020, https://www.dhakatribune.com/business/banks/2020/04/15/bb-introduces-200m-green-transformation-fund; U. Bhaskar, "New tariffs on import of solar cells and modules on the cards", Hindustan Times, 14 December 2020, https://www.hindustantimes.com/business-news/new-tariffs-on-import-of-solar-cells-and-modules-on-the-cards/story-MlTA8w0MZ0XykyM23Y5bcK.html; R. Ranjan, "2020 a look back: Developments that shaped the solar sector", Mercom India, 29 December 2020, https://mercomindia.com/2020-look-back-developments-solar.

8 New/updated NDCs were submitted by Andorra, Argentina, Australia, Bangladesh, Brazil, Brunei, Cambodia, Chile, Colombia, Costa Rica, Cuba, the Dominican Republic, Fiji, Ethiopia, Grenada, Japan, Jamaica, Kenya, Maldives, Marshall Islands, Mexico, Monaco, Norway, Moldova, Mongolia, Nepal, New Zealand, Nicaragua, Norway, Panama, Papua New Guinea, Peru, the Republic of Korea, the Russian Federation, Rwanda, Senegal, Singapore, Suriname, Switzerland, Thailand, Tonga, the United Arab Emirates, the United Kingdom, Vietnam and Zambia. The EU's 27 Member States are considered one bloc. J. Gabbatiss, "Which countries met the UN's 2020 deadline to raise 'climate ambition'?" Carbon Brief, 9 January 2021, https://www.carbonbrief.org/analysis-which-countries-met-the-uns-2020-deadline-to-raise-climate-ambition; United Nations Framework Convention on Climate Change (UNFCCC), "Nationally Determined Contributions (NDCs)", https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs, viewed 2 February 2021; UNFCCC, "NDC Synthesis Report", https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report, viewed 2 February 2021. **Figure 12** based on the following: carbon pricing policies from World Bank, "Carbon Pricing Dashboard", https://carbonpricingdashboard.worldbank.org/map_data, viewed 11 January 2021; net zero emission targets from Energy and Climate Intelligence Unit, "Net Zero Tracker", https://eciu.net/netzerotracker, viewed 11 January 2021 (unless specified; see GSR 2021 Data Pack); fossil fuel ban data from various sources compiled in the REN21 Policy Database. See **Reference Tables R4, R6, and R9** in GSR 2021 Data Pack for details.

9 **Table 4** based on 2019 data from European Commission, Emissions Database for Global Atmospheric Research (EDGAR), Joint Research Centre Data Catalogue, https://data.jrc.ec.europa.eu/dataset/jrc-edgar-emissiontimeseriesv41.

10 "China, top global emitter, aims to go carbon-neutral by 2060", CBC, 23 September 2020, https://www.cbc.ca/news/technology/china-carbon-neutral-1.5735172; F. Harvey, "China pledges to become carbon neutral before 2060", *The Guardian* (UK), 22 September 2020, https://www.theguardian.com/environment/2020/sep/22/china-pledges-to-reach-carbon-neutrality-before-2060; E. Lies, "PM Suga says Japan will attain zero-emissions, carbon neutral society by 2050", *Reuters*, 26 October 2020, https://www.reuters.com/article/japan-politics-suga/pm-suga-says-japan-will-attain-zero-emissions-carbon-neutral-society-by-2050-idUKL4N2HE2HS; S. Denyer and A. Kashiwagi, "Japan, world's third largest economy, vows to become carbon neutral by 2050", *Washington Post*, 26 October 2020, https://www.washingtonpost.com/world/japan-climate-emissions/2020/10/26/b6ea2b5a-1752-11eb-8bda-814ca56e138b_story.html; J. McCurry, "South Korea vows to go carbon neutral by 2050 to fight climate emergency", 28 October 2020, https://www.theguardian.com/world/2020/oct/28/south-korea-vows-to-go-carbon-neutral-by-2050-to-fight-climate-emergency.

11 Data for 2019 from World Bank, "Carbon Pricing Dashboard", https://carbonpricingdashboard.worldbank.org, viewed 22 December 2020; data for 2020 from World Bank, "Carbon Pricing Dashboard", https://carbonpricingdashboard.worldbank.org, viewed 22 October 2019.

12 "Montenegro introduces cap and trade scheme for major CO_2 emitters", *Reuters*, 24 February 2020, https://www.reuters.com/article/us-montenegro-climate/montenegro-introduces-cap-and-trade-scheme-for-major-co2-emitters-idUSKCN20I18O; Government of Mexico, "Programa de prueba del sistema de comercio de emisiones", 5 March 2021, https://www.gob.mx/semarnat/acciones-y-programas/programa-de-prueba-del-sistema-de-comercio-de-emisiones-179414.

13 M. Mazengarb, "NZ puts hard cap on emissions for first time to strengthen its trading scheme", RenewEconomy, 2 June 2020, https://reneweconomy.com.au/nz-puts-hard-cap-on-emissions-for-first-time-to-strengthen-its-trading-scheme-27417.

14 France, Ireland, Italy, Portugal, the Slovak Republic, Sweden and the United Kingdom also plan to exit coal by 2025. J. Tirone, "Austria ends coal era and commits to more renewable energy", The Financial Post, 17 April 2020, https://business.financialpost.com/pmn/business-pmn/austria-ends-coal-era-and-commits-to-more-renewable-energy; M. Willuhn, "Sweden exits coal two years early", pv magazine, 22 April 2020, https://www.pv-magazine.com/2020/04/22/sweden-exits-coal-two-years-early.

15 The Coal Phase-Out Act indicates that no new coal-fired plants may start operating after 14 August 2020 (with the exception of those that received a licence to operate before 29 January 2020). The Act also provides financial compensation for operators of coal-fired plants and sets out amendments to the German Renewable Energy Sources Act which enshrine into law the German goal of 65% renewable power by 2030. J. Gesley, "Germany: Law on phasing-out coal-powered energy by 2038 enters into force", Global Legal Monitor, 31 August 2020, https://www.loc.gov/law/foreign-news/article/germany-law-on-phasing-out-coal-powered-energy-by-2038-enters-into-force; F. Schulz, "German cabinet approves final 'Coal Phase-out Act'", EURACTIV, 25 June 2020, https://www.euractiv.com/section/energy/news/german-cabinet-finally-approves-the-coal-phase-out; "Germany adds brown coal to energy exit under landmark deal", *Reuters*, 16 January 2020, https://www.reuters.com/article/us-climate-change-germany-coal/germany-adds-brown-coal-to-energy-exit-under-landmark-deal-idUSKBN1ZF0OS.

16 Around 100 older, low-efficiency coal plants are expected to close as a result. "Japan to accelerate closure of old coal power plants", *Reuters*, 2 July 2020, https://www.reuters.com/article/us-japan-powerstation-coal/japan-to-accelerate-closure-of-old-coal-power-plants-idUSKBN2440AA; T. Sawa, "Plan to phase out inefficient coal plants breaks no new ground", *Japan Times*, 7 August 2020, https://www.japantimes.co.jp/opinion/2020/08/07/commentary/japan-commentary/meti-coal-plants-energy.

17 H. Alcoseba Fernandez, "Philippines announces moratorium on new coal power", Eco-Business, 28 October 2020, https://www.

eco-business.com/news/philippines-announces-moratorium-on-new-coal-power; J. Lo, "Pakistan signals coal power exit, in potential model for China's belt and road", Climate Home News, 16 December 2020, https://www.climatechangenews.com/2020/12/16/pakistan-signals-coal-power-exit-potential-model-chinas-belt-and-road; T. Fransen et al., "Outcomes and next steps from the Climate Ambition Summit", WRI Blog, 17 December 2020, https://www.wri.org/blog/2020/12/outcomes-and-next-steps-climate-ambition-summit; "75 leaders announce new commitments during Climate Ambition Summit", IISD, 17 December 2020, https://sdg.iisd.org/news/75-leaders-announce-new-commitments-during-climate-ambition-summit.

18 German Federal Ministry of the Interior, Building and Community, *The New Buildings Energy Act*, https://www.bmi.bund.de/EN/topics/building-housing/building/energy-efficient-construction-renovation/buildings-energy-act/buildings-energy-act-node.html, viewed 14 November 2020; L. Frank, "Germany's new Building Energy Act is a missed opportunity", Institute for Advanced Sustainability Studies, 15 July 2020, https://www.iass-potsdam.de/en/blog/2020/07/germanys-new-building-energy-act-missed-opportunity.

19 Government of Finland, "Government reaches agreement on fourth supplementary budget proposal for 2020", 2 June 2020, https://valtioneuvosto.fi/en/-/10616/hallitus-paatti-vuoden-2020-neljannesta-lisatalousarvioesityksesta.

20 R. Harrabin, "Climate pledge on gas boilers for 2023 'vanishes'", BBC, 20 November 2020, https://www.bbc.com/news/science-environment-55020558.

21 V. Spasić, "Slovenia's NECP: Local communities, protected areas limit renewables growth", Balkan Green Energy News, 22 October 2020, https://balkangreenenergynews.com/slovenias-necp-local-communities-protected-areas-limit-renewables-growth; Republic of Slovenia, *Integrated National Energy and Climate Plan of the Republic of Slovenia* (Ljubljana: 27 February 2020), https://ec.europa.eu/energy/sites/ener/files/documents/si_final_necp_main_en.pdf.

22 "Japan aims to eliminate gasoline vehicles by mid-2030s, boost green growth", *Reuters*, 25 December 2020, https://uk.reuters.com/article/us-japan-economy-green-idUKKBN28Z09P.

23 Scottish Construction Now, "Plan for one million zero emission homes by 2030 is 'ambitious' but detail needed on delivery", 17 December 2020, https://www.scottishconstructionnow.com/article/plan-for-one-million-zero-emission-homes-by-2030-is-ambitious-but-detail-needed-on-delivery; Scotland's Cabinet Secretary for Environment, Climate Change and Land Reform, *Securing a Green Recovery on a Path to Net Zero: Climate Change Plan 2018–2032 – Update*, Section 3.3.16 (Edinburgh: 16 December 2020), https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/pages/9.

24 D. Shepardson and N. Groom, "California passes landmark mandate for zero emission trucks", *Reuters*, 25 June 2020, https://news.trust.org/item/20200625230325-cvhq2; R. Mitchell, "California mandates big increase in zero-emission trucks", Los Angeles Times, 25 June 2020, https://www.latimes.com/business/story/2020-06-25/new-california-truck-mandate-100-000-zero-emission-commercial-haulers-sold-annually-by-2030.

25 R. Baldwin, "Massachusetts to ban sale of new gas-powered cars by 2035", Car and Driver, 31 December 2020, https://www.caranddriver.com/news/a35104768/massachusetts-ban-new-gas-cars-2035; *Government of Massachusetts, Massachusetts 2050 Decarbonization Roadmap* (Boston: December 2020), https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download.

26 By 2019, there were nearly 300 LEZs in Europe alone, spread across a dozen countries, from Groupe Renault, "Low emission zones (LEZs) in Europe", 25 March 2020, https://easyelectriclife.groupe.renault.com/en/outlook/cities-planning/low-emission-zones-lezs-in-europe. Others were implemented in 2020, for example in the UK: A. Campion, "New low emission zones to charge polluting cars", Confused.com, 6 January 2021, https://www.confused.com/on-the-road/cost-of-motoring/low-emission-zones.

27 K. Vandy, "Coronavirus: How pandemic sparked European cycling revolution", BBC News, 2 October 2020, https://www.bbc.com/news/world-europe-54353914.

28 "Denmark set to end all new oil and gas exploration", BBC News, 4 December 2020,https://www.bbc.com/news/business-55184580; I. Slav, "Denmark to end oil production in 2050", OilPrice.com, 4 December 2020, https://oilprice.com/Latest-Energy-News/World-News/Denmark-To-End-Oil-Production-In-2050.html.

29 C. Nugent, "U.K. says it will end support for overseas oil, gas and coal projects with 'very limited exceptions'", *TIME*, 11 December 2020, https://time.com/5920475/u-k-fossil-fuels-overseas; Government of the United Kingdom, "PM announces the UK will end support for fossil fuel sector overseas", press release (London: 12 December 2020), https://www.gov.uk/government/news/pm-announces-the-uk-will-end-support-for-fossil-fuel-sector-overseas.

30 T. Helm and R. McKie, "UK urged to follow Denmark in ending North Sea oil and gas exploration", *The Guardian* (UK), 6 December 2020, https://www.theguardian.com/environment/2020/dec/06/uk-urged-to-follow-denmark-in-ending-north-sea-oil-and-gas-exploration; World Oil, "UK projects up to 20 billion barrels of oil remain to be found offshore", 14 September 2020, https://www.worldoil.com/news/2020/9/14/uk-projects-up-to-20-billion-barrels-of-oil-remain-to-be-found-offshore.

31 **Sidebar 4** contributed by IISD and based on the following sources: subsidies in 2019 from Organisation for Economic Co-operation and Development (OECD), "Governments should use Covid-19 recovery efforts as an opportunity to phase out support for fossil fuels, say OECD and IEA", 5 June 2020, https://www.oecd.org/environment/governments-should-use-covid-19-recovery-efforts-as-an-opportunity-to-phase-out-support-for-fossil-fuels-say-oecd-and-iea.htm; Friends of Fossil Fuel Subsidy Reform, "'We must act now': Ten governments call on world leaders to phase out fossil fuel subsidies", 10 December 2020, http://fffsr.org/2020/12/we-must-act-now-ten-governments-call-on-world-leaders-to-phase-out-fossil-fuel-subsidies; R. Bridle et al.,*Fossil Fuel to Clean Energy Subsidy Swaps: How to Pay for an Energy Revolution* (Winnipeg: IISD, June 2019), p. 10, https://www.iisd.org/system/files/publications/fossil-fuel-clean-energy-subsidy-swap.pdf; renewables capacity from REN21, *Renewables 2020 Global Status Report* (Paris: 2020), p. 47, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf; captured by rich from P. Gass et al., *Raising Ambition Through Fossil Fuel Subsidy Reform: Greenhouse Gas Emissions Modelling Results from 26 Countries* (Winnipeg: IISD, June 2019), https://www.iisd.org/publications/raising-ambition-through-fossil-fuel-subsidy-reform; C. Beaton et al., *Mapping India's Energy Subsidies 2020: Fossil Fuels, Renewables, and Electric Vehicles* (Winnipeg: IISD, April 2020), https://www.iisd.org/system/files/publications/india-energy-transition-2020.pdf; N. Oza, "India will achieve 450 GW renewable energy by 2030: Modi", The Week, 21 November 2020, https://www.theweek.in/news/india/2020/11/21/india-will-achieve-450gw-renewable-energy-2030.html.

32 European Commission, "The European Green Deal Investment Plan and Just Transition Mechanism explained", 14 January 2020, https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_24.

33 L. Hurst and M. McMahon, "EU Green Week: Here's Europe's plan to be first carbon-neutral continent", Euro News, https://www.euronews.com/2020/10/19/eu-green-week-here-s-europe-s-plan-to-be-first-carbon-neutral-continent, updated 20 October 2020; European Commission, "A European Green Deal", https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, viewed 15 November 2020; C. Papanicolaou, "European Commission announces 2030 Climate Target Plan", Lexology, 3 November 2020, https://www.lexology.com/library/detail.aspx?g=9ea6d939-1301-408c-9ec7-5cf4cfd4223d; I. Todorović, "EU leaders agree on budget, green recovery funds, 55% emission cut goal", Balkan Green Energy News, 12 December 2020, https://balkangreenenergynews.com/eu-leaders-agree-on-budget-green-recovery-funds-55-emission-cut-goal.

34 J. Spaes, "France makes 44 GW solar target official", pv magazine, 23 April 2020, https://www.pv-magazine.com/2020/04/23/france-makes-2028-solar-target-official; "France set to ban sale of petrol and diesel vehicles by 2040", BBC, 6 July 2017, https://www.bbc.com/news/world-europe-40518293.

35 Government of the United Kingdom, *The Ten Point Plan for a Green Industrial Revolution* (London: November 2020), p. 20, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf; J. Parnell, "UK boosts hydrogen, EVs and carbon capture with new net-zero plan", Greentech Media, 18 November 2020, https://www.

greentechmedia.com/articles/read/uk-unveils-ten-point-plan-to-be-net-zero-by-2050; Covington & Burling LLP, "The UK's 10-point Green Industrial Revolution Plan", Lexology, 19 November 2020, https://www.lexology.com/library/detail.aspx?g=5a3688a4-a6d0-492b-8404-be67c4c36a46.

36 Ibid., all references.

37 R. Harrabin, "Ban on new petrol and diesel cars in UK from 2030 under PM's green plan", BBC, 18 November 2020, https://www.bbc.com/news/science-environment-54981425.

38 H. Shin and S. Cha, "S. Korea to spend $95 bln on green projects to boost economy", *Reuters*, 14 July 2020, https://news.trust.org/item/20200714053209-5b4wg; S-Y. Kim et al., "The Republic of Korea's Green New Deal shows the world what a smart economic recovery looks like", The Conversation, 9 September 2020, https://theconversation.com/south-koreas-green-new-deal-shows-the-world-what-a-smart-economic-recovery-looks-like-145032; C. Huang, "The Republic of Korea is using coronavirus stimulus to green the economy", Nikkei Asia, 15 May 2020, https://asia.nikkei.com/Opinion/South-Korea-is-using-coronavirus-stimulus-to-green-the-economy.

39 Ibid., all references.

40 Africa Energy Portal, "Zimbabwe launches renewable energy, biofuels policies", 23 March 2020, https://africa-energy-portal.org/news/zimbabwe-launches-renewable-energy-biofuels-policies; "Zimbabwe government launches renewable energy policy", *Xinhua*, 19 March 2020, http://www.china.org.cn/world/Off_the_Wire/2020-03/19/content_75836009.htm.

41 "Zimbabwe government launches renewable energy policy", op. cit. note 40.

42 Ibid.

43 For buildings, the plan includes CAD 2.6 billion (USD 2.03 billion) for residential energy efficiency retrofit grants, CAD 2 billion (USD 1.6 billion) in financing for commercial and large-scale building retrofits. For transport, the plan includes CAD 287 million (USD 225 million) in funding to continue Canada's zero-emission vehicle programme until March 2022 (which provides rebates of up to CAD 5,000 (USD 3,911) for zero-emission passenger vehicles) as well as CAD 150 million (USD 117 million)to fund EV charging and hydrogen refuelling stations across Canada and a 100% tax write off for commercial light-duty, medium- and heavy-duty zero-emission vehicles. For industry, Canada's climate plan includes CAD 1.5 billion (USD 1.2 billion) in a Low-carbon and Zero-emissions Fuels Fund to increase the production and use of low-carbon fuels such as hydrogen (as well as renewable natural gas, renewable diesel and ethanol) and support for agriculture. D. Baic, "From building retrofits and a national hydrogen strategy to higher carbon taxes and planting trees: A primer on Canada's climate plan", *Globe and Mail*, 11 December 2020, https://www.theglobeandmail.com/canada/article-from-building-retrofits-and-a-national-hydrogen-strategy-to-higher; Environment and Climate Change Canada, "A healthy environment and a healthy economy", 11 December 2020, https://www.canada.ca/en/environment-climate-change/news/2020/12/a-healthy-environment-and-a-healthy-economy.html; M. Walsh, "Liberals pitch $15-billion in new spending, hike carbon tax to pass 2030 emissions goals", *Globe and Mail*, 11 December 2020, https://www.theglobeandmail.com/politics/article-liberals-pitch-15-billion-in-new-spending-170-carbon-tax-by-2030-to.

44 Transport commitments include a target of 1.5 million EVs by 2030, a target of 55% of city buses and 65% of school buses to be electrified by 2030, a mandate of 15% ethanol in gasoline by 2025 and 10% in biodiesel by 2030, a commitment to 50% reduction of emissions related to heating for buildings by 2030 by way of funding for electrification of building heating and cooling and a requirement for 10% renewable natural gas to be added to the natural gas network by 2030. Government of Quebec, "2030 Plan for a Green Economy", https://www.quebec.ca/en/government/policies-orientations/plan-green-economy, updated 16 November 2020; Government of Quebec, "The Implementation Plan: Unparalleled resources", https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/environnement/publications-adm/plan-economie-verte/fiche-synthese-pev2030-en.pdf, viewed 18 November 2020; Government of Quebec, *Gagnant pour le Quebec. Gagnant pour la planete* (Montreal : 2020), p. 30, https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/environnement/publications-adm/plan-economie-verte/plan-economie-verte-2030.pdf; CBC, "Quebec to ban sale of new gas-powered vehicles as of 2035", 14 November 2020, https://www.cbc.ca/news/canada/montreal/gas-vehicles-ban-electric-quebec-1.5802374; M. Lowrie, "Quebec to ban sale of gas-powered cars by 2035 as part of climate plan", The Canadian Press, 16 November 2020, https://globalnews.ca/news/7465476/quebec-climate-plan-unveiled-2020.

45 In 2019, CO_2 emissions from the operation of buildings increased to their highest level yet at around 10 gigatonnes, or 28% of total global energy-related CO_2 emissions. IEA, *World Energy Balances* (Paris: July 2020), https://www.iea.org/reports/world-energy-balances-overview; Global Alliance for Buildings and Construction, *2020 Global Status Report for Buildings and Construction* (Nairobi: 2020), http://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf.

46 IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Paris and Abu Dhabi: 2020), p. 11, https://www.irena.org/publications/2020/Nov/Renewable-Energy-Policies-in-a-Time-of-Transition-Heating-and-Cooling.

47 IEA, *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020/renewable-heat; IRENA, IEA and REN21, op. cit. note 46, p. 31.

48 **Figure 13** from REN21 Policy Database. See GSR 2021 Data Pack at www.ren21.net/gsr.

49 IRENA, IEA and REN21, op. cit. note 46.

50 M. Hall, "Covid-19 weekly round-up: Residential systems in Italy will get a 110% tax rebate and UK consumers are being paid to turn appliances on as coronavirus turns the energy world upside down", pv magazine, 27 May 2020, https://www.pv-magazine.com/2020/05/27/covid-19-weekly-round-up-residential-systems-in-italy-will-get-a-110-tax-rebate-and-uk-consumers-are-being-paid-to-turn-appliances-on-as-coronavirus-turns-the-energy-world-upside-down; "Italy enables homeowners to install PV systems for free", Balkan Green Energy News, 2 June 2020, https://balkangreenenergynews.com/italy-enables-homeowners-to-install-pv-systems-for-free; E. Bellini, "Italy extends 110% fiscal break for rooftop PV linked to building renovations to 2022", pv magazine, 21 December 2020, https://www.pv-magazine.com/2020/12/21/italy-extends-110-fiscal-break-for-rooftop-pv-linked-to-building-renovations-to-2022.

51 Agency of the Ministry of Environment of the Republic of Lithuania, "An invitation to replace old and inefficient heating boilers has been published", 2 January 2020, https://www.apva.lt/paskelbtas-kvietimas-senu-ir-neefektyviu-sildymo-katilu-keitimui-2.

52 Dentons, "Dutch subsidies for renewable energy: The end of the SDE+ scheme and the launch of the broadened SDE++", 16 April 2020, https://www.dentons.com/en/insights/alerts/2020/april/16/ams-dutch-subsidies-for-renewable-energy-the-end-of-the-sde-scheme.

53 Government of Scotland, "Green Recovery: Low Carbon Energy Project Development Funding (closed)",https://www.gov.scot/policies/renewable-and-low-carbon-energy/low-carbon-infrastructure-transition-programme, viewed 10 March 2021; Government of the United Kingdom, "Changes to RHI support and COVID-19 response: Notice of proposals: Extension of the Domestic Renewable Heat Incentive Scheme (DRHI) for an additional year until 31 March 2022", https://www.gov.uk/government/publications/changes-to-the-renewable-heat-incentive-rhi-schemes/changes-to-rhi-support-and-covid-19-response, updated 30 June 2020.

54 The programme includes support for the installation of thermal insulation, efficient air conditioning and heating systems including heat pumps, and for the installation of solar thermal or solar PV. IISD, "Eur4.5 million for energy efficiency in Portugal", 11 September 2020, https://www.iisd.org/sustainable-recovery/news/eur4-5-milllion-for-energy-efficiency-in-portugal; P. Dias, Solar Heat Europe, personal communication with REN21, 19 January 2021.

55 IEA, *2019 Global Status Report for Buildings and Construction* (Paris: 2019), p. 20, https://webstore.iea.org/download/direct/2930?fileName=2019_Global_Status_Report_for_Buildings_and_Construction.pdf.

56 IRENA, IEA, REN21, op. cit. note 46.

57 M. Jordan, IEA, personal communication with REN21, 7 May 2021.

58 Ibid.

59 A. Moore, "California home solar panels to become a necessary part of new building codes", Hydrogen Fuel News, 2 January 2020, https://www.hydrogenfuelnews.com/california-home-solar-panels-to-become-a-necessary-part-of-new-building-codes/8539135; N. Nellis, "Building code updates to encourage solar power", *Journal of Business*, 18 June 2020, https://www.spokanejournal.com/up-close/building-code-updates-to-encourage-solar-power. At the local level, Honolulu (Hawaii), included "solar-ready" roofs and solar water heating requirements in its building code, from E. Stampe and M. Stamas, "Honolulu votes to build back better for climate", Natural Resources Defense Council, 20 May 2020, https://www.nrdc.org/experts/elizabeth-stampe/honolulu-votes-build-back-better-climate.

60 F. Jossi, "This new building code in Minnesota is going to hurt its residential solar market", Solar Builder, 2 April 2020, https://solarbuildermag.com/news/this-new-building-code-in-minnesota-is-going-to-hurt-its-residential-solar-market.

61 IEA, op. cit. note 47.

62 "Danish Climate Agreement for Energy and Industry 2020 – Overview", 22 June 2020,https://kefm.dk/Media/C/B/faktaark-klimaaftale%20(English%20august%2014).pdf.

63 Provincial Government of British Columbia, "CleanBC Better Homes Low-Interest Financing Program", https://betterhomesbc.ca/rebates/financing, viewed 27 November 2020; *Canada Energy Regulator, Canada's Renewable Power Landscape 2016: Energy Market Analysis* (Calgary: 2016), https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/electricity/report/2016-canadian-renewable-power/2016cndrnwblpwr-eng.pdf.

64 J. Gerdes, "California moves to tackle another big emissions source: Fossil fuel use in buildings", Greentech Media, 4 February 2020, https://www.greentechmedia.com/articles/read/california-moves-to-tackle-another-big-emissions-source-fossil-fuel-use-in-buildings; "New Mexico governor signs solar energy, grid update bills", US News, 3 March 2020, https://www.usnews.com/news/best-states/new-mexico/articles/2020-03-03/new-mexico-governor-signs-solar-energy-grid-update-bills.

65 M. Mazengarb, "ACT government to build first all-electric hospital, powered by renewables", RenewEconomy, 2 September 2020, https://reneweconomy.com.au/act-government-to-build-first-all-electric-hospital-powered-by-renewables-76968.

66 A. Richter, "EUR 150m scheme to support renewable energy district heating systems in Romania", Think GeoEnergy, 7 November 2020, https://www.thinkgeoenergy.com/eur-150m-scheme-to-support-renewable-energy-district-heating-systems-in-romania.

67 B. Epp, "Poland shifts away from coal-fired district heating", Solarthermalworld.org, 6 December 2020, https://www.solarthermalworld.org/news/poland-shifts-away-coal-fired-district-heating.

68 IRENA, IEA and REN21, op. cit. note 46, p. 33.

69 European Commission, "Renovation Wave: Doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty", https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835, updated 16 October 2020; F. Simon, "EU launches 'renovation wave' for greener, more stylish buildings", EURACTIV, 15 October 2020, https://www.euractiv.com/section/energy/news/eu-launches-renovation-wave-for-greener-more-stylish-buildings; SolarPower Europe, *EU Market Outlook for Solar Power 2020-2024* (Brussels: December 2020), p. 25, https://www.solarpowereurope.org/wp-content/uploads/2020/12/3520-SPE-EMO-2020-report-11-mr.pdf.

70 Simon, op. cit. note 69.

71 Ibid.

72 M. Brignall, "Green Homes Grant: Homeowners can apply for up to £5,000 in England", *The Guardian* (UK), 30 September 2020, https://www.theguardian.com/environment/2020/sep/30/green-homes-grant-apply-egland-vouchers-insulation-double-glazing.

73 S. Surkes, "Ministry unveils program to make Israeli economy more energy efficient", Times of Israel, 17 November 2020, https://www.timesofisrael.com/ministry-unveils-program-to-make-israeli-economy-more-energy-efficient; "Israel launches 10-year national energy efficiency plan", *Xinhua*, 16 November 2020, http://www.xinhuanet.com/english/2020-11/16/c_139520363.htm.

74 Beveridge & Diamond PC, "Washington adopts 'PACER' legislation that will create a proven source of financing for energy and resiliency retrofits in commercial buildings", Lexology, 25 March 2020, https://www.lexology.com/library/detail.aspx?g=df6a1e2d-b68f-4cda-8aeb-f0e34292ece.

75 IRENA, IEA and REN21, op. cit. note 46, p. 11.

76 **Sidebar 5** based on the following sources: IRENA, "Hydrogen from renewable power", https://www.irena.org/energytransition/Power-Sector-Transformation/Hydrogen-from-Renewable-Power, viewed 10 March 2021; K. Appunn, "EU aims for 40 GW of green hydrogen electrolysers, and one million jobs, by 2030", RenewEconomy, 9 July 2020, https://reneweconomy.com.au/eu-aims-for-40gw-of-green-hydrogen-electrolysers-and-one-million-jobs-by-2030; J. Parnell, "European Union sets gigawatt-scale targets for green hydrogen", Greentech Media, 9 July 2020, https://www.greentechmedia.com/articles/read/eu-sets-green-hydrogen-targets-now-blue-hydrogen-has-to-keep-up; SolarPower Europe, op. cit. note 69, p. 27; "German government to agree national hydrogen strategy", *Economic Times*, 10 June 2020, https://energy.economictimes.indiatimes.com/news/renewable/german-government-to-agree-national-hydrogen-strategy/76299802; "Germany plans to promote 'green' hydrogen with €7 billion", EURACTIV, 11 June 2020, https://www.eceee.org/all-news/news/news-2020/germany-plans-to-promote-green-hydrogen-with-7-billion; CNBC, "UK government announces millions in funding for 'low carbon' hydrogen production", 18 February 2020, https://www.cnbc.com/2020/02/18/uk-government-announces-funding-for-low-carbon-hydrogen-production.html; "Norway sees hydrogen as a 'story of hope'", 8 June 2020, https://www.kallanishenergy.com/2020/06/08/norway-sees-hydrogen-as-a-story-of-hope; "Spain approves hydrogen strategy to spur low-carbon economy", EURACTIV, 7 October 2020, https://www.euractiv.com/section/energy/news/spain-approves-hydrogen-strategy-to-spur-low-carbon-economy; E. Bellini, "Scotland stimulates hydrogen economy with £100m investment", pv magazine, 22 December 2020, https://www.pv-magazine.com/2020/12/22/scotland-stimulates-hydrogen-economy-with-100m-investment. The AUD 300 million (USD 230 million) fund will provide finance, through direct investment and loans, to projects looking to grow Australia's renewable hydrogen sector, including the development of new domestic supply chains, export infrastructure and investing in projects that help grow local demand for hydrogen. M. Mazengarb, "CEFC to kick-start Australia's hydrogen industry with new $300m investment fund", RenewEconomy, 4 May 2020, https://reneweconomy.com.au/cefc-to-kick-start-australias-hydrogen-industry-with-new-300m-investment-fund-38339; V. Petrova, "Australia opens USD-44m funding round for green hydrogen", Renewables Now, 15 April 2020, https://renewablesnow.com/news/australia-opens-usd-44m-funding-round-for-green-hydrogen-695144; HyResource, *A Short Report on Hydrogen Industry Policy Initiatives and the Status of Hydrogen Projects in Australia* (December 2020), https://research.csiro.au/hyresource/wp-content/uploads/sites/378/2020/12/HyResource-Short-Report.pdf; S. Vorrath, "NT unveils strategy to lead global renewable hydrogen market", RenewEconomy, 10 July 2020, https://reneweconomy.com.au/nt-unveils-strategy-to-lead-global-renewable-hydrogen-market-75048; M. Mazengarb, "Tasmania boosts renewable hydrogen aspirations with $50m 'action plan'", RenewEconomy, 2 March 2020, https://reneweconomy.com.au/tasmania-boosts-renewable-hydrogen-aspirations-with-50m-action-plan-87011; BNAmericas, "Chile unveils green hydrogen strategy to become world-class exporter", 3 November 2020, https://www.bnamericas.com/en/news/chile-unveils-sweeping-green-hydrogen-strategy-to-become-world-class-exporter; Acera, "Ministerio de Energía adelanta los cuatro ejes de la estrategia nacional de hidrógeno verde a 2050", 19 May 2020, https://acera.cl/ministerio-de-energia-adelanta-los-cuatro-ejes-de-la-estrategia-nacional-de-hidrogeno-verde-a-2050. **Table 5** from IRENA (2020), *Green Hydrogen: A guide to policy making*, International Renewable Energy Agency, Ab Dhabi, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf; E. Bianco and S. Diab, IRENA, personal communication with REN21, 11 April 2021; R. Zeller, Vestas, personal communication with REN21, 12 April 2021; see GSR 2021 Data Pack for additional references at www.ren21.net/gsr.

77 IEA, op. cit. note 47.

78 Government of the United Kingdom, "PM commits £350 million to fuel green recovery", press release (London: 21 July 2020), https://www.gov.uk/government/news/pm-commits-350-million-to-fuel-green-recovery.

79 Netherlands Enterprise Agency, "Stimulation of sustainable energy production and climate transition (SDE++)", https://english.rvo.nl/subsidies-programmes/sde, viewed 10 March 2021.

80 "Danish Climate Agreement for Energy and Industry 2020", op. cit. note 62.

81 Zero Waste Scotland, "SME Loan Fund", https://energy.zerowastescotland.org.uk/SMELoan, viewed 18 December 2020.

82 E. Bellini, "Jamaica turns to solar for irrigation, water treatment", pv magazine, 15 December 2020, https://www.pv-magazine.com/2020/12/15/jamaica-turns-to-solar-for-irrigation-water-treatment.

83 J. M. Takouleu, "Egypt: $11.6 million to modernise several irrigation systems in the north", Afrik 21, 29 April 2020, https://www.afrik21.africa/en/egypt-11-6-million-to-modernise-several-irrigation-systems-in-the-north.

84 Baic, "From building retrofits and a national hydrogen strategy to higher carbon taxes and planting trees", op. cit. note 43; Environment and Climate Change Canada, op. cit. note 43; Walsh, op. cit. note 43.

85 IEA, *Energy Efficiency Indicators* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-indicators-2020.

86 "Trump's agriculture department announces 30% biofuel goal for 2050", *Reuters*, 20 February 2020, https://www.reuters.com/article/us-usa-ethanol/trumps-agriculture-department-announces-30-biofuel-goal-for-2050-idUSKBN20E1F3.

87 Africa Energy Portal, op. cit. note 40; "Zimbabwe government launches renewable energy policy", op. cit. note 40.

88 Presidencia de la República del Paraguay, Ministerio de Industria Y Comercio, "Por el cual se reglamenta la Ley N° 6389/2019, que establece el régimen de promoción para la elaboración sostenible y utilización obligatoria del biocombustible apto para la utilización en motores diésel", 30 March 2020, https://www.presidencia.gov.py/archivos/documentos/DECRETO3500_0m7n1d1y.PDF.

89 Biofuels International, "Brazil increases volume of biodiesel in fuel to 12%", 3 March 2020, https://biofuels-news.com/news/brazil-increases-volume-of-biodiesel-in-fuel-to-12; Biofuels International, "Brazil's ANP temporarily reduces biodiesel blend to 10%", 17 August 2020, https://biofuels-news.com/news/brazils-anp-temporarily-reduces-biodiesel-blend-to-10.

90 Biofuels Digest, "Cyprus government getting flack for higher fuel prices after boosting biofuel blend", 21 January 2020, https://www.biofuelsdigest.com/bdigest/2020/01/21/cyprus-government-getting-flack-for-higher-fuel-prices-after-boosting-biofuel-blend.

91 Standard & Poors Global, "Analysis: Indonesia's diesel, gasoline imports under pressure as biofuel targets increase", 20 February 2020, https://www.spglobal.com/platts/en/market-insights/latest-news/oil/022020-analysis-indonesias-diesel-gasoline-imports-under-pressure-as-biofuel-targets-increase.

92 Government of Ontario, "Greener gasoline", https://www.ontario.ca/page/greener-gasoline, viewed 19 October 2020; Government of Ontario, "Ontario to be national leader and require cleaner and greener gasoline", 26 November 2020, https://news.ontario.ca/en/release/59352/ontario-to-be-national-leader-and-require-cleaner-and-greener-gasoline-1.

93 Republic of Latvia, *Latvia's National Energy and Climate Plan 2021-2030* (Riga: 2020), p. 13, https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf.

94 "European Commission approves extension of Swedish tax exemption regime for liquid biofuels", Bloomberg, 13 October 2020, https://news.bloombergtax.com/daily-tax-report-international/european-commission-approves-extension-of-swedish-tax-exemption-regime-for-liquid-biofuels; The Iowa Biodiesel Board and *Biodiesel Magazine*, "Iowa legislature extends fuel tax incentive for biodiesel blends", 4 June 2020, http://www.biodieselmagazine.com/articles/2517034/iowa-legislature-extends-fuel-tax-incentive-for-biodiesel-blends.

95 Y. Praiwan, "Energy Ministry keen to maintain subsidies for biofuels", *Bangkok Post*, 30 January 2020, https://www.bangkokpost.com/business/1846739/energy-ministry-keen-to-maintain-subsidies-for-biofuels.

96 Biofuels International, "Finnish postal fleet to use renewable diesel to drive down emissions", 15 June 2020, https://biofuels-news.com/news/finnish-postal-fleet-to-use-renewable-diesel-to-drive-down-emissions.

97 Biofuels International, "Paraguayan Government grants 'free zone regime' for Omega Green biofuel plant", 27 January 2020, https://biofuels-news.com/news/paraguayan-government-grants-free-zone-regime-for-omega-green-biofuel-plant.

98 Biofuture Platform, "Brazil's RenovaBio emissions reduction credits start trading in the stock exchange", 27 April 2020, http://www.biofutureplatform.org/post/brazil-s-renovabio-emissions-reduction-credits-start-trading-in-the-stock-change.

99 The funding was for four plants producing biofuels from household waste, unused straw from farmland and old wood, and the biofuel generated at these plants is expected to help the country decarbonise road and air transport, from Biofuels International, "UK's Department for Transport announces funding for biofuel projects", 6 January 2020, https://biofuels-news.com/news/uks-department-for-transport-announces-funding-for-biofuel-projects.

100 Biofuels International, "US Department of Energy to provide $75 million for biofuel crop research", 15 January 2020, https://biofuels-news.com/news/us-department-of-energy-to-provide-75-million-for-biofuel-crop-research; "USDA announces $100 million in competitive grants for biofuels infrastructure", Successful Farming, 4 April 2020, https://www.agriculture.com/news/business/usda-announces-100-million-in-competitive-grants-for-biofuels-infrastructure.

101 Iowa Renewable Fuels Association, "Iowa legislature funds state's biofuel infrastructure program", *Biodiesel Magazine*, 16 June 2020, http://www.biodieselmagazine.com/articles/2517045/iowa-legislature-funds-stateundefineds-biofuel-infrastructure-program.

102 "Japan to offer up to ¥800,000 in subsidies for electric vehicles", *Japan Times*, 25 November 2020, https://www.japantimes.co.jp/news/2020/11/25/business/subsidies-electric-vehicles; Japan Ministry of Economy, Trade and Industry, "'Clean energy vehicle introduction project cost subsidy that can be used even in the event of a disaster' was included in the third supplementary budget for the second year of Reiwa", 22 December 2020, https://www.meti.go.jp/press/2020/12/20201222006/20201222006.html; Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, "E-Mobilitätsoffensive 2021", https://www.klimaaktiv.at/mobilitaet/elektromobilitaet/foerderaktion_emob2021.html, viewed 10 March 2021. Policies linking renewables and EVs previously were in place in Germany and Luxembourg but were no longer in place as of 2018 and 2017, respectively.

103 "Kolkata: Solar panels on depot roofs to charge e-buses", *Economic Times*, 10 February 2020, https://energy.economictimes.indiatimes.com/news/renewable/kolkata-solar-panels-on-depot-roofs-to-charge-e-buses/74062260.

104 K. Pyzyk, "Delaware transit agency to power electric buses with solar array", Smart Cities Dive, 26 August 2020, https://www.smartcitiesdive.com/news/delaware-transit-agency-electric-bus-solar-array/584048.

105 REN21 Policy Database. See GSR 2021 Data Pack for details: www.ren21.net/gsr-2021.

106 R. Saeed Khan, "Pakistan launches electric vehicle plan with cars in slow lane", *Reuters*, 29 June 2020, https://news.trust.org/item/20200629031504-axvnf.

107 "Denmark agrees deal to have 775,000 electric cars by 2030", *Reuters*, 4 December 2020, https://news.trust.org/item/20201204160932-5143z.

108 Notes from Poland, "Polish government's electric vehicle subsidies fail to attract applications", 10 July 2020, https://notesfrompoland.com/2020/07/10/polish-governments-electric-vehicle-subsidies-fail-to-attract-applications.

109 M. Mazengarb, "NSW government triples EV fleet pledge, to ease regulations for charging infrastructure", The Driven, 2 June 2020, https://thedriven.io/2020/06/02/nsw-government-triples-ev-fleet-pledge-to-ease-regulations-for-charging-infrastructure.

110 D. Wagman, "Sunrise brief: New York offers funds for electric bus transition", pv magazine, 30 December 2020, https://pv-magazine-usa.com/2020/12/30/sunrise-brief-new-york-offers-funds-for-electric-bus-transition.

111 Government Technology, "New Hawaii law could help boost EV charging access", 21 January 2020, https://www.govtech.com/fs/infrastructure/New-Hawaii-Law-Could-Help-Boost-EV-Charging-Access.html; J. St. John, "California targets nearly $400M to fill gaps in EV charging infrastructure", Greentech Media, 16 October 2020, https://www.greentechmedia.com/articles/read/california-targets-384m-to-fill-gaps-in-electric-vehicle-charging-infrastructure.

112 "Greece goes after cleaner transport with tax breaks for electric cars", *Reuters*, 5 June 2020, https://www.reuters.com/article/us-climatechange-greece-autos-idUSKBN23C1P6; Rokas Law Firm, "Law for the Promotion of Electric Mobility provides economic incentives to purchase e-vehicles", Lexology, 14 December 2020, https://www.lexology.com/library/detail.aspx?g=3b6925aa-ded5-494f-b30e-15478c98005f.

113 Tax treatments for hybrids and EVs includes establishment of a 0% import duty, exemption from paying VAT, and exemption from the payment of annual registration fees. Consortium Legal, "Trends in electric mobility: El Salvador on the road to sustainable mobility in its regulatory framework", Lexology, 20 October 2020, https://www.lexology.com/library/detail.aspx?g=af058893-8c15-4b0e-947c-38de7cf6d0ea.

114 "New Jersey passes aggressive e-mobility legislation in effort to decarbonize transport", Renewable Energy World, 14 January 2020, https://www.renewableenergyworld.com/2020/01/14/new-jersey-passes-aggressive-e-mobility-legislation-in-effort-to-decarbonize-transport.

115 IEA, op. cit. note 1, p. 160.

116 M. Sharmina et al., "Decarbonising the critical sectors of aviation, shipping, road freight and industry to limit warming to 1.5–2°C", *Climate Policy* (2020), https://doi.org/10.1080/14693062.2020.1831430; B. Lucas, "Sectors that are challenging to decarbonise", K4D, 22 March 2020, p. 9, https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/15249/786_Sectors_challenging_to_decarbonise.pdf.

117 "Indian Railways gears up to become 'Green Railway' by 2030", *Economic Times*, 13 July 2020, https://energy.economictimes.indiatimes.com/news/power/indian-railways-gears-up-to-become-green-railway-by-2030/76938990.

118 C. Rollet, "French railway operator buys 40 MW of power through solar PPA", pv magazine, 18 June 2020, https://www.pv-magazine.com/2020/06/18/french-railway-operator-buys-40-mw-of-power-through-solar-ppa.

119 "Network Rail's emissions pathway to Net Zero", Carbon Intelligence, https://carbon.ci/case-studies/network-rail-becomes-the-first-railway-organisation-to-set-science-based-targets-aligned-to-1-5-degrees, viewed 10 March 2021.

120 Biofuels International,"Netherlands examines biofuels' law changes to meet RED II targets", 11 December 2020, https://biofuels-news.com/news/netherlands-examines-biofuels-law-changes-to-meet-red-ii-targets.

121 S. Djunisic, "Port of Valencia plans to add 8.5 MW of PV for own operations", Renewables Now, 22 April 2020, https://renewablesnow.com/news/port-of-valencia-plans-to-add-85-mw-of-pv-for-own-operations-695937; E. Bellini, "Portuguese green hydrogen for the Port of Rotterdam", pv magazine, 24 September 2020,,https://www.pv-magazine.com/2020/09/24/portuguese-green-hydrogen-for-the-port-of-rotterdam.

122 E. Voegele, "Norway to implement biofuel mandate for aviation fuel in 2020", *Biodiesel Magazine*, 11 October 2018, http://www.biodieselmagazine.com/articles/2516476/norway-to-implement-biofuel-mandate-for-aviation-fuel-in-2020; Gevo, Inc., "Sweden and Norway target increased use of sustainable aviation fuel", *Global Newswire*, 21 September 2020, https://www.globenewswire.com/news-release/2020/09/21/2096569/0/en/Sweden-and-Norway-Target-Increased-Use-of-Sustainable-Aviation-Fuel.html.

123 European Commission, "Sustainable aviation fuels – ReFuelEU Aviation", https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-ReFuelEU-Aviation-Sustainable-Aviation-Fuels, viewed 23 February 2021; "Aviation and fuel sectors respond favourably to major EU policy initiative to boost sustainable aviation fuels", Green Air, 30 April 2020, https://www.greenaironline.com/news.php?viewStory=2688.

124 Connexion, "France to oblige airlines to use green but expensive biofuel", 12 December 2020, https://www.connexionfrance.com/French-news/France-to-oblige-airlines-to-use-green-but-expensive-biofuel.

125 "Europe makes legislative push for aviation transition", Argus Media, 30 September 2020, https://www.argusmedia.com/en/news/2145902-europe-makes-legislative-push-for-aviation-transition.

126 Neste, "Neste: Sweden becomes a frontrunner in sustainable aviation", 17 September 2020, https://www.neste.com/releases-and-news/aviation/neste-sweden-becomes-frontrunner-sustainable-aviation.

127 Government of the United Kingdom, "Jet Zero Council", https://www.gov.uk/government/groups/jet-zero-council, viewed 10 March 2021.

128 Globally, distributed solar PV capacity is forecast to increase more than 250% by 2024. IEA, *Renewables 2019* (Paris: 2019), https://www.iea.org/reports/renewables-2019/distributed-solar-pv; IRENA, *Climate Change and Renewable Energy: National Policies and the Role of Communities, Cities and Regions* (Abu Dhabi: 2019), p. 27, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_climate_sustainability_2019.pdf; SolarPower Europe, op. cit. note 69, p. 25; IEA, *Trends in Photovoltaic Applications 2020* (Paris: 2020), p. 4, https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf.

129 **Box 5** based on the following sources: IRENA, *Towards 100% Renewable Energy: Utilities In Transition* (Abu Dhabi: 2020), pp. 14, 16, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/IRENA_Coalition_utilities_2020.pdf; "Greece's PPC to spend 3.4 bln euro on power grid, renewables by 2023", *Reuters*, 3 December 2020, https://energy.economictimes.indiatimes.com/news/renewable/greeces-ppc-to-spend-3-4-bln-euro-on-power-grid-renewables-by-2023/79539896. At least 15 utilities had renewable commitments by the end of 2019. L. Bird and T. Clevenger, "2019 was a watershed year for clean energy commitments from U.S. states and utilities", WRI Blog, 20 December 2019, https://www.wri.org/blog/2019/12/2019-was-watershed-year-clean-energy-commitments-us-states-and-utilities; H. K. Trabish, "As 100% renewables goals proliferate, what role for utilities?" Utility Dive, 2 April 2019, https://www.utilitydive.com/news/as-100-renewables-goals-proliferate-what-role-for-utilities/551165; J. St. John, "As fossil fuel pipelines fall to opposition, utilities see renewable energy as safe bet", Greentech Media, 6 July 2020, https://www.greentechmedia.com/articles/read/as-fossil-fuel-pipelines-fall-to-opposition-can-clean-energy-replace-them; S. Vorrath, "New Mexico utility to replace coal plant with four solar and battery projects", RenewEconomy, 16 October 2020, https://reneweconomy.com.au/new-mexico-utility-to-replace-coal-plant-with-four-solar-and-battery-projects-31989; J. St. John, "FirstEnergy's carbon-reduction pledge lacks clear path to cutting coal use", Greentech Media, 11 November 2020,https://www.greentechmedia.com/articles/read/firstenergys-carbon-neutral-by-2050-pledge-lacks-clear-path-to-cutting-coal-use; T. Bacon, "Power company commitments to cut carbon pollution are an important step for our climate and health. Here's what we need next", Environmental Defense Fund, 5 May 2020, http://blogs.edf.org/climate411/2020/05/05/power-company-commitments-to-cut-carbon-pollution-are-an-important-step-for-our-climate-and-health-heres-what-we-need-next; J. St. John, "The 5 biggest us utilities committing to zero carbon emissions by 2050", Greentech Media, 16 September 2020, https://www.greentechmedia.com/articles/read/the-5-biggest-u.s-utilities-committing-to-zero-carbon-emissions-by-mid-century; S. Carpenter, "U.S. utility companies rush to declare net-zero targets", *Forbes*, 15 October 2020, https://www.forbes.com/sites/scottcarpenter/2020/10/15/us-utility-companies-rush-to-declare-net-zero-targets.

130 Bundesministerium Klimashutz, Umwelt, Energie, Mobilität, Innovation und Technologie, "Energiewende für Österreich eingeleitet: Bundesregierung präsentiert Erneuerbaren-Ausbau-Gesetz", 11 March 2021, https://www.bmk.gv.at/service/presse/gewessler/20210311_eag.html.

131 Fransen et al., op. cit. note 17; IISD, "75 leaders announce…", op. cit. note 17; UNFCCC, "Climate Ambition Summit builds momentum for COP26", 12 December 2002, https://unfccc.int/news/climate-ambition-summit-builds-momentum-for-cop26; M. Darby, J. Lo and C. Farand, "As it happened: World leaders upgrade climate commitments on Paris anniversary", 12 December 2020, https://www.climatechangenews.com/2020/12/12/live-world-leaders-upgrade-climate-commitments-paris-anniversary-summit.

132 "Rhode Island governor aims for 100% renewable power by 2030", *Reuters*, 17 January 2020, https://www.nytimes.com/reuters/2020/01/17/us/17reuters-usa-rhode-island-renewables.html.

133 S. Vorrath, "Tasmania sets world-leading target of 200 per cent renewables by 2040", RenewEconomy, 4 March 2020, https://reneweconomy.com.au/tasmania-sets-world-leading-target-of-200-per-cent-renewables-by-2040.

134 Africa Energy Portal, "Zimbabwe launches renewable energy, biofuels policies", 23 March 2020, https://africa-energy-portal.org/

news/zimbabwe-launches-renewable-energy-biofuels-policies; "Zimbabwe government launches renewable energy policy", op. cit. note 40.

135 H. Alshammari, "Saudi Arabia aims to generate 50% of power from renewables by 2030", Arab News, 20 January 2021, https://www.arabnews.com/node/1795406/saudi-arabia; A. Aziz Aluwaisheg, "The benefits of Saudi Arabia's renewable energy push", Arab News, 29 June 2020, https://www.arabnews.com/node/1697306; S. Surkes, "Cabinet greenlights target of 30% renewable energy by 2030", Times of Israel, 25 October 2020, https://www.timesofisrael.com/cabinet-greenlights-target-of-30-renewable-energy-by-2030; E. Bellini, "Israel wants another 15 GW of solar by 2030", pv magazine, 3 June 2020, https://www.pv-magazine.com/2020/06/03/israel-wants-another-15-gw-of-solar-by-2030; E. Bellini, "Israeli government greenlights plan to add 15 GW of solar by 2030", pv magazine, 26 October 2020, https://www.pv-magazine.com/2020/10/26/israeli-government-greenlights-plan-to-add-15-gw-of-solar-by-2030.

136 Enerdata, "Papua New Guinea unveils its new Nationally Determined Contribution", 17 December 2020, https://www.enerdata.net/publications/daily-energy-news/papua-new-guinea-unveils-its-new-nationally-determined-contribution.html.

137 The Republic of Korea also committed that all coal-fired power plants whose 30-year lifecycles expire by 2034 would be retired (representing around 30 plants out a total of 60 currently in operation, although 24 coal-fired plants are expected to be converted to fossil gas). "S. Korea unveils draft plan to foster renewable energy", Yonhap News Agency, 8 May 2020, https://en.yna.co.kr/view/AEN20200508002200320; "The Republic of Korea confirms energy policy favouring renewables", NEI Magazine, 12 May 2020, https://www.neimagazine.com/news/newssouth-korea-confirms-energy-policy-favouring-renewables-7919619; I. Slav, "South Korea embarks on an ambitious renewable energy plan", OilPrice.com, 26 May 2020, https://oilprice.com/Latest-Energy-News/World-News/South-Korea-Embarks-On-An-Ambitious-Renewable-Energy-Plan.html.

138 Nikkei, "Japan sets sights on 50% renewable energy by 2050", 26 December 2020, https://asia.nikkei.com/Spotlight/Environment/Japan-sets-sights-on-50-renewable-energy-by-2050; L. Griffith, "Japan is setting 50% renewable energy capacity by 2050", Sunday Vision, 26 December 2020, https://www.sundayvision.co.ug/japan-is-setting-50-renewable-energy-capacity-by-2050.

139 "Uzbekistan plans route to cleaner electricity mix", World Nuclear News, 6 May 2020, https://www.world-nuclear-news.org/Articles/Uzbekistan-plans-route-to-cleaner-electricity-mix.

140 J. Costa Figueira, "Government unveils new plans claiming to make UK world leader in green energy", Climate Action, 9 October 2020, http://www.climateaction.org/news/government-unveils-new-plans-to-make-uk-world-leader-in-green-energy.

141 "Hungary unveils 'Christian democratic'-based climate strategy", Economic Times, 17 January 2020, https://energy.economictimes.indiatimes.com/news/renewable/hungary-unveils-christian-democratic-based-climate-strategy/73320204.

142 A. Frangoul, "Europe is planning a 25-fold increase in offshore wind capacity by 2050", CNBC, 19 November 2020, https://www.cnbc.com/2020/11/19/europe-plans-25-fold-increase-in-offshore-wind-capacity-by-2050.html; Ocean Energy Europe, *Ocean Energy: Key Trends and Statistics 2020* (Brussels: February 2021), p. 4, https://www.weamec.fr/en/wp-content/uploads/sites/2/2021/03/OEE-Stats-Trends-2020.pdf; WindEurope, *Wind Energy in Europe – 2020 Statistics and the Outlook for 2021-2025* (Brussels: February 2021), pp. 11, 17, https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-in-2020-trends-and-statistics.

143 R. Randazzo, "Arizona power must come from 100% carbon-free sources by 2050, regulators decide", AZ Central, 29 October 2020, https://www.azcentral.com/story/money/business/energy/2020/10/29/arizona-regulators-require-utilities-have-100-carbon-free-power-2050/6071275002.

144 J. St. John, "Virginia mandates 100% clean power by 2045", Greentech Media, 6 March 2020, https://www.greentechmedia.com/articles/read/virginia-100-clean-energy-by-2050-mandate-law.

145 Deloitte, *Power and Utilities Industry Outlook 2020*, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-2020-power-utilities-midyear.pdf; R. Bowers, "Maine and New York become the 6th and 7th states to adopt 100% clean electricity targets", US Energy Information Administration (EIA), 26 September 2019, https://www.eia.gov/todayinenergy/detail.php?id=41473.

146 IEA, op. cit. note 1, p. 146.

147 "Cabinet approves Renewable Energy Act amendment bill", Lexology, 23 March 2020, https://www.lexology.com/library/detail.aspx?g=684805eb-06b4-4b73-93c6-1ea5d06048c7; Baker McKenzie, "Vietnam increases feed-in-tariffs for biomass power projects", 11 March 2020, https://www.bakermckenzie.com/en/insight/publications/2020/03/vietnam-feed-in-tariffs-biomass-power-projects; B. Publicover, "Vietnam finally unveils new FITs for large-scale, rooftop, floating PV", pv magazine, 7 April 2020, https://www.pv-magazine.com/2020/04/07/vietnam-finally-unveils-new-fits-for-large-scale-rooftop-floating-pv.

148 A. Richter, "Turkey extends feed-in-tariff scheme for geothermal to mid-2021", Think GeoEnergy, 18 September 2020, https://www.thinkgeoenergy.com/turkey-extends-feed-in-tariff-scheme-for-geothermal-to-mid-2021; "Turkey's clean energy production gets nearly $570M in incentives in June", Daily Sabah, 19 July 2020, https://www.dailysabah.com/business/energy/turkeys-clean-energy-production-gets-nearly-570m-in-incentives-in-june.

149 E. Bellini, "Moldova introduces feed-in tariff for small scale solar", pv magazine, 2 March 2020, https://www.pv-magazine.com/2020/03/02/moldova-introduces-feed-in-tariff-for-small-scale-solar.

150 E. Bellini, "Czech government plans retroactive cuts for PV incentives, again", pv magazine, 25 May 2020, https://www.pv-magazine.com/2020/05/25/czech-plans-retroactive-cuts-for-pv-incentives-again; G. Deboutte, "French parliament approves retroactive FIT cuts for pre-2011, large scale PV", pv magazine, 17 December 2020, https://www.pv-magazine.com/2020/12/17/french-parliament-approves-retroactive-fit-cuts-for-pre-2011-large-scale-pv.

151 Legislature of Ukraine, "About modification of some laws of Ukraine concerning improvement of conditions of support of production of electric energy from alternative energy sources", 21 July 2020,https://zakon.rada.gov.ua/laws/show/810-20; S. Djunisic, "Ukrainian parliament confirms retroactive FiT cuts", Renewables Now, 24 July 2020, https://renewablesnow.com/news/ukrainian-parliament-confirms-retroactive-fit-cuts-707525; M. Hall, "Ukraine defines level of retroactive FIT cuts", pv magazine, 22 July 2020, https://www.pv-magazine.com/2020/07/22/ukraine-defines-level-of-retroactive-fit-cuts.

152 S. Enkhardt, "Switzerland provides additional $47m for solar incentives", pv magazine, 20 April 2020, https://www.pv-magazine.com/2020/04/20/switzerland-provides-additional-47m-for-solar-incentives; J. Spaes, "Switzerland renews support for renewables", pv magazine, 8 April 2020, https://www.pv-magazine.com/2020/04/08/switzerland-renews-support-for-renewables.

153 E. Bellini, "China entering post-FIT era with solid prospects", pv magazine, 17 June 2020, https://www.pv-magazine.com/2020/06/17/china-entering-post-fit-era-with-solid-prospects.

154 Macau Hub, "Angolan minister announces new investment in solar energy", 12 February 2020, https://macauhub.com.mo/2020/02/12/pt-ministro-de-angola-anuncia-novos-investimentos-em-energia-solar; Power Engineering International, "Djibouti's first renewables project launched", 13 February 2020, https://www.powerengineeringint.com/2020/02/13/djiboutis-first-renewables-project-launched; E. Bellini, "Nigeria launches off-grid solar tender", pv magazine, 24 August 2020, https://www.pv-magazine.com/2020/08/24/nigeria-launches-off-grid-solar-tender; E. Bellini, "Tender for 32 MW solar project subcontractors in Chad", pv magazine, 21 July 2020, https://www.pv-magazine.com/2020/07/21/tender-for-32-mw-solar-project-subcontractors-in-chad.

155 E. Bellini, "Slovakia launches first renewables auction", pv magazine, 26 February 2020, https://www.pv-magazine.com/2020/02/26/slovakia-launches-first-renewables-auction.

156 E. Bellini, "Bhutan launches ground-mounted PV tender", pv magazine, 9 September 2020, https://www.pv-magazine.com/2020/09/09/bhutan-launches-ground-mounted-pv-tender; A. J. Ang, "Green energy auction seen starting next year", BW World, 9 August 2020, https://www.bworldonline.com/green-energy-auction-seen-starting-next-year.

157 E. Bellini, "Croatia introduces provisions to tender 1 GW of solar", pv magazine, 22 May 2020,

https://www.pv-magazine.com/2020/05/22/croatia-introduces-provisions-to-tender-1-gw-of-solar.

158 S. Enkhardt, "Germany launches 650 MW tender for 'innovative' renewables", pv magazine, 13 July 2020, https://www.pv-magazine.com/2020/07/13/germany-launches-650-mw-tender-for-innovative-renewables; "New innovation rules for German tenders", reNEWS, 29 January 2020, , https://renews.biz/57684/new-innovation-rules-for-german-tenders.

159 "UK plans to include onshore wind, solar in next round of support auctions", *Economic Times*, 3 March 2020, https://energy.economictimes.indiatimes.com/news/renewable/uk-plans-to-include-onshore-wind-solar-in-next-round-of-support-auctions/74454411; Smart Energy, "UK govt reinstates subsidies for wind, solar from 2021", 17 April 2020, https://www.smart-energy.com/industry-sectors/policy-regulation/uk-govt-reinstates-subsidies-for-wind-solar-from-2021.

160 E. Bellini, "Botswana launches net metering scheme for rooftop PV", pv magazine, 10 November 2020, https://www.pv-magazine.com/2020/11/10/botswana-launches-net-metering-scheme-for-rooftop-pv.

161 E. Bellini, "Tunisia introduces new rules for self-consumption, net metering", pv magazine, 28 February 2020, https://www.pv-magazine.com/2020/02/28/tunisia-introduces-new-rules-for-self-consumption-net-metering.

162 E. Bellini, "Zimbabwe launches smart-meter-led net metering and 500 MW solar tender", pv magazine, 18 May 2020, https://www.pv-magazine.com/2020/05/18/zimbabwe-launches-smart-meter-led-net-metering-and-500-mw-solar-tender; E. Bellini, "Saudi Arabia outlines new provisions for rooftop PV", pv magazine, 13 July 2020, https://www.pv-magazine.com/2020/07/13/saudi-arabia-introduces-new-provisions-for-rooftop-pv.

163 A. Parikh, "Kerala orders discoms to give net metering to prosumers on a first come, first serve basis", Mercom India, 20 February 2020, https://mercomindia.com/kerala-discoms-net-metering-prosumers; S. Weigel, "Virginia Clean Economy Act passes in the Virginia General Assembly", Edison Energy, 13 March 2020, https://www.edisonenergy.com/blog/energy-policy-were-watching-in-2020-vcea.

164 A. Verma, "Kerala Commission issues renewable energy and net metering regulations", Saur Energy International, 24 February 2020, https://www.saurenergy.com/solar-energy-news/kerala-commission-issues-renewable-energy-and-net-metering-regulations; I. Tsagas, "Dubai utility clamps down on net-metered commercial solar", pv magazine, 26 May 2020, https://www.pv-magazine.com/2020/05/26/dubai-utility-clamps-down-on-net-metered-commercial-solar.

165 M. Hall, "Egypt to impose 'merger fee' on net-metered solar", pv magazine, 28 September 2020, https://www.pv-magazine.com/2020/09/28/egypt-to-impose-merger-fee-on-net-metered-solar; M. Farag, "EgyptERA pursues solar energy users by charging amalgamation fees", Daily News Egypt, 22 September 2020, https://dailynewsegypt.com/2020/09/22/egyptera-pursues-solar-energy-users-by-charging-amalgamation-fees.

166 J. Spaes, "Wallonia's prosumer grid fee comes into force", pv magazine, 29 September 2020, https://www.pv-magazine.com/2020/09/29/wallonias-prosumer-grid-fee-comes-into-force.

167 A. Proudlove, B. Lips and D. Sarkisian, *The 50 States of Solar: 2020 Policy Review and Q4 2020 Quarterly Report Executive Summary* (Raleigh: North Carolina Clean Energy Technology Center, January 2021), https://static1.squarespace.com/static/5ac5143f9d5abb8923a86849/t/601093095908283f619d1b34/1611698959121/Q4-20-Solar-Exec-Summary-Final.pdf; K. Pickerel, "Which states offer net metering?" Solar Power World, 27 March 2020, https://www.solarpowerworldonline.com/2020/03/which-states-offer-net-metering; A. Brentan, "A unanimous FERC decision saves net metering, but its future remains uncertain", *Forbes*, 17 July 2020, https://www.forbes.com/sites/brentanA./2020/07/17/a-unanimous-ferc-decision-saves-net-metering-but-its-future-remains-uncertain.

168 Ibid., all references.

169 Ibid., all references.

170 R. Walton, "New York adopts net metering alternative, delays implementation due to COVID-19", Utility Dive, 17 July 2020, https://www.utilitydive.com/news/new-york-adopts-net-metering-alternative-delays-implementation-due-to-covi/581812.

171 Proudlove, Lips and Sarkisian, op. cit. note 167; Pickerel, op. cit. note 167; Brentan, op. cit. note 167.

172 European Commission, *EU Renewable Energy Financing Mechanism* (Brussels: 2020), https://ec.europa.eu/energy/sites/ener/files/documents/eu_renewable_energy_financing_mechanism_en.pdf; J. Scully, "EU raises emissions reduction ambition following renewables progress", PV Tech, 18 September 2020, https://www.pv-tech.org/news/eu-announces-new-emissions-reduction-target-following-renewables-progress.

173 T. Tsanova, "Austria sets budget, deadline for small solar subsidy programme", Renewables Now, 23 June 2020, https://renewablesnow.com/news/austria-sets-budget-deadline-for-small-solar-subsidy-programme-703741.

174 V. Spasić, "Greece earmarks EUR 850 million for energy efficiency, prosumers", Balkan Green Energy News, 11 August 2020, https://balkangreenenergynews.com/greece-earmarks-eur-850-million-for-energy-efficiency-prosumers; E. Bellini, "Greece supports rooftop PV and residential storage through energy efficiency program", pv magazine, 15 December 2020, https://www.pv-magazine.com/2020/12/15/greece-supports-rooftop-pv-and-residential-storage-through-energy-efficiency-program.

175 "Dutch gov't doubles 2020 renewable energy subsidies to 4 bln euros", National Post, 4 March 2020, https://nationalpost.com/pmn/environment-pmn/dutch-govt-doubles-2020-renewable-energy-subsidies-to-4-bln-euros; "Spain to offer $215 million in renewable energy subsidies", *Economic Times*, 11 September 2020, https://energy.economictimes.indiatimes.com/news/renewable/spain-to-offer-215-million-in-renewable-energy-subsidies/78056370.

176 S. Enkhardt, "Switzerland allocates another $513m for solar incentives", pv magazine, 15 November 2020, https://www.pv-magazine.com/2020/11/16/switzerland-allocates-another-513m-for-solar-incentives; S. Enkhardt, "Switzerland provides additional $47m for solar incentives", pv magazine, 20 April 2020, https://www.pv-magazine.com/2020/04/20/switzerland-provides-additional-47m-for-solar-incentives.

177 Costa Figueira, op. cit. note 140.

178 P. Sánchez Molina, "Colombia streamlines tax incentives for renewables", pv magazine, 16 June 2020,https://www.pv-magazine.com/2020/06/16/colombia-streamlines-tax-incentives-for-renewables.

179 E. Bellini, "Turkey cuts admin fee for rooftop PV systems", pv magazine, 13 February 2020, https://www.pv-magazine.com/2020/02/13/turkey-cuts-admin-fee-for-small-pv-systems.

180 E. Bellini, "Soft loans for Jordan's solar rebate scheme", pv magazine, 30 November 2020, https://www.pv-magazine.com/2020/11/30/soft-loans-for-jordans-solar-rebate-scheme;J. Rojo Martín, "Israel's new government plots 15GW-plus solar plan as policy priority", PV Tech, 4 June 2020, https://www.pv-tech.org/news/israels-new-government-plots-15gw-plus-solar-plan-as-policy-priority.

181 R. Ranjan, "UP announces ₹15,000-30,000 subsidy for residential rooftop solar systems up to 10 kW", Mercom India, 12 March 2020, https://mercomindia.com/up-announces-subsidy-residential-rooftop-solar-systems.

182 S. Vorrath, "Renewables industry rejoices as Australia's biggest electricity state goes green", RenewEconomy, 9 November 2020, https://reneweconomy.com.au/renewables-industry-rejoices-as-australias-biggest-electricity-state-goes-green-25202; S. Vorrath, "New crack in solar ceiling as Victoria sweetens rooftop deal for landlords", One Step Off the Grid, 28 July 2020, https://onestepoffthegrid.com.au/new-crack-in-solar-ceiling-as-victoria-sweetens-rooftop-deal-for-landlords.

183 C. Xuewan and L. Yutong, "China to slash subsidies for renewable energy amid drive to cut state support", Caixin Global, 11 March 2020, https://www.caixinglobal.com/2020-03-11/china-to-slash-subsidies-for-renewable-energy-amid-drive-to-cut-state-support-101527138.html; M. Xu and T. Daly, "UPDATE 2-China lifts renewable power subsidy for 2021 by nearly 5% y/y", *Reuters*, 20 November 2020, https://www.reuters.com/article/china-renewables-subsidy/update-2-china-lifts-renewable-power-subsidy-for-2021-by-nearly-5-y-y-idUKL1N2I60PC; C. Xiao, "China unveils boost for 2021 renewable subsidies, solar wins biggest share", PV Tech, 25 November 2020,https://www.pv-tech.org/news/china-unveils-boost-for-2021-renewable-subsidies-solar-wins-biggest-share.

184 Global Wind Energy Council, "A gust of growth in China makes 2020 a record year for wind energy", 21 January 2021, https://gwec.net/a-gust-of-growth-in-china-makes-2020-

a-record-year-for-wind-energy; K. Lowder, "Wind power & renewables surge to new record in China", CleanTechnica, 22 January 2021, https://cleantechnica.com/2021/01/22/wind-power-renewables-surge-to-new-record-in-china.

185 Xuewan and Yutong, op. cit. note 183; Xu and Daly, op. cit. note 183; Xiao, op. cit. note 183.

186 T. Gillies, "Why California's new solar mandate could cost new homeowners up to an extra $10,000", CNBC, 17 February 2019, https://www.cnbc.com/2019/02/15/california-solar-panel-mandate-could-cost-new-homeowners-big.html; SolarPower Europe, *Global Market Outlook for Solar Power, 2020-2024* (Brussels: June 2020), p. 34,https://www.solarpowereurope.org/global-market-outlook-2020-2024.

187 SolarPower Europe, op. cit. note 186, p. 34.

188 Stuff, "Businesses are paying extra for 'renewable electricity' certificates, but are they any more than hot air?" 8 November 2020, https://www.stuff.co.nz/environment/climate-news/123158045/businesses-are-paying-extra-for-renewable-electricity-certificates-but-are-they-any-more-than-hot-air; "New rules to crack down on 'greenwash' in corporate clean energy claims," *Reuters*, 29 October 2018, https://www.reutersevents.com/sustainability/new-rules-crack-down-greenwash-corporate-clean-energy-claims.

189 South Pole, "Energy Attribute Certificates (EACs)", https://www.southpole.com/sustainability-solutions/renewable-energy-certificates, viewed 6 May 2021.

190 Trade Arabia, "Bahrain's SEA issues Renewable Energy Certificate", 19 July 2020, http://www.tradearabia.com/news/IND_370512.html.

191 Energy Global, "Renewable energy becomes available to buy in West Africa", 4 February 2020, https://www.energyglobal.com/special-reports/04022020/renewable-energy-becomes-available-to-buy-in-west-africa.

192 US Environmental Protection Agency, "Community Choice Aggregation", https://www.epa.gov/greenpower/community-choice-aggregation, viewed 2 February 2020.

193 P. Sánchez Molina, "Chile introduces energy communities", pv magazine, 28 September 2020, https://www.pv-magazine.com/2020/09/28/chile-introduces-energy-communities.

194 C. Rollett, "Energy communities are now allowed in France", pv magazine, 23 March 2020, https://www.pv-magazine.com/2020/03/23/energy-communities-are-now-allowed-in-france.

195 E. Bellini, "Energy community provisions for Italy", pv magazine, 3 March 2020, https://www.pv-magazine.com/2020/03/03/energy-community-provisions-for-italy; S. Matalucci, "Italy awards tariff of €0.11/kWh for shared electricity in energy communities", pv magazine, 25 November 2020, https://www.pv-magazine.com/2020/11/25/italy-awards-tariff-of-e0-11-kwh-for-shared-electricity-in-energy-communities.

196 CE Legal Matters, "A legislative boost to the energy sector in Montenegro", 19 October 2020, https://ceelegalmatters.com/briefings/14839-a-legislative-boost-to-the-energy-sector-in-montenegro.

197 Virginia State Corporation Commission, "SCC adopts rules for introduction of shared community solar projects", 23 December 2020, https://www.scc.virginia.gov/newsreleases/release/SCC-Sets-Rules-for-Shared-Community-Solar-Projects.

198 Intergovernmental Panel on Climate Change (IPCC), *Renewable Energy Sources and Climate Change Mitigation* (Geneva: 2012), p. 16, https://archive.ipcc.ch/pdf/special-reports/srren/SRREN_FD_SPM_final.pdf.

199 Ibid., p. 16.

200 Ibid., p. 16.

201 Federal Energy Regulatory Commission, "FERC opens wholesale markets to distributed resources: Landmark action breaks down barriers to emerging technologies, boosts competition", 17 September 2020, https://www.ferc.gov/news-events/news/ferc-opens-wholesale-markets-distributed-resources-landmark-action-breaks-down.

202 US National Renewable Energy Laboratory, *Sources of Operational Flexibility* (Golden, CO: May 2015), https://www.nrel.gov/docs/fy15osti/63039.pdf.

203 S. Mahapatra, "India moves ahead with new renewable energy transmission projects", CleanTechnica, 10 April 2020, https://cleantechnica.com/2020/04/10/india-moves-ahead-with-new-renewable-energy-transmission-projects.

204 S. Dludla, "Eskom on R118bn expansion project to add 30 GW over 10 years", IOL, 20 October 2020, https://www.iol.co.za/business-report/energy/eskom-on-r118bn-expansion-project-to-add-30gw-over-10-years-b5e0cdf7-cb08-4d7a-ae99-682e6d5b11d3.

205 UK Office of Gas and Energy Markets (Ofgem), "Ofgem proposes £25 billion to transform Great Britain's energy networks", press release (London: 9 July 2020), https://www.ofgem.gov.uk/publications-and-updates/ofgem-proposes-25-billion-transform-great-britain-s-energy-networks.

206 M. Maisch, "Queensland fast-tracks new transmission line to unlock renewables, battery industry investment", pv magazine, 20 May 2020, https://www.pv-magazine-australia.com/2020/05/20/queensland-fast-tracks-new-transmission-line-to-unlock-renewables-battery-industry-investment; Mondaq, " UK: Energy update – Victoria acts to enable transmission upgrades required for renewable generation projects", 25 February 2020, https://www.mondaq.com/Article/896954; NSW Government, "Renewable Energy Zones", https://energy.nsw.gov.au/renewables/renewable-energy-zones, viewed 20 October 2020; M. Mazengarb, "NSW to fast-track network approvals for first renewable energy zone", RenewEconomy, 17 December 2020, https://reneweconomy.com.au/nsw-to-fast-track-network-approvals-for-first-renewable-energy-zone-53918.

207 Deloitte, "2020 Renewable Energy Industry Outlook: Exploring renewable energy policy, innovation, and market trends", https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/renewable-energy-outlook.html, viewed 4 November 2019.

208 E. Bellini, "Turkey introduces new provisions for energy storage", pv magazine, 19 February 2020, https://www.pv-magazine.com/2020/02/19/turkey-introduces-new-provisions-for-energy-storage.

209 G. Parkinson, "NSW to fund four new big battery projects as it readies to flick switch from coal", RenewEconomy, 15 August 2020, https://reneweconomy.com.au/nsw-to-fund-four-new-big-battery-projects-as-it-readies-to-flick-switch-from-coal-82272.

210 S. Enkhardt and E. Bellini, "Incentives for small solar-plus-storage in Austria and Italy", pv magazine, 11 March 2020, https://www.pv-magazine.com/2020/03/11/incentives-for-small-solar-plus-storage-in-austria-and-italy; E. Bellini, "Italy's Lombardy region adds another €20 million for residential PV+storage", pv magazine, 30 October 2020, https://www.pv-magazine.com/2020/10/30/italys-lombardy-region-allocates-another-e20-million-for-residential-solarstorage.

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1 International Energy Agency (IEA), *Energy Technology Perspectives 2020* (Paris: 2020), https://www.iea.org/reports/energy-technology-perspectives-2020/etp-model.

2 For a description of the bioenergy options and their levels of maturity, see, for example: Ibid.; Renewable Energy Policy Network for the 21st Century (REN21), *Renewable Energy Pathways in Road Transport* (Paris: 2020), https://www.ren21.net/2020-re-pathways-in-road-transport; International Renewable Energy Agency (IRENA), *Recycle: Bioenergy, a report for the G20 Energy Sustainability Working Group* (Abu Dhabi: 2020), https://www.irena.org/publications/2020/Sep/Recycle-Bioenergy; IRENA, IEA and REN21, *Renewable Energy Polices in a Time of Transition: Heating and Cooling* (Paris: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_IEA_REN21_Policies_Heating_Cooling_2020.pdf.

3 Based on analysis summarised in **Figure 17**; see endnote 5 for this section.

4 Based on IEA, *World Energy Outlook 2020* (Paris: 2020), Annex A, World Balance, https://www.iea.org/reports/world-energy-outlook-2020.

5 Around half from IEA, *Renewables 2018* (Paris: 2018), https://www.iea.org/renewables-2018. **Figure 17** estimated shares based on sources in endnote 50 in Global Overview chapter.

6 IEA, op. cit. note 5.

7 Based on data in **Figures 18, 19** and **20**; see relevant endnotes.

8 **Figure 18** estimated shares in 2019 based on historical data from IEA, *World Energy Balances and Statistics*, op. cit. note 5. Figure of 2.81 EJ of renewable electricity for heat in buildings in 2018 from IEA, op. cit. note 4, and for previous years based on compound annual growth rate of 5.3% from idem. Total heat demand in buildings includes electricity for heating and cooling, derived from estimated renewable electricity for heat and calculated share of renewable energy in electricity production for target year. See also Global Overview chapter of this report, Figures 1 and 4.

9 IRENA, IEA and REN21, op. cit. note 2.

10 Based on IEA, op. cit. note 5.

11 IEA et al., *Tracking SDG 7: The Energy Progress Report 2020* (Washington, DC: 2020), https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/May/SDG7Tracking_Energy_Progress_2020.pdf.

12 Ibid. Household air pollution from polluting cook stoves is linked directly to 2.5 million premature deaths annually (equal to the combined total of deaths from malaria, tuberculosis and HIV/AIDS). In addition, the low efficiency of cooking stoves and charcoal production means that fuel requirements are high and often exceed local sustainable supply, leading to pressure on local forestry resources and damage to local forests, with 27-34% of wood-fuel harvesting in tropical regions classified as unsustainable. The collection of biomass, such as firewood, for cooking is very time consuming and has a high opportunity cost, as the time spent gathering fuelwood takes time away time from other income-generating activities and education. These issues disproportionately affect women and children, as they are the ones often tasked with the cooking and fuel collection. See IRENA, IEA and REN21, op. cit. note 2.

13 Biogas is a mixture of methane, carbon dioxide and other gases produced when organic matter is broken down by bacteria in the absence of air (anaerobic digestion). The gas can be used for heating and electricity production in engines or turbines. If the carbon dioxide and other gases are removed, a pure methane stream can be produced (biomethane). It can be used in the same way as natural gas, and pressurised and injected into gas distribution systems for use as a heating fuel or for transport applications.

14 IEA, op. cit. note 5.

15 IEA, op. cit. note 6.

16 Ibid.

17 Ibid.

18 IEA, op. cit. note 5.

19 IEA, op. cit. note 6

20 Ibid.

21 Ibid.

22 IEA, *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020.

23 Ibid.

24 Ibid.

25 Ibid.

26 Ibid.

27 Ibid.

28 Ibid.

29 Ibid.

30 Ibid.

31 Ibid.

32 Ibid. China is also an important user of biomass for heating in both buildings and industry, but this is not reflected in current statistics due to data collection and reporting challenges.

33 REN 21, "Bioenergy", in *Renewables Global Status Report 2020* (Paris: 2020), https://www.ren21.net/gsr-2020/chapters/chapter_03/chapter_03.

34 Such uses of bioenergy are concentrated in developing and emerging economies. In more developed countries, large quantities of wood are used to heat homes in inefficient and often polluting devices such as open grates, contributing to local air pollution problems. However, under the statistical conventions that define traditional biomass as that used for heating in countries outside the Organisation for Economic Co-operation and Development (OECD), such fuel use is classified as "modern". See, for example, UK Department of Environment and Rural Affairs, *The Potential Air Quality Impacts of Biomass Combustion* (London: 2017), https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf.

35 IRENA, IEA and REN 21, op. cit. note 2.

36 This concentration in the EU is due in part to climatic reasons, as building heating requirements are limited in more southern countries and, to date, bioenergy plays a very limited role in cooling. Also, by definition, the use of biomass for residential heating outside the OECD is classified as a "traditional use of biomass". Thus, it is not included in the statistics as a "modern use of biomass". See IEA, *Renewables 2019* (Paris: 2019), p. 136, https://www.iea.org/renewables2019. Increase of 2% based on analysis of heat data in the 2018 and 2019 Eurostat SHARES database, https://ec.europa.eu/eurostat/web/energy/data/shares, viewed 28 February 2021.

37 Restrictions on the use of oil for heating and on gas connections for new properties and developments have been announced or implemented in the United Kingdom, Germany, the Netherlands and other countries. See IRENA, IEA and REN21, op. cit. note 2.

38 Eurostat SHARES database, op. cit. note 36.

39 Bioenergy Europe, *Statistical Report 2020: Pellets* (Brussels: 2021), https://bioenergyeurope.org/article.html/268. China also uses significant quantities of pellets from wood and agricultural residues, but reliable information on such uses is not available.

40 Ibid.

41 Ibid.

42 Based on analysis of 2019 data in Eurostat SHARES database, op. cit. note 36.

43 US Energy Information Administration (EIA), *Winter Fuels Outlook* (Washington, DC: October 2020), https://www.eia.gov/outlooks/steo/special/winter/2020_winter_fuels.pdf.

44 Ibid.

45 US EIA, *Monthly Energy Review* (Washington, DC: October 2019), Table 10.2a, https://www.eia.gov/totalenergy/data/monthly/index.php#renewable.

46 Natural Resources Canada, "Renewable energy facts", https://www.nrcan.gc.ca/science-and-data/data-and-analysis/energy-data-and-analysis/energy-facts/renewable-energy-facts/20069, updated 3 April 2020.

47 Bioenergy Europe, op. cit. note 39.

48 Ibid.

49 Bioenergy Europe, *Statistical Report 2020: Bioheat* (Brussels: 2020), https://www.bioenergyeurope.org/article/258-bioheat.html.

50 Ibid.

51 Ibid.

52 Ibid.

53 Based on analysis of data on biomass for district heating in France from Eurostat SHARES database, op. cit. note 36. Fonds Chaleur is the French support scheme that provides for funding for renewable heat projects; see ADEME, "Le Fonds Chaleur en bref", 29 March 2021, https://www.ademe.fr/expertises/energies-renouvelables-enr-production-reseaux-stockage/passer-a-laction/produire-chaleur/fonds-chaleur-bref.

54 Bioenergy Europe, op. cit. note 49; three-fold based on analysis of biomass for district heating data for Lithuania in Eurostat SHARES database, op. cit. note 36; R. Jonynas et al., "Renewables for district heating: The case of Lithuania", *Energy*, vol. 211 (15 November 2020), p. 119064, https://www.sciencedirect.com/science/article/pii/S036054422032171X.

55 Jonynas et al., op. cit. note 54.

56 Based on national biofuels data as referenced elsewhere in this section; biofuels supplemented by data from IEA, *Oil 2021* (Paris: March 2021), https://www.iea.org/reports/oil-2021.

57 Ibid.

58 Ibid.

59 Ibid.

60 **Figure 19** based on the following sources: data for 2020 and 2021 based on national biofuels data as referenced elsewhere in this section; biofuels supplemented by data from IEA, op. cit. note 56; for previous years, see earlier editions of the GSR and related endnotes. Volumes of fuel converted to energy content using conversion factors from US Department of Energy, Alternative Fuels Data Center, https://www.afdc.energy.gov. Lower caloric value for ethanol is 76,330 Btu/US gallon (21.27 MJ/litre) and for biodiesel, 119,550 Btu/US gallon (33.32 MJ/litre). Caloric value for HVO is 34.4 MJ/litre. See Neste, *Neste Renewable Diesel Handbook* (Espoo, Finland: 2016), p. 15, https://www.neste.com/sites/default/files/attachments/neste_renewable_diesel_handbook.pdf.

61 Based on data on biomethane and other advanced biofuels referenced elsewhere in this section.

62 Based on national biofuels data as referenced elsewhere in this section; biofuels supplemented by data from IEA, op. cit. note 56.

63 Ibid.

64 US EIA, op. cit. note 45, Table 10.3, updated 22 February 2021.

65 Ibid.

66 IEA, op. cit. note 22, p. 119.

67 Agencia Nacional do Petroleo, Gas Natural e Biocombustiveis (ANP), "Dados estatísticos",http://www.anp.gov.br/dados-estatisticos, viewed 28 February 2021.

68 Ibid., "Vendas, pelas Distribuidoras, dos Derivados Combustíveis de Petróleo (metros cúbicos)".

69 A. Oliveira da Costa, Empresa de Pesquisa Energética, "Analysis of biofuels' current outlook 2019, July 2020", presentation, 30 July 2020, https://www.epe.gov.br/sites-en/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-213/Presentation_Biofuels_Current_Outlook-Year_2019.pdf.

70 IEA, op. cit. note 22.

71 US Department of Agriculture (USDA), Global Agricultural Information Network (GAIN), *Corn Ethanol Production Booms in Brazil* (Washington, DC: October 2020), https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Corn%20Ethanol%20Production%20Booms%20in%20Brazil%20_Brasilia_Brazil_10-04-2020.

72 Ibid.

73 Ibid.

74 IEA, op. cit. note 56.

75 IEA, op. cit. note 22.

76 Ibid.

77 Ibid.

78 Ibid.

79 Based on national biofuels data as referenced elsewhere in this section; biofuels supplemented by data from IEA, op. cit. note 56.

80 Ibid.

81 Based on biofuels data in Ibid., supplemented by national data as referenced elsewhere in this section.

82 Ibid.

83 IEA, op. cit. note 22 Palm Oil Analytics, "Indonesia 2021 biodiesel production to rise sharply. 2020 usage up 34% and production rise by 2.30%", 2020, https://palmoilanalytics.com/indonesia-2021-biodiesel-production-to-rise-sharply-2020-usage-up-34-and-production-rise-by-2-30.

84 IEA, op. cit. note 22.

85 US EIA, op. cit. note 45, Table 10.4, updated 22 February 2021.

86 The Biodiesel Blender's tax credit provides support of USD 1 per gallon for biodiesel blended with diesel fuel. The measure was first put in place in 2005, but was suspended several times and then restored retroactively. In late 2019, it was restored retroactively for 2018 and 2019 and guaranteed until 2022. M. Schneider, "The Biodiesel Tax Credit: What does the new extension mean?" OPIS Blog, 9 March 2020, http://blog.opisnet.com/biodiesel-tax-credit.

87 IEA, op. cit. note 22.

88 Ibid.

89 ANP, op. cit. note 67, viewed 28 February 2021.

90 IEA, op. cit. note 22.

91 Ibid.

92 Ibid.

93 HVO is also called HEFA and renewable diesel. It is produced by treating vegetable oils and other bio-based oils and liquids, including waste materials such as used cooking oil, with hydrogen, which removes the oxygen and produces a hydrocarbon that can be refined into a product whose fuel qualities are equivalent to fossil-based diesel. The refining process also produces bio-based LPG and can be tuned to produce other fuels, including biojet. Renewable diesel can be used mixed in any proportion with fossil diesel or used on its own.The production estimate is based on analysis of existing and new capacity, as shown in the slides in J. Lane, "50 renewable diesel projects and the technologies behind them", Biofuels Digest, 8 February 2021,https://www.biofuelsdigest.com/bdigest/2021/02/08/50-renewable-diesel-projects-and-the-technologies-behind-them and in research on specific plant outputs. See Industry section of Bioenergy text.

94 Based on analysis of Renewable Fuel Standard (RFS) data for 2019 and 2020, from US Environmental Protection Agency (EPA), "Public data for the Renewable Fuel Standard", https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard, viewed February25 2021.

95 Lane, op. cit. note 93.

96 Based on analysis of RFS data for 2019 and 2020, from US EPA, op. cit. note 94.

97 IEA, *World Energy Outlook Special Report: Prospects for Biogas and Biomethane* (Paris: 2020), https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.

98 S. Olson, "RNG, cellulosic fuels and the Renewable Fuel Standard", BioCycle, 14 February 2017, https://www.biocycle.net/2017/02/14/biomethane-cellulosic-fuels-renewable-fuel-standard.

99 Based on data in US EPA, "RIN generation and renewable fuel volume production by fuel type from December 2020", https://www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel-0, updated February 2021.

100 Based on an analysis of data to 2019 for biogas use in the transport sector for each EU country. See Eurostat SHARES database, "SHARES 2019 detailed results", Transport tab, https://ec.europa.eu/eurostat/web/energy/data/shares, viewed 26 February 2021.

101 Ibid.

102 Based on data in US EPA, op. cit. note 99.

103 Bioelectricity capacity based on the national data referenced elsewhere in this section and for other countries based on forecast 2020 capacity figures from IEA, op. cit. note 22, datafiles.

104 Ibid.

105 Bioelectricity generation based on national data referenced elsewhere in this section and for other countries based on forecast 2020 generation figures from IEA, op. cit. note 22, datafiles.

106 Ibid.

107 Ibid

108 Ibid.

109 China Energy Portal, "Notice on results of the 2020 central government subsidy applications for biomass power generation projects", 17 November 2020, https://chinaenergyportal.org/en/notice-on-results-of-the-2020-central-government-subsidy-applications-for-biomass-power-generation-projects.

110 Ibid.

111 US Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for January 2021" (Washington, DC: 2021), https://cms.ferc.gov/sites/default/files/2021-03/JanuaryMIR%202021.pdf.

112 US EIA, *Electric Power Monthly* (Washington, DC: February 2021), Table 1.1a, https://www.eia.gov/electricity/data.php, corrected for difference between net and gross electricity.

113 Ibid.

114 IEA, op. cit. note 22, datafiles.

115 Ibid.

116 IEA, op. cit. note 22.

117 Ibid.

118 German Federal Ministry for Economic Affairs and Energy (BMWi), "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, 1990-2020" (Berlin: February 2021), Tables 3 and 4, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html.

119 IEA, op. cit. note 22, datafiles; ECN, "Dutch renewable energy support scheme (SDE+)", https://www.ecn.nl/collaboration/sde/index.html, viewed 15 March 2021.

120 UK Department for Business, Energy and Industrial Strategy, "Energy Trends: Renewables", Table 6.1, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, updated 25 March 2021.

121 Ibid.

122 IEA, op. cit. note 22, datafiles.

123 Ibid.

124 Government of India, Ministry of New and Renewable Energy, "Physical progress", https://mnre.gov.in/the-ministry/physical-progress, viewed 23 February 2021; IEA, op. cit. note 22, datafiles.

125 Bioenergy Europe. cit. note 39.

126 Ibid

127 Ibid.

128 Ibid.

129 Ibid.

130 Ibid.

131 Ibid.

132 Ibid.

133 Ibid.

134 Ibid.

135 Calculation based on calorific value of pellets of 17 GJ per tonne, from Forest Research, "Typical calorific values of fuels", https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels and on total bioheat for buildings for 2018. See Markets section of Bioenergy text.

136 Bioenergy Europe, op. cit. note 39.

137 Ibid.

138 Based on US EIA, *Monthly Densified Biomass Fuel Report* (Washington, DC: 15 April 2020), https://www.eia.gov/biofuels/biomass/#table_data.

139 Bioenergy Europe, op. cit. note 39.

140 Ibid.

141 R. Levinson, "2021: Major changes to the Japanese biomass market", Biomass Magazine, 3 February 2021, http://biomassmagazine.com/articles/17690/2021-major-changes-to-the-japanese-biomass-market.

142 The debate focuses on the greenhouse gas savings generated by the use of forestry materials. Some claim that greenhouse gas emissions from pellets are higher than from coal and that using forestry materials can also lead to loss of forestry carbon stocks. Others call for applying a full life-cycle approach and for harvesting and using forestry materials in line with sustainable forest management principles, with energy use integrated with timber production and use for long-lived products, such as building materials. See, for example: F. Simon,"'Win-win or lose-lose': EU scientists highlight two-faced bioenergy policies", EURACTIV, 1 February 2021, https://www.euractiv.com/section/biomass/news/win-win-or-lose-lose-eu-scientists-highlight-two-faced-bioenergy-policies; IEA Bioenergy, "Is woody biomass positive for the climate?" (Paris: January 2018), https://www.ieabioenergy.com/wp-content/uploads/2018/01/FAQ_WoodyBiomass-Climate_final-1.pdf.

143 EU Science Hub, "Renewable Energy – Recast to 2030 (RED II)", https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii, updated 23 July 2019. In the original RED, sustainability criteria applied only to liquid biofuels. The revised directive extends this to cover solid biomass feedstocks.

144 Levinson, op. cit. note 141.

145 **Box 6** based on the following sources: There are many different definitions of the bioeconomy, which the EU defines as "using renewable biological resources from land and sea, like crops, forests, fish, animals and micro-organisms to produce food, materials and energy", from European Commission, "Bioeconomy", https://ec.europa.eu/info/research-and-innovation/research-area/environment/bioeconomy_en, viewed 1 March 2021. See, for example, Edinburgh Centre for Carbon Management Ltd., *Forestry Commission Scotland Greenhouse Gas Emissions Comparison: Carbon Benefits of Timber in Construction* (Edinburgh: 2006), https://forestry.gov.scot/images/corporate/pdf/carbon-benefits-of-timber-in-construction-2006.pdf. High value-added products include specialty chemicals based on cellulose or lignin, building materials, wood-based textiles and bio-based plastics. They include high-value, specialist bio-based materials, such as graphene for electricity storage applications, and novel supply chains, such as producing insect protein animal feed from low-value residues. European Commission, "Bioeconomy strategy", https://ec.europa.eu/info/research-and-innovation/research-area/environment/bioeconomy/bioeconomy-strategy_en, viewed 1 March 2021; J. Lane, "Renewables Chemicals Act introduced: Tax credit for biobased chemical production, investment", Biofuels Digest, 10 December 2020, https://www.biofuelsdigest.com/bdigest/2020/12/09/renewable-chemicals-act-introduced-tax-credit-for-biobased-chemical-production-investment; European Bioplastics, "Bioplastics market data", https://www.european-bioplastics.org/market, viewed 1 March 2021; Bioplastics News, "Braskem", https://bioplasticsnews.com/braskem, viewed 1 March 2021; UPM, "UPM invests in next generation biochemicals to drive a switch from fossil raw materials to sustainable solutions", press release (Helsinki: 30 January 2020), https://www.upm.com/about-us/for-media/releases/2020/01/upm-invests-in-next-generation-biochemicals-to-drive-a-switch-from-fossil-raw-materials-to-sustainable-solutions.

146 Renewable Fuels Association, *Essential Energy – 2021 Ethanol Industry Outlook* (Washington, DC: 17 February 2021), https://ethanolrfa.org/wp-content/uploads/2021/02/RFA_Outlook_2021_fin_low.pdf.

147 M. Sapp, "ADM not sure when it will reopen idled dry milling ethanol plants", Biofuels Digest, 4 August 2020, https://www.biofuelsdigest.com/bdigest/2020/08/04/adm-not-sure-when-it-will-reopen-idled-dry-milling-ethanol-plants.

148 Based on analysis of petrol and ethanol prices in the United States and Brazil, from GlobalPetrolPrices.com, "Download fuel price data", https://www.globalpetrolprices.com/data_download.php, viewed 5 March 2021.

149 Ibid.; USDA, GAIN, *Biofuels Annual: Brazil 2020* (Washington, DC: 4 September 2020), https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_08-03-2020.

150 IEA, op. cit. note 22.

151 Ibid.

152 Ibid.

153 Estimates based on analysis of data in Lane, op. cit. note 93, plus additional project-specific data for individual projects and proposals as referenced elsewhere in this section.

154 Ibid.

155 Ibid.

156 Based on comparison of capacity projections for HVO with current production levels of FAME and ethanol as cited in the Markets section Transport Biofuels Market and the data for **Figure 19**, op. cit. note 8.

157 The life-cycle analysis for fuels produced from wastes and residues does not need to take into account emissions associated with direct or indirect land-use change, whereas this issue is generally considered when dealing with virgin vegetable oils and other crop-based biofuels, such as ethanol from corn or sugar or FAME biodiesel from canola or palm oil.

158 California Air Resources Board, "LCFS Pathway Certified Carbon Intensities", https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities, viewed 1 March 2021.

159 European Commission, *EU Renewable Energy Directive* (Brussels: 2018), Annex 9, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC.

160 B. Fallas, "Humber's renewable ambitions make grand entrance", Phillips 66, 18 November 2020, https://www.phillips66.com/newsroom/2020-humber-uco; B. Fallas, "Phillips 66 plans world's largest renewable fuels plant", Phillips 66, 12 August 2020, https://www.phillips66.com/newsroom/rodeo-renewed.

161 Fallas, "Phillips 66 plans world's largest renewable fuels plant", op. cit. note 160.

162 Total, "Energy transition: Total is investing more than EUR 500 million to convert its Grandpuits refinery into a zero-crude platform for biofuels and bioplastics", 24 September 2020, https://www.polymers.total.com/latest-news/energy-transition-total-investing-more-eu500-million-convert-its-grandpuits-refinery.

163 Total, "La Mède: A multipurpose facility for the energies of tomorrow", https://www.total.com/energy-expertise/projects/bioenergies/la-mede-a-forward-looking-facility, viewed 2 March 2021.

164 ENI, "Biorefineries, a solid example of circular economy", https://www.eni.com/en-IT/operations/biorefineries.html, viewed 2 March 2021.

165 R. Tuttle, "Massive refiners are turning into biofuel plants in the west", Bloomberg, 12 August 2020, https://www.bloomberg.com/news/articles/2020-08-12/phillips-66-is-latest-refiner-to-shun-crude-oil-in-favor-of-fat.

166 BioRefineries Blog, "Pertamina selects Honeywell UOP technologies for two HVO projects in Indonesia", 7 October 2020, https://biorrefineria.blogspot.com/2020/10/Pertamina-selects-Honeywell-UOP-technologies-for-two-HVO-projects-in-Indonesia.html.

167 Gasification involves heating biomass feedstocks with a limited supply of air to produce synthesis gas, a mixture of carbon monoxide, carbon dioxide, methane and water. This can be used to produce hydrocarbon fuels via the Fischer-Tropsch process, which uses iron, cobalt ruthenium or nickel catalysts. The catalyst composition and process conditions determine the product mix. While several earlier attempts at using such processes have not been successful, the process was successfully demonstrated at a pre-commercial scale in Sweden. IEA Bioenergy, *Advanced Biofuels: Potential for Cost Reduction* (Paris: 2020), https://www.ieabioenergy.com/wp-content/uploads/2020/02/T41_CostReductionBiofuels-11_02_19-final.pdf.

168 J. Lane, "Drop-in sustainable aviation fuel: The Digest's 2020 multi-slide guide to Red Rock", Biofuels Digest, 6 January 2021, https://www.biofuelsdigest.com/bdigest/2021/01/06/drop-in-sustainable-aviation-fuel-the-digests-2020-multi-slide-guide-to-red-rock.

169 H. Tavares Kennedy, "Competitive Edge: Velocys", Biofuels Digest, 3 September 2020, https://www.biofuelsdigest.com/bdigest/2020/09/03/competitive-edge-velocys.

170 M. Sapp, "Japanese consortium to study SAF production using Fulcrum's bioenergy technology", Biofuels Digest, 27 February 2020, https://www.biofuelsdigest.com/bdigest/2020/02/27/japanese-consortium-to-study-saf-production-using-fulcrum-bioenergys-technology.

171 Pyrolysis involves heating biomass with a very restricted supply of air. This produces gases (often used to heat the process), a char and pyrolysis oil. This can be used as a heating oil or else further refined to produce renewable diesel or other fuels.

172 Green Fuel Nordic, "Lieska Refinery begins bio-oil deliveries to customers", 4 December 2020, https://www.greenfuelnordic.fi/en/articles/lieksa-refinery-begins-bio-oil-deliveries-customers.

173 M. Sapp, "FLITE Consortium to build first-of-its kind Lanzajet ATJ Facility", Biofuels Digest, 7 January 2021, https://www.biofuelsdigest.com/bdigest/2021/01/07/flite-consortium-to-build-first-of-its-kind-lanzajet-atj-facility.

174 Ibid.

175 P. Marchand, "You don't say: Cellulosic ethanol's future is in Europe?" Transport Energy Strategies, 3 March 2021, https://www.transportenergystrategies.com/2021/03/03/you-dont-say-cellulosic-ethanol-future-is-in-europe.

176 M. Sapp, "Clariant expects Romanian sunliquid plant to be online by Q4 2020", Biofuels Digest, 5 August 2020, https://www.biofuelsdigest.com/bdigest/2020/08/05/clariant-expects-romanian-sunliquid-plant-to-be-online-by-q4-2021; M. Sapp, "Clariant and Chemtex team on developing sunliquid in China", Biofuels Digest, 18 August 2020, https://www.biofuelsdigest.com/bdigest/2020/08/18/clariant-and-chemtex-team-on-developing-sunliquid-in-china; M. Sapp, "Clariant licenses sunliquid® cellulosic ethanol technology for Bulgarian facility", Biofuels Digest, 27 July 2020, https://www.biofuelsdigest.com/bdigest/2020/07/27/clariant-licenses-sunliquid-cellulosic-ethanol-technology-for-bulgarian-facility.

177 International Air Transport Association (IATA), "Fact Sheet 2: Sustainable Aviation Fuel: Technical Certification" (Geneva: undated), https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf.

178 J. Lane, "Sustainable aviation fuels and the technologies, constraints and burgeoning demand", 16 February 2021, https://www.biofuelsdigest.com/bdigest/2021/02/16/sustainable-aviation-fuels-and-the-technologies-constraints-and-burgeoning-demand/17.

179 IATA, "Developing sustainable aviation fuel (SAF)", https://www.iata.org/en/programs/environment/sustainable-aviation-fuels, viewed 2 March 2021.

180 H. Tavares Kennedy, "Flying high with aviation biofuel – continuous SAF supply arrives at SFO and LTN airports, RSB recognized by ICAO for CORSIA", Biofuels Digest, 13 December 2020, https://www.biofuelsdigest.com/bdigest/2020/12/13/flying-high-with-aviation-biofuel-continuous-saf-supply-arrives-at-sfo-and-ltn-airports-rsb-recognized-by-icao-for-corsia.

181 IEA, op. cit. note 97.

182 Ibid. Total biomethane production is estimated at 35 million tonnes of oil equivalent (mtoe) (1.05 EJ), compared to 2018 overall global gas demand of 3,284 mtoe (137 EJ), from IEA, op. cit. note 5.

183 IEA, op. cit. note 97.

184 Based on analysis of data from US EPA, op. cit. note 99, and from Eurostat SHARES database,op. cit. note 36.

185 US EPA, *An Overview of Renewable Natural Gas From Biogas* (Washington, DC: July 2020), https://www.epa.gov/sites/production/files/2021-02/documents/lmop_rng_document.pdf.

186 Energy Vision, "Energy Vision/Argonne study shows rapid expansion of the US renewable natural gas industry", press release (New York: 18 December 2020), https://energy-vision.org/wp-content/uploads/2020/12/EV-Argonne-2020-RNG-Release.pdf.

187 Ibid.

188 H. Tavares Kennedy, "RNG heats up with slurry of 2020 deals, big players involved, Chevron, BP, Brightmark, Aemetis, Verbio, Greenlane Renewables", Biofuels Digest, 11 October 2020, https://www.biofuelsdigest.com/bdigest/2020/10/11/rng-heats-up-with-slurry-of-2020-deals-big-players-involved-chevron-bp-brightmark-aemetis-verbio-greenlane-renewables.

189 M. Sapp, "Tennessee landfill gas biomethane project commissioned by BP and partners", Biofuels Digest, 20 August 2020, https://www.biofuelsdigest.com/bdigest/2020/08/20/tennessee-landfill-gas-rng-project-commissioned-by-bp-and-partners.

190 M. Sapp, "Construction at $33M Ohio RNG project launched", Biofuels Digest, 17 September 2020, https://www.biofuelsdigest.com/bdigest/2020/09/17/construction-at-33m-ohio-rng-project-launched/.

191 H. Tavares Kennedy, "Aemetis completes construction of Phase I dairy digester and pipeline project for RNG", Biofuels Digest, 23 August 2020, https://www.biofuelsdigest.com/bdigest/2020/08/23/aemetis-completes-construction-of-phase-i-dairy-digester-and-pipeline-project-for-rng.

192 M. Sapp, "Verbio's RNG facility at former DuPont cellulosic ethanol plant seen for fall 2021", Biofuels Digest, 7 September 2020, https://www.biofuelsdigest.com/bdigest/2020/09/07/verbios-rng-facility-at-former-dupont-cellulosic-ethanol-plant-seen-for-fall-2021.

193 European Biogas Association, *Renewable Gas Success Stories 2020* (Brussels: 2020), https://www.europeanbiogas.eu/wp-content/uploads/2020/12/EBA_Renewable-Gas-Success-Stories-2020.pdf.

194 Bioenergy Insight, "Gasum receives €30 m to build two new biogas plants", 11 December 2020, https://www.bioenergy-news.com/news/gasum-receives-e30m-to-build-two-new-biogas-plants.

195 Bioenergy Insight, "WELTEC BIOPOWER's €11m biomethane plant goes live in France", 30 November 2020, https://www.bioenergy-news.com/news/weltec-biopowers-e11m-biomethane-plant-goes-live-in-france.

196 Ibid.

197 Bioenergy Insight, "Construction underway on two EnviTec Biogas projects in China", 29 September 2020, https://www.bioenergy-news.com/news/construction-underway-on-two-envitec-biogas-projects-in-china.

198 Ibid.

199 Bioenergy Insight, "Asda welcomes 202 biomethane-fuelled trucks to its fleet", 10 December 2020, https://www.bioenergy-news.com/news/asda-welcomes-202-biogas-fuelled-trucks-to-its-fleet.

200 Air Liquide, "Air Liquide steps up its biomethane activity in the UK with a major contract with ASDA", 21 December 2020, https://energies.airliquide.com/air-liquide-steps-its-biomethane-activity-uk-major-contract-asda.

201 IEA, "CCUS in Clean Energy Transitions", part of *Energy Technology Perspectives* (Paris: September 2020), https://www.iea.org/reports/ccus-in-clean-energy-transitions.

202 S. Budinis, "Going carbon negative: What are the technology options?" IEA, 31 January 2020, https://www.iea.org/commentaries/going-carbon-negative-what-are-the-technology-options. "Net negative emissions" means that for each unit of energy produced and used, there is a net reduction in greenhouse gas emissions. In this case, the energy is produced from biomass, which produces CO_2 that is then captured and stored. Since the biomass-based emissions do not involve transferring carbon from fossil reserves into the atmosphere, each unit of energy produced reduces atmospheric CO_2 levels when the whole cycle is taken into account.

203 IEA, op. cit. note 202.

204 Bioenergy Insight, "Drax to start BECCS planning application process", 1 March 2021, https://www.bioenergy-news.com/news/drax-to-start-beccs-planning-application-process.

205 Bioenergy Insight, "PowerTap to produce blue hydrogen using RNG as feedstock", 16 February 2021, https://www.bioenergy-news.com/news/powertap-to-produce-blue-hydrogen-using-rng-as-feedstock.

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1 Estimates based on the following sources: power capacity data for Iceland, Japan and New Zealand from International Energy Agency (IEA) Geothermal, *2019 Country Reports* (Taupo, New Zealand: February 2020), http://iea-gia.org/publications-2/annual-reports and sources noted elsewhere in this section; power capacity data for Indonesia, the Philippines, Turkey and the United States from sources noted elsewhere in this section; capacity data for other countries from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2021* (Abu Dhabi: 2021), https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021; estimated electricity generation in 2020 based on 95 TWh in 2019 from G. W. Huttrer, "Geothermal power generation in the world 2015-2020 update report", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01017.pdf; and 97 TWh from Organisation for Economic Co-operation and Development (OECD) and IEA, *Market Report Series – Renewables 2020, Databook* (Paris: 2020). Heat capacity and output in 2020 an extrapolation based on five-year average annualised growth from 2015 through 2019, from J. W. Lund and A. N. Toth, "Direct utilization of geothermal energy 2020 worldwide review", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01018.pdf.

2 End-2019 capacity data and capacity additions in 2020 from sources in endnote 1.

3 Ibid. **Figure 21** based on end-2019 capacity data and capacity additions in 2020 from sources in endnote 1 and sources noted elsewhere in this section. For the purpose of this figure, end-2019 capacity is assumed to be equal to end-2020 capacity less new capacity installed (or capacity expansion) during 2020.

4 End-2019 capacity data from sources in endnote 1; capacity additions in 2020, by country, from sources noted elsewhere in this section.

5 This resource-limited capability of a geothermal plant defines its dependable running capacity, as opposed to the total nameplate capacity of its generator(s). For the United States, most of the difference between nameplate and running capacity (about 800 MW) results from plant derating at the Geysers geothermal field in California, which is not able to the produce enough steam, due to productivity decline, to operate at nameplate capacity. Net summer capacity from US Energy Information Administration (EIA), *Electric Power Monthly, February 2021*, Table 6.2.B, https://www.eia.gov/electricity/monthly; nameplate capacity from US EIA, "Form EIA-860M (Preliminary Monthly Electric Generator Inventory)", December 2020, https://www.eia.gov/electricity/data/eia860m; US Department of Energy (DOE), Office of Scientific and Technical Information (OSTI), "GeoVision: Harnessing the heat beneath our feet" (Oak Ridge, TN: June 2019), p. 24 (footnote 34), https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet.

6 Capacity of 1,514.7 MW and 54 plants at end-2019, 60 plants and 1,613.2 MW at end-2020, and annual capacity additions for 2014-2019 from Turkish Electricity Transmission Company (TEİAŞ), http://www.teias.gov.tr, viewed March 2021.

7 See sum of individual installations as noted in the text. "Sürdürülebilir Enerji Kaynağı Olan Jeotermal Enerjideki Artış Umut Verici!" Enerji Gazetesi, 14 December 2020, https://www.enerjigazetesi.ist/surdurulebilir-enerji-kaynagi-olan-jeotermal-enerjideki-artis-umut-verici.

8 Exergy, "Exergy delivering more green power: A 26 MWe, a 12 MWe and a 10 MWe geothermal plants come online in Turkey", press release (Olgiate Olona, Italy: 9 November 2020), https://www.exergy-orc.com/upload/pages/537/exergy-geothermal_start_up_october.pdf; Ormat, "Ormat I Turkey – Oct 2020", 17 November 2020, https://www.ormat.com/en/company/news/view/?ContentID=497.

9 Exergy, op. cit. note 8; Ormat, op. cit. note 8.

10 JESDER (Turkey's geothermal power plants investor association), "Çelikler Termik Elektrik Üretim A.Ş.'ye ait 32 MWe Kapasiteli JES-5ORC7 Devreye Alındı", 17 December 2020, http://jesder.org/celikler-termik-elektrik-uretim-a-s-ye-ait-32-mwe-kapasiteli-jes-5orc7-devreye-alindi; A. Richter, "Celikler Holdings brings additional 32 MW geothermal unit online at Pamukören Turkey", Think GeoEnergy, 18 December 2020, https://www.thinkgeoenergy.com/celikler-holdings-brings-additional-32-mw-geothermal-unit-online-at-pamukoren-turkey.

11 One of two 30 MW unit completed, from Ormat, "Another success in Turkey", 24 December 2020, https://www.ormat.com/en/company/news/view/?ContentID=8821; Ormat, "Global projects", https://www.ormat.com/en/projects/all/main/?Country=Turkey&Seg=0&Tech=0&pageNum=1, viewed March 2020; two 25 MW units completed, from "'EFE 8 Jeotermal Enerji Santrali' Bir Dünya Rekoruyla Devreye Alındı!" Enerji Gazetesi, 29 December 2020, https://www.enerjigazetesi.ist/efe-8-jeotermal-enerji-santrali-bir-dunya-rekoruyla-devreye-alindi; European Bank for Reconstruction and Development, "Efeler Geothermal Power Plant", https://www.ebrd.com/work-with-us/projects/psd/efeler-gpp.html, viewed March 2021; Mogan Energy Investment Holding Co., "Energy power plants", https://www.mogan.com.tr/EN,1102/energy-power-plants.html, viewed March 2021.

12 See map of geothermal plants at Jesder, http://jesder.org, viewed March 2021.

13 Capacity of 1,514.7 MW and 54 plants at end-2019, 60 plants and 1,613.2 MW at end-2020, and annual capacity additions 2014-2019 from TEİAŞ, http://www.teias.gov.tr, viewed March 2021.

14 TEİAŞ, op. cit. note 13.

15 "Support mechanism key to Turkey's renewables growth, EBRD official says", Daily Sabah, 11 December 2020, https://www.dailysabah.com/business/energy/support-mechanism-key-to-turkeys-renewables-growth-ebrd-official-says; E. B. Erşen, "Turkey's renewable energy sector to continue enjoying European financier EBRD support", Daily Sabah, 26 February 2020, https://www.dailysabah.com/business/energy/turkeys-renewable-energy-sector-to-continue-enjoying-european-financier-ebrd-support.

16 "Support mechanism key to Turkey's renewables growth", op. cit. note 15; "Turkey's renewable energy sees nearly $7B investments in 2020", Daily Sabah, 21 January 2021, https://www.dailysabah.com/business/energy/turkeys-renewable-energy-sees-nearly-7b-investments-in-2020.

17 Feed-in tariff reduction of around one-third based on existing tariff of USD 0.105 (plus local content increment of up to USD 0.027) and new tariff of TRY 0.54 (plus local content increment of TRY 0.08). Existing tariff from General Directorate of Law and Legislation, "Law no. 5346 on the use of renewable energy resources for the purpose of generation of electric energy", https://www.mevzuat.gov.tr/MevzuatMetin/1.5.5346.pdf; new tariff from General Directorate of Law and Legislation, "Presidential Decision no. 3453", 30 January 2021, https://www.resmigazete.gov.tr/eskiler/2021/01/20210130-9.pdf.

18 Net summer capacity from US EIA, *Electric Power Monthly*, op. cit. note 5; nameplate capacity from US EIA, "Form EIA-860M", op. cit. note 5.

19 Ormat, "Steamboat Hills geothermal power plant enhancement in Nevada begins commercial operation", press release (Reno, NV: 22 June 2020), https://investor.ormat.com/news-events/news/news-details/2020/Steamboat-Hills-Geothermal-Power-Plant-Enhancement-in-Nevada-Begins-Commercial-Operation/default.aspx.

20 Ibid.

21 Ormat, "Puna geothermal power plant – an island within an island", 12 November 2020, https://www.ormat.com/en/company/news/view/?ContentID=8820; Puna Geothermal Venture, https://punageothermalproject.com, viewed March 2021.

22 Generation for 2020 and revised generation for 2019 from US EIA, *Electric Power Monthly*, op. cit. note 5, Tables ES1.B, 1.1 and 1.1.A. Originally reported and revised generation for 2018 and original reported generation for 2019 from US EIA, *Electric Power Monthly*, February 2019 and February 2020, Tables ES1.B, https://www.eia.gov/electricity/monthly.

23 Mitsubishi Power, "Mitsubishi Power completes renovation of generating facilities at Otake Geothermal Power Station – efficient utilization of geothermal resources to curb CO_2 emissions, and contribute to decarbonized economy", press release (Yokohama: 5 October 2020), https://power.mhi.com/news/20201005.html.

24 Ibid.

25 Climeon, "A symbolic power plant proving the synergies of Onsen and Heat Power", 8 July 2020, https://climeon.com/a-symbolic-power-plant-proving-the-synergies-of-onsen-and-heat-power; Climeon, "Geothermal heat power", https://climeon.com/geothermal-plants, viewed March 2021.

26 "Tiga PLTP akan Beroperasi Tahun 2020, Total Kapasitas Capai 140 MW", OG Indonesia, March 2020, http://www.ogindonesia.

com/2020/03/tiga-pltp-akan-beroperasi-tahun-2020.html; R. Rina, "Terpukul Corona, Sederet Proyek Energi Baru RI Molor ke 2021", CNBC Indonesia, 21 April 2020, https://www.cnbcindonesia.com/news/20200421181003-4-153485/terpukul-corona-sederet-proyek-energi-baru-ri-molor-ke-2021; "Akibat Covid-19, target tambahan 140 MW listrik panas bumi mundur ke semester I-2021", 10 November 2020, https://industri.kontan.co.id/news/akibat-covid-19-target-tambahan-140-mw-listrik-panas-bumi-mundur-ke-semester-i-2021.

27 Anisatul Umah, "Gas Pipa Diduga Bocor, PLTP Sorik Marapi Dihentikan Sementara", CNBC Indonesia, 26 January 2021, https://www.cnbcindonesia.com/news/20210126110557-4-218729/gas-pipa-diduga-bocor-pltp-sorik-marapi-dihentikan-sementara; "Akibat Covid-19, target tambahan 140 MW listrik panas bumi mundur ke semester I-2021", op. cit. note 26.

28 Indonesian Ministry of Energy and Mineral Resources (ESDM), "Empat Program Prioritas EBTKE di Tahun 2021", 15 January 2021, https://ebtke.esdm.go.id/post/2021/01/18/2768/empat.program.prioritas.ebtke.di.tahun.2021.

29 ESDM, "Keberlangsungan Panas Bumi di Indonesia: Belajar dari Sorik Marapi", 10 February 2021, https://ebtke.esdm.go.id/post/2021/02/11/2792/keberlangsungan.panas.bumi.di.indonesia.belajar.dari.sorik.marapi; ESDM, "Hasil Investigasi Lapangan Terkait Kejadian Diduga Paparan Gas H2s pada PLTP Sorik Marapi", 3 February 2021, https://ebtke.esdm.go.id/post/2021/02/04/2787/hasil.investigasi.lapangan.terkait.kejadian.diduga.paparan.gas.h2s.pada.pltp.sorik.marapi.

30 Capacity at year-end 2015-2020 from ESDM, "Capaian Kinerja Tahun 2020 dan Program Kerja 2021 Sektor ESDM" (Jakarta: 7 January 2021), https://www.esdm.go.id/assets/media/content/content-capaian-kinerja-tahun-2020-dan-program-kerja-tahun-2021-sektor-esdm.pdf.

31 ESDM, *Handbook of Energy & Economic Statistics of Indonesia* (Jakarta: July 2020), https://www.esdm.go.id/id/publikasi/handbook-of-energy-economic-statistics-of-indonesia.

32 ESDM, "Strategi Pengembangan EBT Menuju Target 23%", 24 November 2020, https://ebtke.esdm.go.id/post/2020/11/25/2707/strategi.pengembangan.ebt.menuju.target.23; ESDM, "Ini Strategi Pemerintah Untuk Percepatan Pengembangan Panas Bumi", 18 June 2020, https://ebtke.esdm.go.id/post/2020/06/18/2562/ini.strategi.pemerintah.untuk.percepatan.pengembangan.panas.bumi.

33 ESDM, "UU Cipta Kerja dan Aturan Turunannya Dukung Kepastian Berusaha Panas Bumi", 26 March 2021, https://ebtke.esdm.go.id/post/2021/03/29/2830/uu.cipta.kerja.dan.aturan.turunannya.dukung.kepastian.berusaha.panas.bumi; F. B. Iskana, "Kementerian ESDM Tunda Lelang Wilayah Kerja Panas Bumi Hingga 2022", Katadata, 6 August 2020, https://katadata.co.id/febrinaiskana/ekonomi-hijau/5f2bd2ffaeaa7/kementerian-esdm-tunda-lelang-wilayah-kerja-panas-bumi-hingga-2022; V. N. Setiawan, "ESDM Targetkan Eksplorasi Panas Bumi di 3 Lokasi Rampung Tahun ini", Katadata, 14 January 2021, https://katadata.co.id/sortatobing/ekonomi-hijau/60001a6196012/esdm-targetkan-eksplorasi-panas-bumi-di-3-lokasi-rampung-tahun-ini.

34 ESDM, "Pacu Investasi Panas Bumi, Pemerintah Siapkan Kompensasi Eksplorasi", 30 July 2020, https://ebtke.esdm.go.id/post/2020/07/30/2600/pacu.investasi.panas.bumi.pemerintah.siapkan.kompensasi.eksplorasi.

35 Setiawan, op. cit. note 33; V. N. Setiawan, "Terbentur Anggaran, Pengeboran Panas Bumi Terpangkas Jadi 2 Wilaya", Katadata, 20 January 2021, https://katadata.co.id/sortatobing/ekonomi-hijau/600826d609482/terbentur-anggaran-pengeboran-panas-bumi-terpangkas-jadi-2-wilayah.

36 ESDM, "Targetkan Tambahan 16,7 Giga Watt Pembangkit EBT, Menteri ESDM: Ini Tantangannya", 24 September 2020, https://ebtke.esdm.go.id/post/2020/09/26/2634/targetkan.tambahan.167.giga.watt.pembangkit.ebt.menteri.esdm.ini.tantangannya.

37 A. D. Fronda et al., "Geothermal energy development: The Philippines country update", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org; Republic of the Philippines, Department of Energy, *2019 Power Situation Report* (Manila: 2019), https://www.doe.gov.ph/sites/default/files/pdf/electric_power/2019-power-situation-report.pdf.

38 M. M. Velasco, "Guidelines to push geothermal energy investment readied", Manila Bulletin, 1 July 2020, https://mb.com.ph/2020/07/01/guidelines-to-push-geothermal-energy-investment-readied; M. M. Velasco, "PH to open RE for 100% foreign ownership", Manila Bulletin, 12 July 2020, https://mb.com.ph/2020/07/12/ph-to-open-re-for-100-foreign-ownership; M. M. Velasco, "Gov't opens full foreign ownership to integrated geothermal projects", Manila Bulletin, 28 October 2020, https://mb.com.ph/2020/10/28/govt-opens-full-foreign-ownership-to-integrated-geothermal-projects.

39 M. M. Velasco, "No foreign firm takers of PH geothermal blocks yet", Manila Bulletin, 22 December 2020, https://mb.com.ph/2020/12/22/no-foreign-firm-takers-of-ph-geothermal-blocks-yet; M. M. Velasco, "DOE eyeing 114 prospective bidders in new hydro, geothermal projects", Manila Bulletin, 8 January 2021, https://mb.com.ph/2021/01/08/doe-eyeing-114-prospective-bidders-in-new-hydro-geothermal-projects.

40 M. M. Velasco, "Geothermal investors seek 'risk insurance perks' for new projects", Manila Bulletin, 19 January 2021, https://mb.com.ph/2021/01/19/geothermal-investors-seek-risk-insurance-perks-for-new-projects.

41 J. L. Mayuga, "Lack of incentives crimps investments in geothermal", *Business Mirror*, 2 March 2020, https://businessmirror.com.ph/2020/03/02/lack-of-incentives-crimps-investments-in-geothermal; Velasco, op. cit. note 40.

42 S. Daysh et al., "New Zealand country update", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org.

43 New Zealand Ministry of Business Innovation and Employment, "Electricity statistics", https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics, viewed April 2021.

44 Contact Energy, "Contact says smelter closure is 'disappointing'", 9 July 2020, https://contact.co.nz/aboutus/media-centre/2020/07/08/contact-says-smelter-closure-is-disappointing.

45 Contact Energy, "Contact confirms world-class Tauhara geothermal resource", 23 June 2020, https://contact.co.nz/aboutus/media-centre/2020/06/23/contact-confirms-world-class-tauhara-geothermal-resource; Contact Energy, "Contact to build Tauhara geothermal power station; will raise $400m in equity", 15 February 2021, https://contact.co.nz/aboutus/media-centre/2021/02/16/contact-to-build-tauhara-geothermal-power-station-will-raise-$400m-in-equity.

46 Contact Energy, "Contact confirms world-class Tauhara geothermal resource", op. cit. note 45.

47 Ormat, "Top Energy new geothermal power plant", 27 January 2021, https://www.ormat.com/en/company/news/view/?ContentID=8835.

48 Calculation based on Lund and Toth, op. cit. note 1. Growth of 2.4 GW in 2020 based on five-year compound annual growth rate of 7.8% from 2014 through 2019 (total capacity having grown from 20,627 MW in 2014 to 30,080 MW in 2019).

49 Calculation based on Lund and Toth, op. cit. note 1. Growth of 11.3 TWh in 2020 based on five-year compound annual growth rate of 9.6% from 2014 through 2019 (total output having grown from 265,790 TJ in 2014 to 420,906 TJ in 2019).

50 Calculation based on Lund and Toth, op. cit. note 1.

51 Ibid.

52 Ibid.

53 **Figure 22** based on ibid.

54 Ibid.

55 T. Tian et al., "Rapid development of China's geothermal industry – China National Report of the 2020 World Geothermal Conference", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org.

56 Ibid.

57 Ibid.

58 Calculation based on Lund and Toth, op. cit. note 1.

59 O. Mertoglu et al., "Geothermal energy use: Projections and country update for Turkey", *Proceedings World Geothermal Congress 2020*, forthcoming, https://www.geothermal-energy.org.

60 A. Ragnarsson et al., "Geothermal development in Iceland 2015-2019", *Proceedings World Geothermal Congress 2020*, forthcoming, https://www.geothermal-energy.org.

61 K. Yasukawa et al., "Country update of Japan", *Proceedings World Geothermal Congress 2020*, forthcoming, https://www.geothermal-energy.org.

62 Ibid.

63 L. Schauer, "Geothermie in München: Sendlings Bohrinsel", Abendzeitung, 10 May 2019, https://www.abendzeitung-muenchen.de/muenchen/geothermie-in-muenchen-sendlings-bohrinsel-art-469592; Erdwerk, "Projekt München-Schäftlarnstraße: Bohrplatz geräumt", 27 May 2020, https://www.erdwerk.com/de/projekt-muenchen-schaeftlarnstrasse-bohrplatz-geraeumt; "München baut Deutschlands größtes Geothermie-Kraftwerk", Sonnenseite, 18 February 2019, https://www.sonnenseite.com/de/energie/muenchen-baut-deutschlands-groesstes-geothermie-kraftwerk.

64 Informationsportal Tiefe Geothermie, "München baut auf geothermische Fernkälte statt stromfressenden Klimaanlagen", 17 April 2020, https://www.tiefegeothermie.de/news/muenchen-baut-auf-geothermische-fernkaelte-statt-stromfressenden-klimaanlagen.

65 "Schöne Schwimmbad-Liegewiese soll für neues Kraftwerk der Stadtwerke München weichen", Merkur tz Redaktions, 4 January 2020, https://www.tz.de/muenchen/stadt/ramersdorf-perlach-ort43348/muenchen-michaelibad-stadtwerke-geothermie-kraftwerk-liegewiese-zr-13419040.html.

66 The project used advanced drilling technology to complete the 1,600 metre multilateral well, which exceeded expectations, producing 400 cubic metres of water per hour at 65°C and thermal output in excess of 16 MW_{th}. ENGIE, "Géothermie à Vélizy-Villacoublay: une première européenne avec 66% d'EnR !" 25 February 2021, https://www.engie-solutions.com/fr/actualites/geothermie-velizy-66-enr; Schlumberger, "Schlumberger drilling technology used to enable geothermal heating solution in Europe", press release (Paris: 8 March 2021), https://www.slb.com/resource-library/article/2021/schlumberger-drilling-technology-used-to-enable-geothermal-heating--solution-in-europe.

67 ENGIE, "Construction du réseau de chaleur géothermique à Noisiel & Champs-sur-Marne", 20 July 2020, https://www.engie-solutions.com/fr/actualites/geothermie-noisiel-champs-marne.

68 Gényo, "Mise en service du réseau de chaleur Gényo: les villes de Bobigny et Drancy chauffées à la géothermie", press release (Paris: 9 March 2021), https://genyo.fr/wp-content/uploads/2021/03/CP-GENYO-09.03.2021-VF.pdf; Gényo, "Les travaux de forage", 8 December 2020, https://genyo.fr/travaux-de-forage.

69 Gényo, "Mise en service du réseau de chaleur Gényo", op. cit. note 68.

70 V. Bapt, "Chronique d'une aventure industrielle mise en suspens", Dernière Nouvelles D'Alsace, 4 December 2020, https://www.dna.fr/environnement/2020/12/04/chronique-d-une-aventure-industrielle-mise-en-suspens; A. Beckelynck, "Les 'écarts importants' de Fonroche à Vendenheim", Dernière Nouvelles D'Alsace, 30 December 2020, https://www.dna.fr/economie/2020/12/30/les-ecarts-importants-de-fonroche-a-vendenheim.

71 A. Beckelynck, "Après les séismes, les autres projets de géothermie suspendus autour de Strasbourg", Dernière Nouvelles D'Alsace, 9 December 2020, https://www.dna.fr/economie/2020/12/09/la-prefecture-suspend-les-autres-projets-de-geothermie; Bapt, op. cit. note 70.

72 Beckelynck, op. cit.note 70.

73 De Rechtspraak, "Central Insolventieregister", 27 October 2020, https://insolventies.rechtspraak.nl/#!/details/03.lim.20.233.F.1300.1.20.

74 J. van Winsen, "Aardwarmteproject CLG vraagt faillissement aan", 20 October 2020, Nieuwe Oogst, https://www.nieuweoogst.nl/nieuws/2020/10/20/aardwarmteproject-clg-vraagt-faillissement-aan; Californië B.V., "Negatieve reactie SodM op verzoek CLG Geothermie BV om weer te mogen opstarten", 10 July 2019, https://www.californie.nu/nieuws/negatieve-reactie-sodm-op-verzoek-clg-geothermie-bv-om-weer-te-mogen-opstarten/109; Californië B.V., "CLG Geothermie BV vraagt Faillissement aan", 15 October 2020, https://www.californie.nu/nieuws/archief/clg-geothermie-bv-vraagt-faillissement-aan/110.

75 Californië B.V., "CLG Geothermie BV vraagt Faillissement aan", op. cit. note 74.

76 Geothermie Nederland, "Toepassing aardwarmte groeit met 10 procent", https://geothermie.nl/index.php/nl/actueel/nieuws/884-toepassing-aardwarmte-groeit-met-10-procent, viewed March 2021; 2019 growth from Dutch Association of Geothermal Operators, "Forse stijging gebruik aardwarmte in de glastuinbouw", 16 March 2020, https://www.dago.nu/forse-stijging-gebruik-aardwarmte-in-de-glastuinbouw.

77 Geothermie Nederland, op. cit. note 76; G. Bakema et al., "Netherland country update", *Proceedings World Geothermal Congress 2020*, https://www.geothermal-energy.org; Dutch Association of Geothermal Operators, op. cit. note 76.

78 See, for example, Well Engineering Partners, "Geothermal projects", https://wellengineeringpartners.com/projects/geothermal-projects, viewed March 2021.

79 Platform Geothermie and DAGO, "Position Paper Mijnbouwwet", https://geothermie.nl/images/bestanden/DAGOSPG_reactie_gewijzigde_mijnbouwwet.pdf, viewed March 2021; Geothermie Nederland, "Voorstel wijziging Mijnbouwwet gepubliceerd", 21 July 2020, https://allesoveraardwarmte.nl/voorstel-wijziging-mijnbouwwet-gepubliceerd.

80 Beckelynck, op. cit. note 71; Bapt, op. cit. note 70; M. Antoine, "Séismes près de Strasbourg: la géothermie inquiète", Le Parisien, 13 November 2020, https://www.leparisien.fr/environnement/seismes-pres-de-strasbourg-la-geothermie-inquiete-13-11-2020-8408166.php.

81 J. Haffner, EPFL, "Reducing human-induced earthquake risk", 6 January 2020, https://actu.epfl.ch/news/reducing-human-induced-earthquake-risk.

82 Geo-Energie Suisse, "Durchbruch für die Tiefengeothermie", press release (Zurich: 21 January 2021), https://www.geo-energie.ch/2021/01/21/durchbruch-f%C3%BCr-die-tiefengeothermie.

83 Ibid.

84 Ibid.; Geo-Energie Suisse, "Geo-Energie Suisse hält am Geothermie-projekt in Haute-Sorne (JU) fest", press release (Zurich: 25 May 2020), https://www.geo-energie.ch/2020/05/25/geo-energie-suisse-h%C3%A4lt-am-geothermieprojekt-in-haute-sorne-ju-fest.

85 Bundesverband Geothermie, "Neue Initiative 'Wärmewende durch Geothermie'", press release (Berlin: 15 July 2020), https://www.geothermie.de/fileadmin/user_upload/Aktuelles/Presse/Pressemitteilungen/Pressemitteilungen_2020/PM_Kampagne_Waermewende_durch_Geothermie.pdf; Informationsportal Tiefe Geothermie, "Initiative 'Wärmewende durch Geothermie' geht in die Offensive", 15 July 2020, https://www.tiefegeothermie.de/news/initiative-waermewende-durch-geothermie-geht-die-offensive.

86 Geothermie Nederland, "Drie acties essentieel voor geothermie, warmtetransitie en Klimaatakkoord", https://geothermie.nl/images/bestanden/210224_GNL_brief_verkiezingen.pdf, viewed March 2021.

87 Unione Geothermica Italiana, "Lettera aperta dell'Unione Geotermica Italianaal Ministro Cingolani", press release (Pisa: 9 March 2021), http://www.unionegeotermica.it/public/Comunicato%20stampa_Unione%20Geotermica%20Italiana_9Marzo2021.pdf; Unione Geothermica Italiana, "L'appello dell'Unione Geotermica Italianaal Governo Draghi", press release (Pisa: 18 February 2021), http://www.unionegeotermica.it/public/Comunicato%20stampa_Unione%20Geotermica%20Italiana_18%20Febbraio2021.pdf.

88 See, for example, S. Akin, Y. Orucu and T. Fridriksson, "Characterizing the declining CO_2 emissions from Turkish geothermal power plant", Proceedings of the 45th Workshop on Geothermal Reservoir Engineering, Stanford University, Palo Alto, CA, 10-12 February 2020, https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2020/Akin.pdf.

89 Carbfix, "Our story", https://www.carbfix.com/our-story, viewed March 2021.

90 Carbfix, "Carbfix and Climeworks commission the first large-scale permanent removal of carbon dioxide from the atmosphere", 25 August 2020, https://www.carbfix.com/carbfix-and-climeworks-commission-the-first-large-scale-permanent-removal-of-carbon-dioxide-from-the-atmosphere; A. Doyle, "Scared by global warming? In Iceland, one solution is petrifying", 4 February 2021, https://news.trust.org/item/20210204081743-h6hoq.

91 Eavor Technologies, "Eavor announces a commercial Eavor-Loop project to be built in Geretsried, Germany", press release (Calgary/Munich: 1 May 2020), https://eavor.com/press-release/eavor-announces-commercial-eavor-loop-project-be-built-geretsried-germany; Informationsportal Tiefe Geothermie, "Bohrplatzerweiterung in Geretsried", 16 December 2020, https://www.tiefegeothermie.de/news/bohrplatzerweiterung-geretsried.

92 The first phase would include four loops providing 8.6 MW of power capacity and 65 MW_{th} for the local district heat demand, with the anticipation of later adding another 48 loops. Eavor Technologies, op. cit. note 91; Informationsportal Tiefe

Geothermie, "Eavor Loop-Projekt in Geretsried im Focus on Geothermal", 21 July 2020, https://www.tiefegeothermie.de/news/eavor-loop-projekt-geretsried-im-focus-geothermal.

93 Eavor Technologies Inc., "The world's first truly scalable form of green baseload power demonstrated by Eavor Technologies Inc.", 5 February 2020, https://eavor.com/press/#press16; Natural Resources Canada, "Eavor-Loop demonstration project", https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/eavor-loop-demonstration-project/21896, viewed March 2021; Eavor Technologies Inc., "Technology", https://eavor.com/technology, viewed March 2021.

94 Eavor Technologies, "Global energy majors lead pivot to Eavor's geothermal solution with USD$40 million investment", 16 February 2021, https://eavor.com/press-release/global-energy-majors-lead-pivot-eavors-geothermal-solution-usd40-million-investment.

95 Chevron, "Chevron invests in geothermal development company", press release (Houston: 28 February 2021), https://www.chevron.com/stories/chevron-invests-in-geothermal-development-company; Baseload Capital, "Projects", https://www.baseloadcap.com/projects, viewed March 2021; Climeon, "How it works", https://climeon.com/how-it-works, viewed March 2021.

96 "Top 20 geothermal power companies 2019", PR Newswire, 4 June 2019, https://markets.businessinsider.com/news/stocks/top-20-geothermal-power-companies-2019-1028250552; Exergy, "Exergy restarts with Tica to boost integrated systems and advanced green power generation", press release (Olgiate Olona, Italy: 14 January 2020), https://www.exergy-orc.com/media/news/exergy-restarts-with-tica-to-boost-integrated-systems-and-advanced-green-power-generation.

97 T. Garabetian, European Geothermal Energy Council (EGEC), "EGEC geothermal market report 2018", presentation, 7 February 2019, https://www.egec.org/wp-content/uploads/media_publication/2-EGEC_Presentation-market-2018-TGA.pdf; P. Dumas, EGEC, "Geothermal energy in Europe – overview, market, business model", presentation at Norwegian Center for Geothermal Energy Research, 4 February 2019, http://cger.no/doc//pdf/presentations%20GeoEnergi2019/4%20februar/05-EGEC_Presentation%20market%202018-Philippe%20Dumas.pdf.

98 See sources on projects completed in Turkey and the United States.

HYDROPOWER

1 International Energy Agency (IEA), *Hydropower Tracking Report* (Paris: June 2020), https://www.iea.org/reports/hydropower#tracking-progress.

2 "Hydropower and the impact of COVID-19", International Water Power & Dam Construction, 18 May 2020, https://www.waterpowermagazine.com/features/featurehydropower-and-the-impact-of-covid-19-7929537.

3 Global capacity based on International Hydropower Association (IHA), *Hydropower Status Report 2021* (London: 2021), https://www.hydropower.org/publications/2021-hydropower-status-report and IHA, personal communication with REN21, 25 May 2021. At the end of 2020, total installed capacity was 1,308 GW, less 158 GW of pumped storage.

4 Country data from IHA, op. cit. note 3, and from the following sources: **China:** total capacity including pumped storage of 370.16 GW, capacity additions of 13.23 GW, utilisation and investment, from China National Energy Administration (NEA), 2020 energy statistics, 20 January 2021, http://www.nea.gov.cn/2021-01/20/c_139683739.htm, and from China Electricity Council (CEC), 2020 electricity and other energy statistics, 31 December 2020, https://english.cec.org.cn/detail/index.html?3-1090; generation of 1,360 TWh and annual growth of 4.1%, from National Bureau of Statistics of China, "Analysis and forecast of China power demand-supply situation 2020-2021", press release (Beijing: 8 February 2021), https://english.cec.org.cn/detail/index.html?3-1128. Total capacity including pumped storage of 356.4 GW, pumped storage capacity of 30.3 GW and hydropower capacity of 326.1 GW; capacity additions (excluding pumped storage) of 3.9 GW; and pumped storage additions of 0.3 GW from IHA, op. cit. note 3. **Brazil:** 177.77 MW (0 MW large hydropower, 176.77 MW small hydropower and 1 MW very small hydro) added in 2020, from National Agency for Electrical Energy (ANEEL), "Acompanhamento da expansão da oferta de geração de energia elétrica – base de dados do RALIE (Fevereiro de 2021)", http://www.aneel.gov.br/acompanhamento-da-expansao-da-oferta-de-geracao-de-energia-eletrica, updated February 2021; year-end capacity of 108 GW from Government of Brazil, ANEEL, "Aneel ultrapassa meta de expansão da geração de energia em 2020", 6 January 2021, https://www.gov.br/pt-br/noticias/energia-minerais-e-combustiveis/2021/01/aneel-ultrapassa-meta-de-expansao-da-geracao-de-energia-em-2020; generation of 509 TWh from National Electrical System Operator of Brazil (ONS), "Geração de energia", http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed 26 February 2021. **United States:** capacity from US Energy Information Administration (EIA), *Electric Power Monthly with Data for December 2020* (Washington, DC: February 2021), Tables 6.2.B and 6.3, http://www.eia.gov/electricity/monthly; generation from idem, Table 1.1, viewed 26 February 2021. **Canada:** capacity and generation from IHA, op. cit. note 3. **Russian Federation:** capacity and generation from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2020* (Moscow: 31 January 2021), p. 9, https://so-ups.ru/fileadmin/files/company/reports/disclosure/2021/ups_rep2020.pdf. **India:** installed capacity in 2020 (units larger than 25 MW) of 42,492 MW and installed small (<25 MW) hydropower capacity of 4,750 MW, from Government of India, Ministry of Power, Central Electricity Authority (CEA), "Installed capacity reports", December 2020, http://www.cea.nic.in/monthlyarchive.html, and 3,306 MW of pumped storage from CEA, "Hydroelectric reports", http://www.cea.nic.in/monthlyarchive.html, viewed 31 January 2021. **Norway:** generation from Statistics Norway, "Elektrisitet", https://www.ssb.no/statbank/list/elektrisitet, viewed 31 January 2021; capacity from Norwegian Water Resources and Energy Directorate (NVE), "Ny kraftproduksjon", https://www.nve.no/energiforsyning/kraftmarkedsdata-og-analyser/ny-kraftproduksjon, viewed 31 January 2020; additions of 256 MW, and year-end capacity of 33 GW and average annual production of 136.6 TWh (excluding pumped storage), from NVE, "Vannkraft", https://www.nve.no/energiforsyning/kraftproduksjon/vannkraft, viewed 18 March 2021. **Figure H1** based on capacity and generation sources provided in this note.

5 Capacity values by country from sources provided in endnote 4 and from IHA, op. cit. note 3. **Turkey:** net installed capacity in 2020 of 2,465 MW for impoundments of 2,266 MW and run-of-river plants of 199 MW, from Energy Market Regulatory Authority of Turkey (EPDK), *Electricity Market Sector Report 2020* (Ankara: January to December 2020), https://www.epdk.gov.tr/Detay/Icerik/3-0-23/aylik-sektor-raporu (using Google Translate). **Angola:** net installed capacity in 2020 of 3,773 MW, from calculations based on recorded additions and on IHA, "Country profile – Angola", https://www.hydropower.org/discover/hydropower-around-the-world, viewed 14 May 2021. **Figure H2** based on capacity and generation sources provided in this note and in note 4.

6 See, for example, J. Deign, "Hydropower jostles for role in global green recovery programs", Greentech Media, 9 February 2021, https://www.greentechmedia.com/articles/read/hydro-jostles-for-role-in-global-green-recovery-programs.

7 IHA, op. cit. note 3, and sources on individual pumped storage projects noted elsewhere in this section.

8 Estimated global hydropower generation and increase from IHA, op. cit. note 3; share of estimated global generation from Ember, *Global Electricity Review 2021* (London: 2021), https://ember-climate.org/project/global-electricity-review-2021. Also see Global Overview chapter.

9 Renewable Energy Policy Network for the 21st Century (REN21), *Renewables Global Status Report* (Paris: various years), https://www.ren21.net/reports/global-status-report; installed capacity in 2019 of 358.04 MW, including 30.29 MW of pumped storage, from CEC, "Generation", https://english.cec.org.cn/menu/index.html?263, viewed 18 March 2021, and from NEA, op. cit. note 4.

10 Based on total hydropower electricity generation in 2015 of 1,126 TWh and hydropower capacity of 296 GW, from REN21, *Renewables 2016 Global Status Report* (Paris: 2016), https://www.ren21.net/gsr-2016; total hydropower electricity generation in 2020 of 1,360 TWh and hydropower capacity of 341 GW, from CEC, op. cit. note 4; CEC, "2020 electricity consumption data of China released", 20 January 2021,https://english.cec.org.cn/detail/index.html?3-1109.

11 State-owned Assets Supervision and Administration Commission of the State Council (SASAC), "Datengxia hydropower project on left bank of Qianjiang River in full operation", 7 August 2020, http://en.sasac.gov.cn/2020/08/07/c_5341.htm; Voith, "Voith supports China to develop hydropower – First Wu Dongde hydropower plant units now in operation", press release (Shanghai: 10 July 2020), https://voith.com/corp-en/news-room/press-releases/2020-07-10-vh-voith-supports-china-to-develop-hydropower.html.

12 GE, "GE Renewable Energy connects the world's most powerful hydro unit to the grid in Wudongde, China", press release (Paris: 6 July 2020), https://www.ge.com/news/press-releases/ge-renewable-energy-connects-worlds-most-powerful-hydro-unit-grid-wudongde-china.

13 Harbin Electric Group (HPEC), "Unit 4 of the Fengman Reconstruction Project developed by the Electric Motor Company was put into production with high quality", 30 April 2020, http://www.hpec.com/newsinfoview.asp?id=9389; "Construction of all underground facilities at Baihetan dam complete", International Water Power & Dam Construction, 14 October 2020, https://www.waterpowermagazine.com/news/newsconstruction-of-all-underground-facilities-at-baihetan-dam-complete-8180917; Xinhua, "Spillway tunnels for Chinese mega hydropower project completed", China Daily, 20 December 2020, https://www.chinadaily.com.cn/a/202012/20/WS5fde918ca31024ad0ba9cd6a.html.

14 CEC, op. cit. note 4; SASAC, "Three Gorges Dam sets world record on annual power output", 20 November 2020, http://en.sasac.gov.cn/2020/11/20/c_6065.htm.

15 EPDK, op. cit. note 5; REN21, op. cit. note 9.

16 B. Muftuoglu, "Turkish renewable additions at new high", Argus Media, 12 August 2020, https://www.argusmedia.com/en/news/2131686-turkish-renewable-additions-at-new-high.

17 N. Gökmen, "Turkey: New renewable energy support mechanism announced", Mondaq, 2 February 2021, https://www.mondaq.com/turkey/renewables/1031996/new-renewable-energy-support-mechanism-announced.

18 "Opening ceremony held for Yusufeli dam in Turkey", International Water Power & Dam Construction, 8 June 2020, https://www.waterpowermagazine.com/news/newsopening-ceremony-held-for-yusufeli-dam-in-turkey-7961289; "500-MW Lower Kaleköy Hydropower plant in Turkey now operating", Hydro Review, 4 February 2021, https://www.hydroreview.com/hydro-industry-news/500-mw-lower-kalekoy-hydropower-plant-in-turkey-now-

operating; "Limak to start last turbine at new 420 MW Çetin hydropower plant in Turkey", Balkan Green Energy News, 2 June 2020, https://balkangreenenergynews.com/limak-to-start-last-turbine-at-new-420-mw-cetin-hydropower-plant-in-turkey; "Turkey's Ilisu Dam on Tigris starts generating at full capacity", *Reuters*, 24 December 2020, https://www.reuters.com/article/turkey-dam-int-idUSKBN28Y0WK.

19 "Threat of drought rises as dams dry up in many regions of Turkey", Daily Sabah, 30 November 2020, https://www.dailysabah.com/turkey/threat-of-drought-rises-as-dams-dry-up-in-many-regions-of-turkey/news; "Hydro plants' electricity generation down 12 pct", Hürriyet Daily News, 6 January 2021, https://www.hurriyetdailynews.com/hydro-plants-electricity-generation-down-12-pct-161412.

20 Total installed capacity of 95,890 MW by end-2020; total hydropower (dam and run-of-river) installed capacity of 30,984 MW; and global new additions of 4,434 MW and hydropower (dam and run-of-river) additions of 2,465 MW, from EPDK, op. cit. note 5.

21 Total added capacity of 1,658 MW excludes pumped storage capacity. Net capacity additions of 1,579 MW for hydropower plants above 25 MW, from Government of India, Ministry of Power, CEA, "State-wise/Station-wise installed capacity of H.E. stations in the country", December 2020, https://cea.nic.in/wp-content/uploads/hpi/2021/01/hydro_stations-12.pdf; implied addition of 79 MW for small hydropower (<25 MW) from Government of India, Ministry of New and Renewable Energy, "Physical progress", January 2021, https://mnre.gov.in/the-ministry/physical-progress, viewed February 2021, and from idem, "Physical progress", January 2020, https://mnre.gov.in/physical-progress-achievements, viewed January 2020; total installed capacity of 47,243 MW (excluding 3,305 MW of pumped storage), from CEA, "All India installed capacity (in MW) of power stations", December 2020, https://cea.nic.in/wp-content/uploads/installed/2020/12/installed_capacity.pdf.

22 "India to have 70,000 MW of hydropower capacity by 2030: Official", *Economic Times*, 21 May 2020, https://energy.economictimes.indiatimes.com/news/power/india-to-have-70000-mw-of-hydropower-capacity-by-2030-official/75859241.

23 Ibid.

24 "2000MW hydropower project to be commissioned in Subansiri, India", Construction Review, 14 December 2020, https://constructionreviewonline.com/news/2000mw-hydropower-project-to-be-commissioned-in-subansiri-india.

25 IEA, *India 2020 Energy Policy Review* (Paris: 2020), p. 111, https://www.iea.org/reports/india-2020; Press Information Bureau, Government of India, "India prepares for a change in electricity sector through proposed Electricity (Amendment) Bill 2020", press release (Delhi: 25 June 2020), https://pib.gov.in/PressReleasePage.aspx?PRID=1634253; "Renewable energy in India's economic development: An analysis of reforms", *Economic Times*, 20 November 2020, https://energy.economictimes.indiatimes.com/news/renewable/renewable-energy-in-indias-economic-development-an-analysis-of-reforms/79325236.

26 Ibid., all references.

27 IHA, "Country profile – Laos", https://www.hydropower.org/country-profiles/laos, viewed 19 May 2021.

28 "Commercial operation confirmed for 260-MW Don Sahong Hydropower in Laos", Hydro Review, 9 November 2020, https://www.hydroreview.com/hydro-industry-news/commercial-operation-confirmed-for-260-mw-don-sahong-hydropower-in-laos; "Laos: The first unit of Selalong Hydropower Station is about to generate electricity", World Energy, 31 July 2020, https://www.world-energy.org/article/11144.html.

29 Vietnam Electricity, National Load Dispatch Center (EVN NLDC), *Summary Report for Operation Activities of National Power System in 2020* (Hanoi: 2021); Tran Phuong Dong, Vnuhcm-University of Science, Vietnam, personal communication with REN21, 25 March 2021.

30 "Électricité: EVN envisage d'accomplir 256 projets en 2021", VietnamPlus, 12 January 2021, https://fr.vietnamplus.vn/electricite-evn-envisage-daccomplir-256-projets-en-2021/154272.vnp.

31 Ministry of Energy of the Republic of Uzbekistan, "The volume of investments in the hydropower sector of Uzbekistan is growing", 25 August 2020, http://minenergy.uz/ru/news/view/726; Ministry of Energy of the Republic of Uzbekistan, "Ministry of Energy: How the growing energy supply in Uzbekistan is ensured", 15 January 2021, http://minenergy.uz/ru/news/view/1063; "Uzbekistan completes modernisation of Kadyrinskaya hydropower", Hydro Review, 4 August 2020, https://www.hydroreview.com/hydro-industry-news/uzbekistan-completes-modernization-of-kadyrinskaya-hydropower; "Uzbekistan launches hydroelectric power plant", UZ Daily, 23 July 2020, https://www.uzdaily.uz/en/post/58682; "New hydropower capacities launched", UZ Daily, 24 March 2020, https://www.uzdaily.uz/en/post/55591.

32 "Commercial operations begin at 178-MW Shuakhevi hydro in Georgia", Hydro Review, 30 March 2020, https://www.hydroreview.com/hydro-industry-news/commercial-operations-begin-at-178-mw-shuakhevi-hydro-in-georgia.

33 IHA, "Country profile – Albania", https://www.hydropower.org/discover/hydropower-around-the-world, viewed 18 March 2021; M. Arabidze, Ministry of Economy and Sustainable Development of Georgia, "Renewable energy in Georgia: Challenges and opportunities", presentation at 10th International Forum on Energy for Sustainable Development, 7 October 2019, https://unece.org/fileadmin/DAM/energy/se/pp/gere/GERE.6_Oct.2019/2_RE_Auctions/2_M.Arabidze_Georgia.6th.GERE.pdf; National Statistics Office of Georgia, "Statistical information – energy", https://www.geostat.ge/ka/modules/categories/81/energetika, available from January to November 2020, viewed February 2021.

34 NVE, op. cit. note 4.

35 Ibid.

36 Electricité de France, "EDF commissions its new Romanche-Gavet hydroelectric plant (Isère)", press release (Paris: 9 October 2020), https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-commissions-its-new-romanche-gavet-hydroelectric-plant-isere; Culture Isère, "Les centrales hydroélectriques de la vallée de la Romanche", https://culture.isere.fr/page/les-centrales-hydroelectriques-de-la-vallee-de-la-romanche, viewed 12 May 2021.

37 Electricité de France, op. cit. note 36.

38 D. Proctor, "Albania seeks investment to support existing hydropower", POWER, 2 March 2020, https://www.powermag.com/albania-seeks-investment-to-support-existing-hydropower; Statkraft, "Moglicë hydropower plant", https://www.statkraft.com/about-statkraft/where-we-operate/albania/moglice-hydropower-plant, viewed February 2021.

39 Total installed capacity in 2020 (including 1.4 GW of pumped storage) of 49,912 MW, from System Operator of the Unified Energy System of Russia, op. cit. note 4; IHA, "Pumped Storage Tracking Tool", https://www.hydropower.org/hydropower-pumped-storage-tool, viewed 11 February 2021; total installed capacity in 2019 (including 1.4 GW of pumped storage) of 49,870 MW, from System Operator of the Unified Energy System of Russia, *Report on the Unified Energy System in 2019* (Moscow: 31 January 2020), p. 7, http://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2020/ups_rep2019.pdf.

40 RusHydro, "RusHydro inaugurates Zaramagskaya HPP-1 in North Ossetia", press release (Moscow: 4 February 2020), http://www.eng.rushydro.ru/press/news/110490.html.

41 "Barsuchkovskaya hydro plant commissioned in Russia", International Water Power & Dam Construction, 4 January 2021, https://www.waterpowermagazine.com/news/newsbarsuchkovskaya-hydro-plant-commissioned-in-russia-8435786; "Ust-Dzhegutinskaya small hydropower plant commissioned in Russia", International Water Power & Dam Construction, 11 November 2020, https://www.waterpowermagazine.com/news/newsust-dzhegutinskaya-small-hydropower-plant-commissioned-in-russia-8357592; RusHydro, "RusHydro inaugurates Verkhnebalkarskaya small-scale hydropower plant", press release (Moscow: 25 June 2020), http://www.eng.rushydro.ru/press/news/111491.html; "LUKOIL commissions renovated 1.5-MW Beshenka River small hydropower plant", Hydro Review, 8 October 2020, https://www.hydroreview.com/hydro-industry-news/lukoil-commissions-renovated-1-5-mw-beshenka-river-small-hydropower-plant.

42 Nornickel, "Stage 6 launched at Ust-Khantayskaya HPP", press release (Moscow: 21 September 2020), https://www.nornickel.com/news-and-media/press-releases-and-news/stage-6-launched-at-ust-khantayskaya-hpp.

43 Ministry of Energy and Water (MINEA), *Angola Energy 2025 – Angola Power Sector Long Term Vision* (Luanda: June 2016),

https://gestoenergy.com/wp-content/uploads/2018/04/ANGOLA-POWER-SECTOR-LONG-TERM-VISION.pdf.

44 MINEA, "Titular do Sector da Energia e Águas constata funcionamento do Sector na Província da Huíla", press reléase (Lubango: 5 November 2020), https://www.minea.gv.ao/index.php/component/content/article/19-destaque/251-nota-de-imprensa-titular-do-sector-da-energia-e-aguas-constata-funcionamento-do-sector-na-provincia-da-huila; "Barragem do Luachimo pode concluir obras em 2021", Angola Press News Agency, 17 August 2020, https://www.angop.ao/noticias-o/?v_link=https://www.angop.ao/angola/pt_pt/noticias/economia/2020/7/34/Barragem-Luachimo-pode-concluir-obras-2021,bb297f84-2ca6-47bc-bd10-5b82ffbe4771.html; MINEA, "Terceiro Conselho Directivo do MINEA Aprecia avanços na implementação das Acções do Projecto Baynes", press release (Luanda: 2 October 2020),https://www.minea.gv.ao/index.php/component/content/article/19-destaque/243-nota-de-imprensa-terceiro-conselho-directivo-do-minea-aprecia-avancos-na-implementacao-das-accoes-do-projecto-baynes?Itemid=490; "Construção da barragem de Baynes inicia em 2021", Angola Press News Agency, 3 March 2020, https://www.angop.ao/noticias-o/?v_link=https://www.angop.ao/angola/pt_pt/noticias/economia/2020/2/10/Construcao-barragem-Baynes-inicia-2021,b4f9f59b-4378-42dd-b756-412f71d994f0.html; "Caculo Cabaça conclui túnel de acesso", *Jornal de Angola*, 30 November 2020, https://jornaldeangola.ao/ao/noticias/caculo-cabaca-conclui-tunel-de-acesso.

45 MINEA, "Entrada em serviço comercial da última turbina de ah Laúca", 9 December 2020, https://www.minea.gv.ao/index.php/component/content/article/19-destaque/259-nota-informativa-comissionamento-do-6-grupo-do-ahe-de-lauca?Itemid=490.

46 IHA, "Country profile – Angola", op. cit. note 5.

47 "Phalombe HPP ready February", BNLTimes, 7 January 2021, https://times.mw/phalombe-hydropower-plant-ready-february; "Gilke gives update on African projects", International Water Power & Dam Construction, 8 December 2020, https://www.waterpowermagazine.com/news/newsgilkes-gives-update-on-african-projects-8398614; Gilkes, "Ruo-Ndiza hydro commissioned in Malawi by Gilkes", 12 June 2020, https://www.gilkes.com/news-media/ruo-ndiza-hydro-commissioned-in-malawi.

48 Rwanda Energy Group, "Giciye III hydropower plant to add 9.8 MW to the national grid", Newsletter, October-December 2020, p. 8, https://www.reg.rw/fileadmin/user_upload/NEWSLETTER_No8.pdf.

49 Ibid.

50 "Vidullanka achieves second major leap in Africa with 6.5MW Bukinda small hydropower project", *Daily Financial Times*, 4 August 2020, http://www.ft.lk/business/Vidullanka-achieves-second-major-leap-in-Africa-with-6-5MW-Bukinda-small-hydropower-project/34-704051; "Spotlight: Uganda to accelerate use of renewable energy in bid to reduce carbon footprint", *Xinhua News Agency*, 14 December 2020, http://www.xinhuanet.com/english/2020-12/14/c_139589047.htm; "Uganda's Karuma hydropower plant nearing completion", *Xinhua News Agency*, 14 November 2020, http://www.xinhuanet.com/english/2020-11/14/c_139514517_2.htm.

51 I. Magoum, "Uganda: UEGCL renovates 3 power lines to operate the Karuma dam", Afrika21, 27 November 2020, https://www.afrik21.africa/en/uganda-uegcl-renovates-3-power-lines-to-operate-the-karuma-dam.

52 Ethiopian Electric Power, "The work on the Great Ethiopian Renaissance has reached 73 percent", 21 May 2020, https://www.eep.com.et/en/the-work-on-the-great-ethiopian-renaissance-has-reached-73-percent; "Ethiopia's mega dam to generate electricity", New Business Ethiopia, 13 October 2020, https://newbusinessethiopia.com/energy/ethiopias-mega-dam-to-generate-electricity; "Three-way talks on Ethiopian dam reach new impasse", *Reuters*, 11 January 2021, https://www.reuters.com/article/us-ethiopia-dam-sudan-egypt-idUSKBN29G0JT.

53 "Ethiopia, Egypt, Sudan make slow progress in Nile dam row", DW, 16 January 2020, https://www.dw.com/en/ethiopia-egypt-sudan-make-slow-progress-in-nile-dam-row/a-52015611.

54 "Construction of Koysha hydropower dam in Ethiopia 39% complete", Construction Review, 13 October 2020, https://constructionreviewonline.com/news/ethiopia/construction-of-koysha-hydropower-dam-in-ethiopia-39-complete; SASAC, "CGGC-contracted hydropower plant in Ethiopia starts operation", 18 February 2020, http://en.sasac.gov.cn/2020/02/18/c_3733.htm; A. Larson, "Award-winning hydropower project helps electrify Ethiopia", POWER, 1 September 2020, https://www.powermag.com/award-winning-hydropower-project-helps-electrify-ethiopia.

55 IHA, "Country profile – Ethiopia", https://www.hydropower.org/country-profiles/ethiopia, viewed 18 March 2021.

56 "Nigeria: New hydropower plant adds 60MW to national grid", Energy Central, 15 December 2020, https://energycentral.com/news/nigeria-new-hydropower-plant-adds-60mw-national-grid.

57 Agence Française de Développement (AFD), "Ghana: A dam for a greener future", 2 December 2020, https://www.afd.fr/en/actualites/grand-angle/ghana-dam-renewable-future; IHA, "Country profile – Ghana", https://www.hydropower.org/discover/hydropower-around-the-world, updated May 2019.

58 Bui Power Authority, "President Akufo-Addo commissions Ghana's first micro hydroelectric plant", 24 November 2020, https://buipower.com/president-akufo-addo-commissions-ghanas-first-micro-hydroelectric-plant.

59 J. M. Takouleu, "Ghana: la construction du barrage polyvalent de Pwalugu débutera en avril 2020", Afrik21, 3 March 2020, https://www.afrik21.africa/ghana-la-construction-du-barrage-polyvalent-de-pwalugu-debutera-en-avril-2020; G. Johnson, "Ghana: les travaux de construction du barrage polyvalent de Pwalugu démarrent finalement fin avril", Agence Ecofin, 5 March 2020, https://www.agenceecofin.com/production/0503-74533-ghana-les-travaux-de-construction-du-barrage-polyvalent-de-pwalugu-demarrent-finalement-fin-avril.

60 IHA, op. cit. note 3.

61 Manitoba Hydro, "Who we are", https://www.manitobahydropower.com/who-we-are, viewed February 2021; N. Frew, "Another Keeyask blockade formed despite injunction on the first", CBC News, 19 May 2020, https://www.cbc.ca/news/canada/manitoba/manitoba-hydro-tataskweyak-injunction-blockade-1.5575317; "Manitoba Hydro announces temporary reduction of workforce at Keeyask", 31 October 2020, https://www.hydro.mb.ca/articles/2020/10/manitoba_hydro_announces_temporary_reduction_of_workforce_at_keeyask. See also Government of Canada, "First Nations in Canada", https://www.rcaanc-cirnac.gc.ca/eng/1307460755710/1536862806124, viewed 23 February 2021.

62 Muskrat Falls Project, *Monthly Report – December 2020* (St. John's, Newfoundland and Labrador: February 2021), https://muskratfalls.nalcorenergy.com/newsroom/reports.

63 IHA, "Country profile – Canada", https://www.hydropower.org/country-profiles/canada, viewed March 2021.

64 EIA, op. cit. note 4; Grant PUD, "Wanapum Dam turbine and generator replacement", https://www.grantpud.org/wanapum-dam-turbine-and-generator-replacement, viewed 19 February 2021; J. Miller, "Lake Livingston hydroelectric plant powers 12,000 households", Texas Coop Power, February 2021, https://www.texascooppower.com/local/sheco/lake-livingston-hydroelectric-plant-powers-12000-households.

65 EIA, op. cit. note 4, Table 6.3 and Table 6.4.

66 Ibid., Table 6.2.B

67 Ibid., Table 1.1.A; EIA, "Electricity Data Browser, net generation", https://www.eia.gov/electricity/data/browser, viewed 21 April 2021.

68 SASAC, "POWERCHINA-contracted hydropower project in Honduras goes into operation", 31 December 2020, http://en.sasac.gov.cn/2020/12/31/c_6340.htm; Empresa Nacional de Energía Eléctrica (ENEE), "Descripción del Sistema Interconectado", http://enee.hn/index.php/centrales-hidroelectricas/80-canaveral/L, viewed February 2021.

69 Celsia, "Celsia encendió nueva central hidroeléctrica San Andrés de Cuerquia en Colombia", 24 September 2020, https://www.celsia.com/es/centrales-hidroelectricas; Asociación Colombiana de Generadores de Energía Eléctrica (ACOLGEN), "Mapa de generación eléctrica en Colombia", https://www.acolgen.org.co/mapa-generacion, viewed February 2021.

70 D. A. Mercado, "Cuenta regresiva en Hidroituango para sus dos primeras turbinas", *El Tiempo*, 16 November 2021, https://www.eltiempo.com/colombia/medellin/hidroituango-comienza-la-instalacion-de-dos-turbinas-549238; J. I. García, "Creciente del rio Cauca dejó afectaciones en localidades cercanas", *El Tiempo*, 13 May 2018, https://www.eltiempo.com/colombia/medellin/creciente-del-rio-cauca-dejo-afectaciones-en-localidades-cercanas-216994.

71 ANEEL, op. cit. note 4; REN21, op. cit. note 9.

72 L. Costa, "Brasil fecha 2020 com menor expansão em hidrelétricas e recorde em geração fóssil", 4 January 2021, https://www.reuters.com/article/energia-eletrica-geracao-idBRKBN299276-OBRBS.

73 ANEEL, "Aneel ultrapassa meta de expansão da geração de energia em 2020", 6 January 2021, https://www.gov.br/pt-br/noticias/energia-minerais-e-combustiveis/2021/01/aneel-ultrapassa-meta-de-expansao-da-geracao-de-energia-em-2020.

74 Inter-American Development Bank, *Impacto de las Paradas en la Generación Hidroeléctrica de Brasil* (Washington, DC: February 2019), https://publications.iadb.org/es/impacto-de-las-paradas-en-la-generacion-hidroelectrica-de-brasil.

75 Ibid.

76 Ibid.

77 Comité de Operación Económica del Sistema Interconectado Nacional (COES SINAC), "Ingreso Operacional de la Central H Manta", https://www.coes.org.pe/Portal/Planificacion/NuevosProyectos/OperacionComercial, viewed 1 February 2021; "Cuatro centrales de energía renovable entraron en operación el 2020", Andina, 4 January 2021, https://andina.pe/agencia/noticia-cuatro-centrales-energia-renovable-entraron-operacion-2020-828586.aspx.

78 "Commercial startup of 84-MW La Virgen hydro in Peru delayed to 2021", Hydro Review, 13 April 2020, https://www.hydroreview.com/hydro-industry-news/commercial-startup-of-84-mw-la-virgen-hydro-in-peru-delayed-to-2021; Government of Peru, Supervisory Agency for Investment in Energy and Mining (OSINERGMIN), "Centrales de generación en construcción", July 2020, https://www.osinergmin.gob.pe/seccion/centro_documental/electricidad/Documentos/PROYECTOS%20GFE/Generaci%C3%B3n/3-EN-CONSTRUCCION-MINEM.pdf.

79 REN21, *Renewables 2020 Global Status Report* (Paris: 2020), https://www.ren21.net/gsr-2020; Comisión Nacional de Energía, "Capacidad instalada de generación", https://www.cne.cl/estadisticas/electricidad, viewed February 2020.

80 IHA, op. cit. note 3.

81 "Israel's 300-MW Mount Gilboa pumped storage begins operating", Hydro Review, 7 May 2020, https://www.hydroreview.com/hydro-industry-news/israels-300-mw-mount-gilboa-pumped-storage-begins-operating; "Jixi Pumped Storage Power Station", NS Energy, https://www.nsenergybusiness.com/projects/jixi-pumped-storage-power-station, viewed 18 May 2020.

82 I. Todorović, "Greece asks EU to approve state aid for 680 MW pumped storage project", Balkan Green Energy News, 7 July 2020, https://balkangreenenergynews.com/greece-asks-eu-to-approve-state-aid-for-680-mw-pumped-storage-project; "SSE Renewables receives government consent for Coire Glas pumped storage scheme", Renewable Energy World, 23 October 2020, https://www.renewableenergyworld.com/baseload/sse-renewables-receives-government-consent-for-coire-glas-pumped-storage-scheme; SASAC, "CGGC to build Turkey's first pumped-storage power project", 1 April 2020, http://en.sasac.gov.cn/2020/04/01/c_4401.htm; G. Çağatay, "Turkey, China, US to build pumped-storage hydro plant", Andalou Agency, 4 September 2020, https://www.aa.com.tr/en/energy/finance/turkey-china-us-to-build-pumped-storage-hydro-plant/28929.

83 "Integrated pumped-storage schemes for India", International Journal on Hydropower and Dams, 14 May 2020, https://www.hydropower-dams.com/news/integrated-pumped-storage-schemes-for-india.

84 IHA, "Country profiles – Australia", https://www.hydropower.org/country-profiles/australia, viewed 13 February 2021; Australian Government, "Pumped hydro", https://www.energy.gov.au/government-priorities/energy-supply/pumped-hydro-and-snowy-20, viewed 18 March 2021..

85 Snow Hydro, "Snowy 2.0 about and progress", https://www.snowyhydro.com.au/snowy-20, viewed 13 February 2021.

86 Hydro Tasmania, "Lake Cethana selected as first pumped hydro project", press release (Hobart: 15 December 2020), https://www.hydro.com.au/news/media-releases/2020/12/15/lake-cethana-selected-as-first-pumped-hydro-project; Hydro Tasmania, "Lake Cethana pumped hydro potential" (Hobart: September 2019), https://www.hydro.com.au/docs/default-source/clean-energy/battery-of-the-nation/botn---cethana-pumped-hydro-fact-sheet-september-2019.pdf.

87 GE, "GE Renewable Energy signs agreement with Walcha Energy to accelerate 500MW pumped hydro storage project in Australia", press release (Paris: 4 August 2020), https://www.ge.com/news/press-releases/ge-renewable-energy-signs-agreement-walcha-energy-accelerate-500mw-pumped-hydro; "GE Renewable Energy signs agreement with BE Power to accelerate 400 MW pumped hydro storage project in Australia", press release (Paris: 15 December 2020), https://www.ge.com/news/press-releases/ge-renewable-energy-signs-agreement-with-be-power-to-accelerate-400-mw-pumped-hydro.

88 Iberdrola, Flagship Projects, "Tâmega: One of the largest hydroelectric projects developed in Europe in the last 25 years", https://www.iberdrola.com/about-us/lines-business/flagship-projects/tamega-project, viewed February 2021; Vietnam Electricity (EVN), "Ceremony of implementing construction and launching emulation for completing discharge gate work cluster of Bac Ai Pumped-Storage Hydropower Project", press release (Hanoi: 6 January 2020), https://en.evn.com.vn/d6/news/Ceremony-of-implementing-construction-and-launching-emulation-for-completing-discharge-gate-work-cluster-of-Bac-Ai-Pumped-Storage-Hydropower-Project-66-142-1744.aspx.

89 K. Illankoon, "DEWA's Al Tayer reviews construction progress at the hydroelectric power station in Hatta", Construction Business News, 23 July 2020, https://www.cbnme.com/news/dewas-al-tayer-reviews-construction-progress-at-the-hydroelectric-power-station-in-hatta; A. Bagchi, "Work on schedule at Hatta pumped hydro storage project", ME Construction News, 7 January 2021, https://meconstructionnews.com/45520/work-on-schedule-at-hatta-pumped-hydro-storage-project.

90 NEA, "The world's largest total installed capacity of pumped storage power plants for water storage", 13 November 2020, http://www.nea.gov.cn/2020-11/13/c_139555787.htm; Drax, "Pumping power: Pumped storage stations around the world", 30 December 2020, https://www.drax.com/technology/pumping-power-pumped-storage-stations-around-the-world.

91 IEA, *Sustainable Recovery World Energy Outlook Special Report* (Paris: 2020), https://www.iea.org/reports/sustainable-recovery; IHA, *Strengthening Sustainable Hydropower to Support the Covid-19 Recovery* (London: 28 May 2020), https://www.hydropower.org/publications/iha-position-paper-strengthening-sustainable-hydropower-to-support-the-covid-19; technologies related to the energy transition (renewables, electric vehicles and battery storage) and digitalisation are among the sectors that have generated the most interest from investors in the post-COVID-19 market, from M. Rathbone, PWC, "Infrastructure investment opportunities in the post-COVID-19 era", presentation at International Finance Corporation (IFC) Korea Workshop Series, 7 October 2020, https://www.ifc.org/wps/wcm/connect/b2364239-ebac-465c-8afc-71a83bdb8900/%28Consolidated%29_Infra+WS_ppt_201005.pdf?MOD=AJPERES&CVID=nk5.nPl.

92 IEA, *Electricity Market Report – December 2020* (Paris: 2020), https://www.iea.org/reports/electricity-market-report-december-2020/2020-global-overview-prices.

93 Voith Hydro, *2020 Annual Report* (Heidenheim, Germany: December 2020), https://voith.com/uk-en/VZ_annual-report-2020_20_vvk_en.pdf.

94 Ibid.

95 GE, *Form 10-K* [as incorporated into 2020 Annual Report] (Boston: February 2021), pp. 11-13, https://www.ge.com/sites/default/files/GE_AR20_AnnualReport.pdf.

96 Andritz Group, *Annual Report 2020* (Graz, Austria: 2020), pp. 61-62, https://www.andritz.com/group-en/investors/annual-reports.

97 IEA, op. cit. note 91.

98 IRENA, "IRENA and IHA forge partnership to advance sustainable hydropower", press release (Abu Dhabi: 3 February 2021), https://www.irena.org/newsroom/pressreleases/2021/Feb/IRENA-and-IHA-Forge-Partnership-to-Advance-Sustainable-Hydropower.

99 "Research suggests ageing dams pose growing threat", International Water Power & Dam Construction, 25 January 2021, https://www.waterpowermagazine.com/news/newsresearch-suggests-ageing-dams-pose-growing-threat-8472001; "O&M strategies for hydropower", International Water Power & Dam Construction, 3 June 2020, https://www.waterpowermagazine.com/features/featureom-strategies-for-hydropower-7954776.

100 See, for example, Končar Ket, "Replacement of USZMR (control, signaling, protection, measuring and regulation), uninterruptible power supply system and own consumption system at HPP Đale",

27 February 2020, https://www.koncar-ket.hr/en/news/zamjena-sustava-uszmr-sustava-besprekidnih-napajanja-i-sustava-vlastite-potrosnje-u-he-dale, and refurbishment references provided in Hydropower Markets section.

101 M. A. Rodríguez, "Dan inicio a proceso para instalación de tres turbinas más en Yacyretá", ABC Color, 31 January 2021, https://www.abc.com.py/nacionales/2021/01/31/dan-inicio-a-proceso-para-instalacion-de-tres-turbinas-mas-en-yacyreta; "Itaipú invertirá US$ 660 millones para digitalizar la operatividad de la usina", ABC Color, 31 Mayo 2020, https://www.abc.com.py/edicion-impresa/economia/2020/05/30/itaipu-invertira-us-660-millones-para-digitalizar-la-operatividad-de-la-usina.

102 Voith, "Voith launches a project for intelligent hydropower in Australia", press release (Heidenheim, Germany: 17 August 2020), https://voith.com/corp-en/news-room/press-releases/2020-08-17-vh-voith-launches-a-project-for-intelligent-hydropower-in-australia.html.

103 XFLEX Hydro, *Flexibility, Technologies and Scenarios for Hydropower Report – Report Summary* (Porto, Portugal: 25 November 2020), https://xflexhydro.net/flexibility-technologies-and-scenarios-for-hydropower-report; IHA, "Greenhouse gas emissions", https://www.hydropower.org/factsheets/greenhouse-gas-emissions, viewed 23 April 2021.

104 Hydro WIRES, US Department of Energy, *Hydropower Value Study: Current Status and Future Opportunities* (Washington, DC: January 2021), https://www.energy.gov/sites/prod/files/2021/01/f82/hydropower-value-study-v2.pdf.

105 Ibid; Bonneville Power Administration, "Energy Imbalance Market", https://www.bpa.gov/PROJECTS/Initiatives/EIM/Pages/Energy-Imbalance-Market.aspx, viewed 19 May 2021.

106 Hydro WIRES, op. cit. note 104.

107 J. Leslie, "Stability Pathfinder", International Water Power & Dam Construction, 4 November 2020, https://www.waterpowermagazine.com/features/featurestability-pathfinder-8345488.

108 Ibid.; National Grid ESO, "National Grid ESO launch Stability Pathfinder phase one", press release (Warwick, UK: 22 October 2019), https://www.nationalgrideso.com/news/national-grid-eso-launch-stability-pathfinder-phase-one.

109 N. Pombo-van Zyl, "West Africa: Hydro to support solar and wind in smart renewable grid", ESI Africa, 1 June 2020, https://www.esi-africa.com/industry-sectors/future-energy/west-africa-hydro-to-support-solar-and-wind-in-smart-renewable-grid; S. Sterl et al., "Smart renewable electricity portfolios in West Africa", *Nature Sustainability*, vol. 3 (25 May 2020), https://doi.org/10.1038/s41893-020-0539-0.

110 See, for example: Vattenfall, "Solar power complements German pumped hydro plants", press release (Stockholm: 9 September 2020), https://group.vattenfall.com/press-and-media/newsroom/2020/solar-power-complements-german-pumped-hydro-plants; A. Colthorpe, "India's Greenko gets nearly US$1bn investment for big hybrid renewables-plus-storage projects", Energy Storage News, 14 September 2020, https://www.energy-storage.news/news/indias-greenko-gets-nearly-us1b-investment-for-big-hybrid-renewables-plus-s.

111 GE, "GE Renewable Energy signs agreement with Walcha Energy to accelerate 500 MW pumped hydro storage project in Australia", press release (Paris: 4 August 2020), https://www.ge.com/news/press-releases/ge-renewable-energy-signs-agreement-walcha-energy-accelerate-500mw-pumped-hydro.

112 D. Pittis, "Why cheap wind power is making Quebec's big, old dams more valuable as a 'battery', say experts", CBC News, 8 February 2021, https://www.cbc.ca/news/business/apuiat-dam-wind-power-1.5903334.

113 See, for example: G. Deboutte, "First unit of 250 MW floating PV project comes online in Ghana", pv magazine, 15 December 2020, https://www.pv-magazine.com/2020/12/15/first-unit-of-250-mw-floating-pv-project-comes-online-in-ghana; RusHydro, "RusHydro brings online first floating solar power plant at Nizhne-Bureyskaya HPP", 11 August 2020, http://www.eng.rushydro.ru/press/news/111675.html; A. Doyle, "Sun, water and ice: Lithuania tests floating solar power", *Reuters*, 29 September 2020, https://www.reuters.com/article/idUSL5N2GL5PJ; H. Figueroa Alcázar, "Urrá le apuesta a paneles solares flotantes", *El Universal*, 24 December 2020, https://www.eluniversal.com.co/economica/paneles-solares-flotantes-en-urra-hn3971180.

114 US National Renewable Energy Laboratory (NREL), "News release: Untapped potential exists for blending hydropower, floating PV" (Golden, CO: 29 September 2020), https://www.nrel.gov/news/press/2020/untapped-potential-exists-for-blending-hydropower-floating-pv.html.

115 E. Bellini, "FV flutuante para compensar o baixo desempenho da energia hidrelétrica no Brasil", pv magazine Latam, 16 September 2020, https://www.pv-magazine-latam.com/brasil-noticias/fv-flutuante-para-compensar-o-baixo-desempenho-da-energia-hidreletrica-no-brasil.

116 Hydro Québec, "Hydro-Québec to operate one of the world's most powerful electrolyzers to produce green hydrogen", press release (Montreal: 8 December 2020), http://news.hydroquebec.com/en/press-releases/1667/hydro-quebec-to-operate-one-of-the-worlds-most-powerful-electrolyzers-to-produce-green-hydrogen; "Landsvirkjun to build hydrogen production facility at 16-MW Ljosifoss hydropower", Renewable Energy World, 9 June 2020, https://www.renewableenergyworld.com/hydrogen/landsvirkjun-to-build-hydrogen-production-facility-at-16-mw-ljosifoss-hydropower.

117 L. Qing, "World's first 1-million-kw hydro-turbine generator unit hoisted", *Beijing Review*, 22 June 2020, http://www.bjreview.com/Business/202006/t20200622_800210916.html.

118 "TUM debuts new 'shaft hydropower plant' in Germany", Hydro Review, 20 July 2020, https://www.hydroreview.com/environmental/tum-debuts-new-shaft-hydropower-plant-in-germany; Natel Energy, "Natel Energy commissioned the Monroe Hydro Project, first fish-safe restoration hydro turbine installation", press release (Alameda, CA: 10 December 2020), https://www.natelenergy.com/2020/12/10/natel-energy-commissioned-the-monroe-hydro-project-first-fish-safe-restoration-hydro-turbine-installation.

119 NREL, "Novel design configuration increases market viability for pumped-storage hydropower in the United States", 21 August 2020, https://www.nrel.gov/news/program/2020/psh-ensures-resilient-energy-future.html.

120 REN21, op. cit. note 79.

121 Mekong River Commission (MRC), "Mekong River drops to 'worrying' levels, some sections turning blue-green", 12 February 2021, https://www.mrcmekong.org/news-and-events/news/pr002-12022021; MRC, "New guidelines for Mekong hydropower released to help optimise benefits, reduce risks", 28 September 2020, https://www.mrcmekong.org/news-and-events/news/new-guidelines-for-mekong-hydropower-released-to-help-optimise-benefits-reduce-risks.

122 MRC, "Mekong River drops to 'worrying' levels", op. cit. note 121; "Three-way talks on Ethiopian dam reach new impasse", op. cit. note 52; "Iraqi MPs: Turkey's operation of Ilisu Dam on Tigris River threatens water security in Iraq", Hawar News Agency, 25 December 2020, http://www.hawarnews.com/en/haber/iraqi-mps-turkeys-operation-of-ilisu-dam-on-tigris-river-threatens-water-security-in-iraq-h21723.html.

123 IEA, *Climate Impacts on Latin American Hydropower* (Paris: January 2021), https://www.iea.org/reports/climate-impacts-on-latin-american-hydropower/measures-to-enhance-the-resilience-of-latin-american-hydropower; *IEA, Climate Impacts on African Hydropower* (Paris: June 2020), https://www.iea.org/reports/climate-impacts-on-african-hydropower/measures-to-enhance-the-resilience-of-african-hydropower.

124 I. Todorović, "Federation of BiH bans construction of small hydropower plants", Balkan Green Energy News, 24 June 2020, https://balkangreenenergynews.com/federation-of-bih-bans-construction-of-small-hydropower-plants; I. Todorović, "Montenegro's new cabinet to ban small hydropower, revise concessions", World Energy, 7 December 2020, https://www.world-energy.org/article/14353.html; I. Todorović, "Sokobanja in Serbia to ban new small hydropower plants, wind parks", Balkan Green Energy News, 26 February 2020, https://balkangreenenergynews.com/sokobanja-in-serbia-to-ban-new-small-hydropower-plants-wind-parks.

125 V. Spasić, "New initiative to support sustainable hydropower in the Western Balkans", Balkan Green Energy News, 13 January 2021, https://balkangreenenergynews.com/new-initiative-to-support-sustainable-hydropower-in-the-western-balkans.

126 IHA, "IHA sustainability assessment fund expands to more countries", 12 February 2021, https://www.hydropower.org/news/iha-sustainability-assessment-fund-expands-to-more-countries; IHA, "Small hydro project leads the way in South Africa on sustainable development", 21 January 2021, https://www.hydropower.org/news/small-hydro-project-leads-the-way-in-south-africa-on-sustainable-development.

OCEAN POWER

1 International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2021* (Abu Dhabi: March 2021), p. 12, https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021.

2 Ibid.

3 Ocean Energy Europe, *Ocean Energy: Key Trends and Statistics 2020* (Brussels: February 2021), p. 13, https://www.oceanenergy-europe.eu/wp-content/uploads/2021/03/OEE-Stats-Trends-2020.pdf.

4 European Commission (EC), *Strategy on Offshore Renewable Energy* (Brussels: November 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A741%3AFIN&qid=1605792629666.

5 EC, *Study on Lessons for Ocean Energy Development* (Brussels: 2017), p. iii, https://publications.europa.eu/resource/cellar/03c9b48d-66af-11e7-b2f2-01aa75ed71a1.0001.01/DOC_1.

6 Ocean Energy Europe, op. cit. note 3, p. 4.

7 G. Smart and M. Noonan, *Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit* (Glasgow, Scotland: Offshore Renewable Energy Catapult, 2018), https://www.marineenergywales.co.uk/wp-content/uploads/2018/05/ORE-Catapult-Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf; European Marine Energy Centre Ltd., "Wave devices", http://www.emec.org.uk/marine-energy/wave-devices, viewed 15 March 2021.

8 Ocean Energy Europe, *Ocean Energy: Key Trends and Statistics 2019* (Brussels: March 2020), p. 10, https://www.oceanenergy-europe.eu/wp-content/uploads/2020/03/OEE_Trends-Stats_2019_Web.pdf.

9 SIMEC Atlantis Energy, "Overcoming the pandemic to build a mammoth turbine in Wuhan: Atlantis helping to open up China's 8.2GW tidal stream renewable power potential", press release (Edinburgh: 27 April 2020), https://simecatlantis.com/2020/04/27/overcoming-the-pandemic-to-build-a-mammoth-turbine-in-wuhan.

10 Ibid.

11 International Energy Agency, Ocean Energy Systems (IEA-OES), *Annual Report 2020* (Lisbon: 2020), p. 11, https://www.ocean-energy-systems.org/documents/40962-oes-annual-report-2020.pdf.

12 IEA-OES, *Spotlight on Ocean Energy* (Lisbon: November 2018), https://www.ocean-energy-systems.org/documents/84169-oes-spotlight-on-ocean-energy.pdf.

13 IEA-OES, op. cit. note 11, p. 12.

14 IEA-OES, "China", https://www.ocean-energy-systems.org/ocean-energy-in-the-world/china, viewed 15 March 2021.

15 Verdant Power, "Three Verdant Power tidal turbines deployed in New York City's East River", press release (New York: 22 October 2020), https://www.verdantpower.com/news-rite-install-10-22-20.

16 Verdant Power, "Verdant Power's New York City tidal turbines exceed expectations", press release (New York: 27 January 2021), https://www.verdantpower.com/turbine-perfrormance.

17 US Department of Energy, *Water Power Technologies Office, 2019-2020 Accomplishments Report* (Washington, DC: 2021), p. 72, https://www.energy.gov/sites/prod/files/2021/01/f82/2019-2020-wpto-accomplishments-report.pdf.

18 Ibid.

19 ORPC, "ORPC selects Maine company to fabricate second commercial underwater power system", press release (Portland, ME: 11 August 2020), https://orpc.co/uploads/news/orpc-selects-maine-company-to-fabricate-second-commercial-underwater-power-system_637327295969885603.pdf; Congresswoman C. Pingree, "Pingree announces $3.6M grant for Maine firm to develop renewable tidal power system", press release (Washington, DC: 24 November 2020), https://pingree.house.gov/news/documentsingle.aspx?DocumentID=3549.

20 Nova Innovation, "Nova Innovation celebrates birthday with Shetland Tidal Array expansion", 17 October 2020, https://www.novainnovation.com/news/news_/i/nova-innovation-celebrates-birthday-with-shetland-tidal-array-expansion.

21 EnFAIT, "The project", https://www.enfait.eu/the-project, viewed 15 March 2021.

22 Nova Innovation, "Europe Case Study – Shetland Tidal Array", https://www.novainnovation.com/markets/scotland-shetland-tidal-array, viewed 15 March 2021.

23 DesignPro Renewables, "60kW testing successfully concludes in Orkney Islands", press release (Limerick, Ireland: 28 January 2020), https://designprorenewables.com/60kw-testing-successfully-concludes-in-orkney-islands.

24 Minesto, "Minesto reaches historic milestone – delivers first tidal energy to the Faroese grid", press release (Västra Frölunda, Sweden: 1 December 2020), https://minesto.com/news-media/minesto-reaches-historic-milestone-%E2%80%93-delivers-first-tidal-energy-faroese-grid.

25 Ibid.; Minesto, "Minesto breaks new ground in the energy sector as it proves its subsea kite technology", press release (Västra Frölunda, Sweden: 30 August 2018), https://minesto.com/news-media/minesto-breaks-new-ground-energy-sector-it-proves-its-subsea-kite-technology; Minesto, "Minesto generates electricity for the first time with commercial-scale unit", press release (Västra Frölunda, Sweden: 9 October 2018), https://minesto.com/news-media/minesto-generates-electricity-first-time-commercial-scale-unit; Minesto, "Minesto signs PPA with electric utility SEV for utility-scale tidal energy installations", press release (Västra Frölunda, Sweden: 19 February 2020), https://minesto.com/news-media/minesto-signs-ppa-electric-utility-sev-utility-scale-tidal-energy-installations; Minesto, "Minesto secures all permits for Faroe Islands' installations", press release (Västra Frölunda, Sweden: 1 April 2020), https://minesto.com/news-media/minesto-secures-all-permits-faroe-islands%E2%80%99-installations.

26 Minesto, "Holyhead Deep – the world's first low-flow tidal stream project", https://minesto.com/projects/holyhead-deep, viewed 15 March 2021.

27 Ibid.; Minesto, "Minesto's Holyhead Assembly Hall is now fully operational", press release (Västra Frölunda, Sweden: 1 October 2020), https://minesto.com/news-media/minesto%E2%80%99s-holyhead-assembly-hall-now-fully-operational.

28 Ibid.

29 Ocean Energy Europe, op. cit. note 3, p. 12.

30 SIMEC Atlantis Energy, "MeyGen Phase 1A completes construction phase and officially enters 25 year operations phase", press release (Edinburgh: 12 April 2018), https://simecatlantis.com/2018/04/12/meygen-phase-1a-completes-construction-phase-and-officially-enters-25-year-operations-phase; SIMEC Atlantis Energy, "MeyGen operational update", 27 January 2020, https://simecatlantis.com/2020/01/27/4036.

31 SIMEC Atlantis Energy, "Operational update", 9 December 2020, https://simecatlantis.com/2020/12/09/4674; SIMEC Atlantis Energy, "Operational update", 7 April 2021, https://simecatlantis.com/2021/04/07/operational-update.

32 Ibid.

33 SIMEC Atlantis Energy, "Atlantis supplied, Scottish manufactured tidal generation equipment arrives in Nagasaki, Japan ahead of deployment in the Naru Strait", 22 December 2020, https://simecatlantis.com/2020/12/22/4705.

34 Nova Scotia Canada, "Developmental Tidal Feed-in Tariff Program", https://energy.novascotia.ca/renewables/programs-and-projects/tidal-fit, viewed 15 March 2021.

35 Ibid.

36 Nova Scotia Ministry of Energy and Mines, "Marine Renewable-energy Demonstration Permit – No. 2020-70-0004 issued to Neweast Energy Corporation n Registry of Joint Stock Companies ID No. 3329875", 20 August 2020, https://energy.novascotia.ca/sites/default/files/files/Signed_DEMO_Permit_for_Neweast_Energy_-_Aug_21_2020.pdf.

37 Natural Resources Canada, "Canada makes historic investments in tidal energy in Nova Scotia", press release (Halifax, Nova Scotia: 5 November 2020), https://www.canada.ca/en/natural-resources-canada/news/2020/11/canada-makes-historic-investments-in-tidal-energy-in-nova-scotia.html; Nova Innovation, "Canadian Government invests in Nova Scotia Tidal Energy Project", 9 September 2020, https://www.novainnovation.com/news/news_/i/canadian-government-invests-in-nova-scotia-tidal-energy.

38 Natural Resources Canada, "Minister Sohi announces major investment in renewable tidal energy that will power 2,500 homes in Nova Scotia", press release (Halifax, Nova Scotia: 20 September 2018), https://www.canada.ca/en/natural-resources-canada/news/2018/09/minister-sohi-announces-major-investment-in-renewable-tidal-energy-that-will-power-2500-homes-in-nova-scotia.html.

39 Nova Scotia Ministry for Energy and Mines, "New tidal energy developer joins FORCE", press release (Halifax, Nova Scotia: 2 September 2020), https://novascotia.ca/news/release/?id=20200902001.

40 IEA-OES, op. cit. note 11, p. 67.

41 HydroQuest, "Project overview", https://www.hydroquest.fr/oceanquest, viewed 15 March 2021.

42 DesignPro Renewables, "DesignPro extends testing at SEENEOH thanks to BlueGift support", press release (Limerick, Ireland: 26 March 2020), https://designprorenewables.com/designpro-extends-testing-at-seeneoh-thanks-to-bluegift-support.

43 Ocean Energy Europe, "Sabella", https://www.oceanenergy-europe.eu/annual/sabella, viewed 15 March 2021.

44 SIMEC Atlantis Energy, "Normandy Prefecture approves transfer of 12MW tidal power development lease from Engie to Normandie Hydroliennes", press release (Edinburgh: 22 June 2020), https://simecatlantis.com/2020/06/22/normandy-prefecture-approves-transfer-of-12mw-tidal-power-development-lease-from-engie-to-normandie-hydroliennes.

45 A. van Unen, "Tocardo acquires the largest tidal array in the world", Tocardo, 12 October 2020, https://www.tocardo.com/tocardo-acquires-1-25mw-oosterschelde-tidal-power-plant-the-largest-tidal-array-in-the-world; A. van Unen, "Oosterschelde Tidal Powerplant resumed full continuous operations again", Tocardo, 9 February 2021), https://www.tocardo.com/oosterschelde-tidal-powerplant-resumed-full-continuous-operations-again.

46 Guangzhou Institute of Energy Conversion, "'Zhoushan' – China's first 500kW Sharp Eagle Wave Energy Converter was officially delivered", 3 July 2020, http://english.giec.cas.cn/ns/tn/202007/t20200703_240147.html.

47 IEA-OES, *Wave Energy Developments: Highlights* (Lisbon: 2021), p. 7, https://www.ocean-energy-systems.org/documents/95502-wave-energy-highlights-march-2021.pdf.

48 Ibid., p. 6.

49 A. Garanovic, "Wavepiston deploys device off Gran Canaria", Offshore Energy, 18 December 2020, https://www.offshore-energy.biz/wavepiston-deploys-device-off-gran-canaria.

50 S. Patel, "Ocean power developers made crucial progress in 2020", POWER, 1 April 2021, https://www.powermag.com/ocean-power-developers-made-crucial-progress-in-2020.

51 IEA-OES, op. cit. note 11, p. 12.

52 "The IHES Consortium led by GEPS Techno installs the wave energy recovery prototype WAVEGEM® on the Centrale Nantes offshore test site", Central Nantes, 26 August 2019, https://sem-rev.ec-nantes.fr/sem-rev/sem-rev-news/the-ihes-consortium-led-by-geps-techno-installs-the-wave-energy-recovery-prototype-wavegem%C2%AE-on-the-centrale-nantes-offshore-test-site.

53 Ocean Power Technologies (OTP), "PB3 PowerBuoy® achieves new operational milestone", 19 August 2020, https://oceanpowertechnologies.com/pb3-powerbuoy-achieves-new-operational-milestone.

54 OPT, "OPT's Italian deployment extended in current location", 27 April 2020, https://oceanpowertechnologies.com/opts-italian-deployment-extended-in-current-location.

55 OPT, "OPT taps SeaTrepid International for first remote OPT PowerBuoy® deployment", 7 December 2020, https://oceanpowertechnologies.com/opt-taps-seatrepid-international-for-first-remote-opt-powerbuoy-deployment.

56 Bombora, "Survey campaign completion milestone achieved for 3.0MW Lanzarote Wave Park project", 23 April 2020, https://bomborawave.com/wp-content/uploads/2020/04/200423-Survey-Campaign-Completion-Milestone-Achieved-for-3MW-Lanzarote-Wave-Park-Project-.pdf.

57 Bombora, "Project InSPIRE has commenced", https://bomborawave.com/latest-news/project-inspire-12mw, viewed 15 March 2021.

58 Ibid.

59 Wave Swell Energy, "A world first project", https://www.waveswell.com/king-island-project-2, viewed 15 March 2021.

60 S. Vorrath, "Carnegie looks to boost CETO 6 wave power efficiency, reliability and smarts", RenewEconomy, 2 March 2020, https://reneweconomy.com.au/carnegie-looks-to-boost-ceto-6-wave-power-efficiency-reliability-and-smarts-91891.

61 A. Dokso, "Carnegie delivers wave predictor; COVID-19 delays validation", Offshore Energy, 6 April 2020, https://www.offshore-energy.biz/carnegie-delivers-wave-predictor-covid-19-delays-validation.

62 A. Garanovic, "Oscilla Power opens another crowdfunding round", Offshore Energy, 29 December 2020, https://www.offshore-energy.biz/oscilla-power-opens-another-crowdfunding-round.

63 Ibid.

64 B. O'Donovan, "Irish company launches wave energy device in the US", RTE, 10 October 2019, https://www.rte.ie/news/2019/1010/1082377-ocean-energy-us.

65 REDstack, "Prototype development of Blue Energy Rack completed", 16 June 2020, https://redstack.nl/en/2020/06/16/prototype-ontwikkeling-blue-energy-rack-afgerond.

66 Akuo, "Akuo and the IANOS European project are targeting a zero-carbon Bora Bora", press release (Bora Bora, French Polynesia: 16 November 2020), https://www.akuoenergy.com/en/documents/getPdf/cp-bora-bora-en.pdf.

67 Government of Puerto Rico, *Puerto Rico Ocean Technology Complex Proposed Roadmap for Development* (San Juan: 6 July 2020), https://refuerzoeconomico.com/images/2020-07-06%20PROTECH_Proposed%20Roadmap%20for%20Development_Red.pdf.

68 IEA-OES, op. cit. note 11, p. 42.

69 D. Magagna, *Ocean Energy Technology Development Report 2018* (Luxembourg: EC Low Carbon Energy Observatory, 2019), https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118296/jrc118296_1.pdf.

70 Ibid.; Directorate-General for Maritime Affairs and Fisheries of the European Commission, *Market Study on Ocean Energy* (Brussels: 20 June 2018), https://publications.europa.eu/en/publication-detail/-/publication/e38ea9ce-74ff-11e8-9483-01aa75ed71a1/language-en/format-PDF/source-99081151.

71 SIMEC Atlantis Energy, "Atlantis announces Share Placement Agreement", 16 December 2020, https://simecatlantis.com/2020/12/16/4690.

72 S. Braun, "Ocean energy about to ride a wave", DW, 9 February 2021, https://www.dw.com/en/ocean-energy-about-to-ride-a-wave/a-56316422.

73 Directorate-General for Maritime Affairs and Fisheries of the European Commission, op. cit. note 70.

74 SET Plan Temporary Working Group, *Ocean Energy – Implementation Plan* (Brussels: 2018), https://setis.ec.europa.eu/system/files/2021-04/set_plan_ocean_implementation_plan.pdf.

75 IEA-OES, *An International Evaluation and Guidance Framework for Ocean Energy Technology* (Lisbon: 29 January 2021), https://www.ocean-energy-systems.org/documents/47763-evaluation-guidance-ocean-energy-technologies2.pdf.

76 European Technology and Innovation Platform for Ocean Energy (ETIP Ocean), *Ocean Energy and the Environment: Research and Strategic Actions* (December 2020), https://www.oceanenergy-europe.eu/wp-content/uploads/2020/12/ETIP-Ocean-Ocean-energy-and-the-environment.pdf.

77 A. Copping, *The State of Knowledge for Environmental Effects Driving Consenting/Permitting for the Marine Renewable Energy Industry* (Richland, WA: IEA-OES and Pacific Northwest National Laboratory, January 2018), https://www.ocean-energy-systems.org/publications/position-papers/document/the-state-of-knowledge-for-environmental-effects-2018-.

78 ETIP Ocean, op. cit. note 76.

79 Ibid.

SOLAR PV

1 At least 139.4 gigawatts direct current (GW_{DC}) was installed and commissioned globally for a year-end total of at least 760.4 GW_{DC}, preliminary data from International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), *Snapshot of Global PV Markets 2021* (Paris: April 2021), p. 6, https://iea-pvps.org/wp-content/uploads/2021/04/IEA_PVPS_Snapshot_2021-V3.pdf, and confirmed by G. Masson, Becquerel Institute and IEA PVPS, Brussels, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 25 May 2021. Estimated 139.4 GW_{DC} of capacity was installed and commissioned globally in 2020 (counting 136 GW of official or industry reported data for 60 countries plus an additional estimated 3.3 GW in the rest of the world) for a year-end global total of an estimated 760.4 GW_{DC} (counting 745 GW of official or industry reported data for 69 countries plus an additional estimated and reported 15.2 GW in rest of world), based on preliminary reported data, from IEA PVPS and Becquerel Institute, Brussels, personal communication with REN21, March to May 2021. By contrast, global additions in 2019 totalled 111,585 MW_{DC}, from IEA PVPS, *Trends in Photovoltaic Applications 2020* (Paris: 2020), p. 85, https://iea-pvps.org/wp-content/uploads/2020/11/IEA_PVPS_Trends_Report_2020-1.pdf. Note that capacity data are uncertain due to several factors, including: a lack of good data in many countries, particularly with regard to small distributed systems, both on and off the grid; lack of information about the amount of capacity that has been decommissioned or is inoperable; large discrepancies between data available in alternating current (AC) and direct current (DC). With regard to the AC/DC issue, reported capacity data often do not specify if numbers are in AC or DC and, even where AC or DC is specified, the conversion rate is generally not published, all from Masson, op. cit. this note. Data from other sources include: additions of 135 GW in 2020 from BloombergNEF, *1Q 2021 Global PV Market Outlook*, cited in E. Bellini, "BloombergNEF expects up to 209 GW of new solar for this year", pv magazine, 23 February 2021, https://www.pv-magazine.com/2021/02/23/bloombergnef-expects-up-to-209-gw-of-new-solar-for-this-year; market expanded 23% with almost 135 GW installed in 2020, from IEA, "Renewable electricity", in *Renewable Energy Market Update 2021* (Paris: 2021), https://www.iea.org/reports/renewable-energy-market-update-2021/renewable-electricity; net additions of 126,735 MW, including a mix of AC and DC, based on a total of 707,495 MW at the end of 2020 and 580,760 MW at the end of 2019, from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2021* (Abu Dhabi: March 2021), https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021; global installations were up 10% to 142 GW in 2020, from IHS Markit, cited in Reuters, "Solar installations on pace for biggest growth in five years, IHS Markit says", *Economic Times*, 30 March 2021, https://energy.economictimes.indiatimes.com/news/renewable/solar-installations-on-pace-for-biggest-growth-in-five-years-ihs-markit-says/81755484; approximately 129.2-GWpeak (DC) added for a global total of 722 GWp, based on shipments during 2020 and supply- and demand-side inventory, and considering losses due to poor quality and breakage in transport and installation, from P. Mints, SPV Market Research, San Francisco, CA, personal communication with REN21, 6 May 2021. Note that cumulative shipments from 1975 through 2020 totalled 722.8 GW direct current (or peak), from P. Mints, *Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2020/2021* (San Francisco: SPV Market Research, April 2021), p. 15. The numbers published by IEA PVPS include all installations (both on-grid and off-grid) when reported, and are based on official data in reporting countries; many of these countries account for decommissioning of existing capacity, but not all countries track either decommissioning or repowering of solar PV capacity. Further, while recycling numbers might also be helpful for determining capacity decommissioned, recycling programmes remain uncommon and data are extremely limited. IEA PVPS assumes that decommissioning is relatively uncommon at this stage, given that most global installations were commissioned in 2005 and later, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. this note, p. 13. Several countries report data officially in AC (i.e., Canada, Chile, Greece, India, Japan, Malaysia, Singapore, Spain, Sweden and the United States); these data were converted to DC by IEA PVPS, Becquerel Institute and other sources in this section for consistency across countries. The difference between DC and AC power can range from as little as 5% (conversion losses, inverter set at DC level) to as much as 60%, and most utility-scale solar PV plants built in 2020 have an AC-DC ratio between 1.1 and 1.6, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. this note, p. 11. MWpeak or MW_{DC} is the rated direct current of a solar system under solar standard test conditions; MWAC, measured in terms of alternating current, is the output a system is designed to deliver to the grid. Losses occur between the solar array and output to the grid, so capacity in AC will always be lower than peak capacity in DC. Conversions done by IEA PVPS and the Becquerel Institute use a multiplier of 1.3 for centralised capacity to convert capacity from AC to DC. In the United States, the median inverter loading ratio (ratio of DC nameplate rating to AC inverter nameplate rating) in 2018, for both tracked and fix-tilt utility-scale projects, was 1.33, but there is significant variation across projects, from M. Bolinger, J. Seel and D. Robson, *Utility-scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2019 Edition* (Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL), December 2019), p. ii, https://eta-publications.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2019_edition_final.pdf. The argument is made that AC ratings are more appropriate for utility-scale capacity because other conventional and renewable utility-scale generating sources also are described in AC terms, and because the difference between a project's DC and AC capacity ratings is increasing in general (at least in the United States) due to a lower relative inverter rating, from M. Bolinger and J. Seel, *Utility-Scale Solar: Empirical Trends in Project Technology, Cost Performance, and PPA Pricing in the United States – 2018 Edition* (Berkeley, CA: LBNL, September 2018), p. 5, https://emp.lbl.gov/utility-scale-solar. However, most analysts, consultancies, industry groups, the IEA and many others report data in DC, from M. Schmela, SolarPower Europe, personal communication with REN21, 11 May 2019. In addition, DC capacity more accurately reflects the rating of panels, from C. Marcy, "Solar plants typically install more panel capacity relative to their inverter capacity", Today in Energy, US Energy Information Administration (EIA), 16 March 2018, https://www.eia.gov/todayinenergy/detail.php?id=35372. In order to maintain a consistent rating type across all solar PV capacity, and because the AC capacity of most countries is not available, GSR 2021 attempts to report all solar PV data in DC units; in addition, the GSR aims to report only capacity that has entered into operation by year's end.

2 See, for example, "Coronavirus cuts PV demand; lower loads lift operators' share", Reuters Events, 1 April 2020, https://analysis.newenergyupdate.com/pv-insider/coronavirus-cuts-pv-demand-lower-loads-lift-operators-share; N. T. Prasad, "Indian solar industry confronts coronavirus crisis", Mercom India, 27 March 2020, https://mercomindia.com/indian-solar-industry-coronavirus-crisis; IEA, "2020 and 2021 forecast overview", in *Renewable Energy Market Update: Outlook for 2020 and 2021* (Paris: May 2020), https://www.iea.org/reports/renewable-energy-market-update/2020-and-2021-forecast-overview.

3 See, for example, "Coronavirus cuts PV demand, op. cit. note 2; Prasad, op. cit. note 2; IEA, op. cit. note 2.

4 Below expectations in, for example, Europe, from SolarPower Europe, *EU Market Outlook for Solar Power 2020-2024* (Brussels: December 2020), p. 3, https://www.solarpowereurope.org/european-market-outlook-for-solar-power-2020-2024; Israel, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 15. Largest increases in capacity based on data for 2020, as noted above, and historical data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85.

5 BloombergNEF, "Household solar demand surges through the roof in 2020", 23 October 2020, https://about.bnef.com/blog/household-solar-demand-surges-through-the-roof-in-2020; "Solar power capacity in the U.S. will jump 43 percent this year", *New York Times*, 15 December 2020, https://www.nytimes.com/live/2020/12/15/business/us-economy-coronavirus#solar-power-capacity-in-the-us-will-jump-43-percent-this-year. See also country-specific information and sources below. The rooftop market grew particularly in Vietnam, as well as in Australia, Germany and the United States, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 12. Distributed definition in footnote from IEA PVPS, *Trends in Photovoltaic Applications 2019* (Paris: 2019), p. 9, https://iea-pvps.org/trends_reports/2019-edition.

6 Top three markets from various sources cited throughout this section, including IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1. Examples of other countries with noteworthy expansion include Australia, Brazil, Germany, Japan, the

Netherlands, Poland, the Republic of Korea and the Russian Federation; see information and sources throughout this section. **Figure 25** based on historical data from IEA *PVPS, Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 84-85, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

7 See, for example, IEA, *World Energy Outlook 2020, Executive Summary* (Paris: 2020), p. 18, https://iea.blob.core.windows.net/assets/80d64d90-dc17-4a52-b41f-b14c9be1b995/WEO2020_ES.PDF. According to the IEA, "solar PV is consistently cheaper than new coal- or gas-fired power plants in most countries", from idem. See also, for example, SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), pp. 9, 13, https://www.solarpowereurope.org/global-market-outlook-2019-2023; IRENA, *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), p. 9, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf; B. Eckhouse, "Solar and wind cheapest source of power in most of the world", Bloomberg, 28 April 2020, https://www.bloomberg.com/news/articles/2020-04-28/solar-and-wind-cheapest-sources-of-power-in-most-of-the-world; M. Brown, "Solar vs. coal: Why the '74 percent report' signals a new era for US energy", Inverse, 28 March 2019, https://www.inverse.com/article/54399-solar-energy-cheaper-than-coal-whats-next; https://www.nature.com/articles/s41560-019-0441-z; J. Weaver, "Solar price declines slowing, energy storage in the money", pv magazine, 8 November 2019, https://pv-magazine-usa.com/2019/11/08/sola-price-declines-slowing-energy-storage-in-the-money; M. Hutchins, "Solar 'could soon be UK's cheapest source of energy'", pv magazine, 12 December 2018, https://www.pv-magazine.com/2018/12/12/solar-could-soon-be-uks-cheapest-source-of-energy; K. Samanta, "India's renewable energy cost lowest in Asia Pacific: WoodMac", *Reuters*, 29 July 2019, https://www.reuters.com/article/us-india-renewables-woodmac/indias-renewable-energy-cost-lowest-in-asia-pacific-woodmac-idUSKCN1UO0L8; J. Yan et al., "City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China", *Nature Geoscience* (2019), cited in J. Gabbatiss, "Solar now 'cheaper than grid electricity' in every Chinese city, study finds", CarbonBrief, 12 August 2019, https://www.carbonbrief.org/solar-now-cheaper-than-grid-electricity-in-every-chinese-city-study-finds.

8 N. Ford, "Europe solar-storage costs fall below markets as learnings kick in", New Energy Update, 2 October 2019, https://analysis.newenergyupdate.com/pv-insider/europe-solar-storage-costs-fall-below-markets-learnings-kick.

9 Figure of 20 in 2020 from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 7; up from 18 countries (Australia, Brazil, China, Chinese Taipei, Egypt, Germany, India, Japan, the Republic of Korea, Mexico, the Netherlands, Pakistan, South Africa, Spain, Ukraine, the United Arab Emirates, the United States and Vietnam) in 2019 based on preliminary estimates from IEA PVPS, *Snapshot of Global PV Markets 2020* (Paris: April 2020), p. 4, https://iea-pvps.org/wp-content/uploads/2020/04/IEA_PVPS_Snapshot_2020.pdf, and on data from Becquerel Institute, op. cit. note 1, 10 April 2020. Note that 16 countries added over 1 GW in 2019, up from 11 in 2018 and 9 in 2017, from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024* (Brussels: 2020), p. 5, https://www.solarpowereurope.org/global-market-outlook-2020-2024; up from 10 countries in 2018 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. this note, p. 9; nine countries in 2017 from IEA PVPS, *Trends in Photovoltaic Applications 2018: Survey Report of Selected IEA Countries Between 1992 and 2017* (Paris: 2018), p. 3, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/2018_iea-pvps_report_2018.pdf; seven countries in 2016 from SolarPower Europe, *Global Market Outlook for Solar Power 2018-2022* (Brussels: 2018), p. 5, https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf.

10 Figure of 42 countries at end of 2020 based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. This was up from 40 countries in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 4. As of the end of 2020, an estimated 95 countries had at least 10 MW of solar PV capacity installed, from F. Jackson, "Solar soars as emerging markets renewables investment hits record high", *Forbes*, 9 December 2020, https://www.forbes.com/sites/feliciajackson/2020/12/09/solar-soars-as-emerging-markets-renewables-investment-hits-record-high.

11 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 16. Based on cumulative capacity in operation at end-2019 and assumes close to optimum siting, orientation and long-term average weather conditions, from idem.

12 **Honduras** sourced 11.2% of its net electricity generation from solar PV, based on data from Empresa Nacional de Energía Eléctrica, p. 7, *Boletín Estadístico – Diciembre 2020* (Tegucigalpa: 2020), http://www.enee.hn/planificacion/2021/12%20diciembre.pdf. **Germany's** share of electricity production was 10.5% in 2020 (up from 9% in 2019), from Fraunhofer ISE, "Annual solar share of electricity production in Germany", Energy-Charts, https://energy-charts.info/charts/renewable_share/chart.htm?l=en&c=DE&share=solar_share&interval=year, updated 24 April 2021; solar PV generation accounted for 9.2% of Germany's gross electricity consumption in 2020 (up from 8.0% in 2019), from Federal Ministry for Economic Affairs and Energy (BMWi) and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany, Based on Statistical Data from the Working Group on Renewable Energy-Statistics (AGEE-Stat)* (Status: February 2021) (Dessa-Roßlau: February 2021), pp. 45, 46, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html. **Greece** based on4,392 GWh of solar PV generation (including 494 GWh from rooftop systems) and 42,230 GWh of total electricity generation, from multiple original sources, all in Greek (including Manager of Renewable Energy Sources and Guarantees of Origin (DAPEEP SA), Μηνιαίο Δελτίο Ειδικού ΛογαριασμούΑΠΕ & ΣΗΘΥΑ, 2021, p. 15, https://www.dapeep.gr/wp-content/uploads/ELAPE/2020/08_DEC_2020_DELTIO_ELAPE_v1.0_21.03.2021.pdf, and total generation, based on data from the Greek Independent Power Transmission Operator (ADMIE), ΜΗΝΙΑΙΟΔΕΛΤΙΟ ΕΝΕΡΓΕΙΑΣ, 2021, pp. 3, 12, 13, 24, 35, https://www.admie.gr/sites/default/files/attached-files/type-file/2021/03/Energy_Report_202012_v2.pdf, and provided by I. Tsipouridis, REDPro Consultants, Athens, personal communication with REN21, April 2021. **Australia** from Clean Energy Council, *Clean Energy Australia Report 2021* (Melbourne: April 2021), p. 9, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf. **Chile** share of generation from Asociación Chilena de Energías Renovables y Almacenamiento AG. (ACERA), *Estadísticas Sector de Generación de Energía Eléctrica Renovable* (December 2020), p. 1, https://acera.cl/wp-content/uploads/2021/01/2020-12-Bolet%C3%ADn-Estad%C3%ADsticas-ACERA.pdf. **Italy** generated 25,549 GWh of electricity with solar PV in 2020, and total net production in the system was 273,108 GWh, for a solar PV share of 9.35%, from Terna, *Rapporto mensile sul Sistema Elettrico December 2020* (Rome: 2020), p. 9, https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202020_8d8b615dca4dafe.pdf. **Japan** from Institute for Sustainable Energy Policies (ISEP), "Share of electricity generated from renewable energy in 2020 (preliminary report)", 12 April 2021, https://www.isep.or.jp/en/1075.

13 Spain and United Kingdom from J. Parnell, "Clean air, clear skies and fresh megawatts cause Europe's solar records to tumble", Greentech Media, 22 April 2020, https://www.greentechmedia.com/articles/read/clean-air-clear-skies-and-fresh-megawatts-see-europes-solar-records-tumble; T. Barrett, "Less air pollution helps UK solar break generation record", Air Quality News, 23 April 2020, https://airqualitynews.com/2020/04/23/less-air-pollution-helps-uk-solar-generation-break-generation-record; S. Vorrath, "Solar generation in Delhi 'clearly' boosted by clear skies of Covid lockdown", RenewEconomy, 29 June 2020, https://reneweconomy.com.au/solar-generation-in-delhi-clearly-boosted-by-clear-skies-of-covid-lockdown-22289; United Arab Emirates from Middle East Solar Industry Association (MESIA), *Solar Outlook Report 2021* (Dubai: January 2021), p. 14, https://mesia.com/information-center/research-papers-reports. Note that sources also mention Germany, from J. Parnell, op. cit. this note, and from S. Hanley, "Clear skies over Germany lead to record amount of solar energy", CleanTechnica, 22 April 2020, https://cleantechnica.com/2020/04/22/clear-skies-over-germany-lead-to-record-amount-of-solar-energy, but it appears that additional capacity was the main driver, along with generally sunny skies throughout the year, because output and capacity both increased by about the same percentage, from S. Hermann, German Environment Agency, Germany, personal communication with REN21, 13 April 2021. Also note that solar output declined in the United Kingdom for all of 2020, down 0.9% relative to 2019, from UK Department for Business, Energy & Industrial Strategy

(BEIS), *Energy Trends – UK, October to December 2020 and 2020* (London: 25 March 2021), p. 17, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972790/Energy_Trends_March_2021.pdf.

14 California output from E. F. Merchant, "California's wildfires hampered solar energy production in September", Greentech Media, 1 October 2020, https://www.greentechmedia.com/articles/read/wildfires-in-california-undercut-solar-production-in-september, and from S. York, "Smoke from California wildfires decreases solar generation in CAISO", Today in Energy, US EIA, 30 September 2020, https://www.eia.gov/todayinenergy/detail.php?id=45336. California variability and forecasting from California Independent System Operator (CAISO), cited in Merchant, op. cit. this note. In California, generation from large-scale solar projects (including concentrating solar power output) in the service territory of CAISO (which covers 90% of the state's utility solar capacity) in the first two weeks of September fell almost 30% below the July average, and 13% year-over-year, despite increased capacity, due to the increase in airborne particulate matter during wildfires, from Merchant, op. cit. this note, and York, op. cit. this note. Australia from Solar Trust Centre Team, "Understanding bushfires and their effect on solar output", Solar Trust Centre, 9 January 2020, https://solartrustcentre.com.au/understanding-bushfires-and-their-effect-on-solar-output.

15 SolarPower Europe, op. cit. note 4; IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 91; grid infrastructure from IEA PVPS and Becquerel Institute, op. cit. note 1, 20 February 2020, from P. Mints, SPV Market Research, *The Solar Flare*, no. 4 (31 August 2019), pp. 8, 10, and from information and sources throughout this section. Financial and bankability challenges are issues of concern particularly in sub-Saharan Africa, from J. Nyokabi, Green Energy, Kenya, personal communication with REN21, 2 April 2021.

16 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 34-35.

17 Lower than a decade ago but challenges remain, fossil and nuclear, from Masson, op. cit. note 1, 20 February 2020, 4 May 2020 and 9 March 2021; IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 17. Regarding utilities, in Brazil, for example, utilities have restricted approval and authorization of solar PV systems, saying that they lack the capacity to make grid connections, to integrate solar energy into the grid, among other things, from R. Baitelo, Associação Brasileira de Energia Solar Fotovoltaica (ABSOLAR), personal communication with REN21, 7 April 2020; in India, distribution companies have pressured policy makers to remove net metering policies and adopt grid usage charges, from Bridge to India, "Bridge to India webinar – India rooftop solar policy round up", email received 2 December 2020. In Australia, the energy market operator has largely prevented attempts by electricity network operators to discriminate against and financially penalise solar customers, but in past years network operators have imposed delays and conditions on the approval of grid connections, which leads to increases in the soft costs of solar deployment, from IEA PVPS, Australian Photovoltaic Institute (APVI) and Australian Renewable Energy Agency (ARENA), *National Survey Report of PV Power Applications in Australia 2018* (Paris: 2019), prepared by R. Egan, APVI, p. 36, https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Australia_2018.pdf.

18 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 5.

19 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 27, 56; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, pp. 48-56; Masson, op. cit. note 1, 9 March and 25 May 2021.

20 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 28. US tax credits continued to play an important role, from Masson, op. cit. note 1, 9 March 2021.

21 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 17, and information and sources throughout this section.

22 Masson, op. cit. note 1, 9 March 2021. In 2020, perhaps 20-30% of the market was installed without direct government incentives, although this does include some tenders that do not provide direct subsidies, from idem. Overall, about 5% of the market volume in 2019 was independent of government support schemes or "adequate regulatory framework", from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 28.

23 Eighth consecutive year based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, and from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1; Asia's share of additions and share without China, based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

24 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

25 Market and manufacturing from SolarPower Europe, *Global Market Outlook for Solar Power*, 2019-2023, op. cit. note 7, p. 89; share of additions in 2020 based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; share of additions in 2019 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. China's share was 44% in 2018 (and 52% in 2017) from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 7, p. 89; China's share of total demand was 27% in 2014, 30% in 2015, 49% in 2016, 56% in 2017, 42% in 2018 and projected 29% in 2019, from P. Mints, SPV Market Research, *The Solar Flare*, no. 5 (31 October 2019), p. 5.

26 Top 10 countries, share of top 5 in 2020 and less concentrated based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; share in 2019 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 12, 85. The share represented by the top 5 in 2018 was about 75%, from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets* (Paris: April 2019), p. 8, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf. The share represented by the top 5 in 2017 was 84%, based on global additions of at least 98 GW_{DC}, and on additions of the top five countries (China, the United States, India, Japan and Turkey), from IEA PVPS, *Snapshot of Global Photovoltaic Markets 2018* (Paris: 2018), p. 4, http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA_PVPS-A_Snapshot_of_Global_PV-1992-2017.pdf.

27 Figure for 2020 based on data of top 10 countries provided throughout this section. The figure for 2019 was 3.1 GW, based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. This was up from 1.3 GW in 2018, from Becquerel Institute, op. cit. note 1, 10 May 2019, and from IEA PVPS, *2019 Snapshot of Global PV Markets*, op. cit. note 26, p. 7, and from 954 MW in 2017, 683 MW in 2016, and 675 MW in 2015, all based on data from IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 9, p. 13.

28 Leading countries for total capacity based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; leaders for capacity per inhabitant from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 7. **Figure 26** based on global and country-specific historical data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, and based on country-specific 2020 data and sources provided throughout this section for China, India, Japan and the United States. EU data for all years from Becquerel Institute, op. cit. note 1, 26 May 2021. India data from the following: data for 2010 and 2011 from European Photovoltaic Industry Association (EPIA), *Global Market Outlook for Photovoltaics Until 2016* (Brussels: May 2012), p. 14, https://www.helapco.gr/pdf/Global_Market_Outlook_2015_-2019_lr_v23.pdf; data for 2012 from IEA PVPS, *PVPS Report, A Snapshot of Global PV 1992-2012* (Paris: 2013), http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2012_-_FINAL_4.pdf; data for 2013 from IEA-PVPS, *PVPS Report – Snapshot of Global PV 1992-2013: Preliminary Trends Information from the IEA PVPS Programme* (Paris: March 2014), http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2013_-_final_3.pdf; data for 2014 from Bridge to India, May 2015, provided by S. Orlandi, Becquerel Institute, Brussels, personal communication with REN21, 11 May 2015; data for 2015 from IEA PVPS, *Trends in Photovoltaic Applications, 2016: Survey Report of Selected IEA Countries Between 1992 and 2015* (Paris: 2016), http://www.iea-pvps.org/fileadmin/dam/public/report/national/Trends_2016_-_mr.pdf; data for 2016 from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress (achievements)", data as on 31 December 2016, http://www.mnre.gov.in/mission-and-vision-2/achievements,

viewed 19 January 2017; data for 2017 and 2018 from IEA PVPS and Becquerel Institute, op. cit. note 1, 3 June 2019 and 4 May 2020; and data for 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 10.

29 China added 48.2 GW for a total of 253.4 GW, from China National Energy Administration (NEA), "National Energy Administration releases 2020 national power industry statistics", 20 January 2021, http://www.nea.gov.cn/2021-01/20/c_139683739.htm (using Google Translate); added 48.2 GW (including 32.68 GW in centralised power stations and 15.52 GW in distributed systems) in 2020 for a year-end total of 253 GW, from National Energy Board, cited in NEA, "Transcript of the online press conference of the National Energy Administration in the first quarter of 2021", 30 January 2021, http://www.nea.gov.cn/2021-01/30/c_139708580.htm (using Google Translate); and added 48.2 GW for a total of 253.4 GW from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Second only to 2017 based on data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. Distributed solar PV in China description in footnote based on the following: F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 22 April 2019; AECEA, "Briefing Paper – China Solar PV Development", September 2017 (provided by Haugwitz, AECEA); AECEA, "China 2017 – what a year with 53 GW of added solar PV! What's in for 2018!" Briefing Paper – China Solar PV Development, January 2018 (provided by Haugwitz, AECEA); A. Rajeshwari, "China's solar PV installations reach almost 10 GW in Q1 of 2018", Mercom India, 26 April 2018, https://mercomindia.com/china-solar-10gw-q1-2018.

30 Increase of 60% based on 48.2 GW added in 2020 and on 30.1 GW added in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1. Two years of contraction based on additions 52.86 GW in 2017, followed by annual additions of 44.26 GW in 2018 and 30.1 GW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 85. Delays and disruptions, from EurObserv'ER, *Photovoltaic Barometer* (Paris: April 2020), p. 4, https://www.eurobserv-er.org/category/all-photovoltaic-barometers. China's solar PV market contracted in 2018 and 2019 because the government temporarily halted subsidy allocations and announced (in 2018) a transition to auctions. In 2020, projects awarded under competitive auctions in mid-2019 and mid-2020 (when almost 26 GW was awarded) were coming online before the phase-out of subsidies for all but residential applications at end of 2020. Residential systems are to receive financial support through the end of 2021, from IEA, "Solar PV", in *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020/solar-pv.

31 National Energy Board, op. cit. note 29.

32 "Multi-pictures: Overview of the details of photovoltaic and wind power installed capacity and power generation in various provinces across the country", 360doc.com, 17 February 2021, http://www.360doc.com/content/21/0217/07/73752269_962367138.shtml (using Google Translate).

33 Year-end total of 253.4 GW, from China NEA, op. cit. note 29, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; total of 253 GW, from National Energy Board, op. cit. note 29. Total grid-connected capacity increased from 204,180 MW in 2019 to 253,430 MW at end-2020, a net increase of 49,250 MW, from official data and based on 204,180 MW of grid-connected capacity in operation at end of 2019 and 253,430 MW in operation at end of 2020, from China Electricity Council (CEC), cited in China Energy Portal, "2020 electricity & other energy statistics (preliminary)", 22 January 2021, https://chinaenergyportal.org/en/2020-electricity-other-energy-statistics-preliminary. Note that data are preliminary and based on grid-connected capacity; in addition, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC, cited in idem. Target for 2020 from Haugwitz, op. cit. note 29, 4 January 2021.

34 IEA, op. cit. note 30.

35 Deficit and backlog from Everchem, "Chinese wind subsidies to end in December China's renewable power price and subsidy: 'new' design in 2020?" 28 October 2020/29 January 2020, https://everchem.com/chinese-wind-subsidies-to-end-in-december; worsened by pandemic and subsidy free from G. Baiyu, "Despite coronavirus, China aims for renewables grid parity", China Dialogue, 2 June 2020, https://chinadialogue.net/en/energy/despite-coronavirus-china-aims-for-renewables-grid-parity. The cumulative deficit for all renewables amounted to the equivalent of USD 50 billion at the end of 2020, from Credit Suisse, cited in J. Wong, "China's green-power funding is blowing in the wind", *Wall Street Journal*, 21 April 2021, https://www.wsj.com/articles/chinas-green-power-funding-is-blowing-in-the-wind-11619003815. One source notes that wind and solar power projects benefit from lower technology costs, but other costs – such as curtailment, taxes on land, financing and initial development – remain high (accounting for 20% or more of wind and solar power project costs) and are barriers to grid parity, from Baiyu, op. cit. this note.

36 Based on additions of 32.7 GW in 2020, from China NEA, provided by Haugwitz, op. cit. note 29, 25 February 2021, and on additions of 17.9 GW in 2019, from China NEA, "PV grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827923.htm (using Google Translate).

37 "China's great energy shift sets mega hybrid plants in motion", Bloomberg, 12 May 2020, https://www.bloomberg.com/news/articles/2020-05-12/china-s-great-energy-shift-sets-mega-hybrid-projects-in-motion.

38 Z. Shahan, "China's largest solar-plus-storage project goes online", CleanTechnica, 1 October 2020, https://cleantechnica.com/2020/10/01/chinas-largest-solar-plus-storage-project-goes-online; E. Bellini, "World's largest solar plant goes online in China — 2.2 GW", pv magazine, 2 October 2020, https://pv-magazine-usa.com/2020/10/02/worlds-largest-solar-plant-goes-online-in-china; G. Wilson, "Sungrow connects China's largest solar-plus-storage project", Business Chief, 30 September 2020, https://medium.com/business-chief/sungrow-connects-chinas-largest-solar-plus-storage-project-565f73faf3bc.

39 Based on additions of 15.5 GW in 2020 (10.1 GW residential and 5.4 GW commercial and industrial), from China NEA, provided by Haugwitz, op. cit. note 29, 25 February 2021, and on additions of 12.2 GW in 2019 (5.3 GW residential and 6.9 GW commercial and industrial), from China NEA, "PV grid-connected operation in 2019", op. cit. note 36.

40 Haugwitz, op. cit. note 29, 4 January 2021.

41 Figure of 2% national average curtailment in 2020, from China NEA, provided by Haugwitz, op. cit. note 29; unchanged from 2019 from China NEA, "PV grid-connected operation in 2019", op. cit. note 36; national electricity consumption was down 6.5% in the first quarter of 2020, with curtailment reaching 2.8% in January and 5.6% in February, from Haugwitz, op. cit. note 29, 14 June 2020.

42 National Energy Board, op. cit. note 29. Curtailment in Xinjiang fell 4.6% relative to 2019, down 2.8 percentage points, and in Gansu it fell 2.2%, down 2.0 percentage points, and across the entire region it declined to 4.8%, a year-on-year decrease of 1.1%, from idem.

43 Haugwitz, op. cit. note 29, 14 June 2020.

44 Based on total power production of 7,623,600 GWh and total solar production of 261,100 GWh (grid-connected capacity) in 2020, for a share of 3.4%, from CEC, cited in China Energy Portal, op. cit. note 33. This was up from just over 3% in 2019, based on total annual generation of 7,326,900 GWh and solar PV generation of 224,000 GWh, from idem. Note that, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC, cited in idem. Generation from solar PV was 260.5 TWh in 2020, from National Energy Board, op. cit. note 29. Also, note that China's solar data likely includes some generation from concentrating solar thermal power projects, but that is relatively small compared to solar PV. See CSP section in this chapter.

45 Central government from China NEA guidance, provided by Haugwitz, op. cit. note 29, 25 February 2021. Governments at all levels from Haugwitz, op. cit. note 29, 7 September 2020. For example, Shaanxi province was offering subsidies for solar PV combined with electrical energy storage, from Haugwitz, op. cit. note 29, 25 February 2021.

46 Haugwitz, op. cit. note 29, 14 November 2020. Provincial and local governments also strengthened existing policies and introduced new ones to support solar PV, particularly distributed systems. In January 2020 alone, 18 solar PV support policies were released

across 14 provinces, with most of these related to distributed solar; in March, several provincial governments released solar PV policies and targets, all from Haugwitz, op. cit. note 29, 1 April 2020. In late 2020, several Chinese cities – including Beijing, Shanghai, Guangzhou and Xian – enacted policies to support solar PV; all of these except Beijing adopted feed-in tariffs, and Beijing began offering investment subsidies, from Haugwitz, op. cit. note 29, 25 February 2021.

47 Vietnam added 4.8 GW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; Vietnam's additions in 2018 and 2017 from M. Maisch, "Vietnam overtakes Australia for commissioned utility scale solar following June FIT rush", pv magazine, 5 July 2019, https://www.pv-magazine.com/2019/07/05/vietnam-overtakes-australia-for-commissioned-utility-scale-solar-following-june-fit-rush; estimated total additions in 2020 of 11.1 GW for a total of 16.4 GW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; third and eighth place based on data and sources provided throughout this section. Vietnam installed 4,898 MW in 2019 and 11.5 GW in 2020, with rooftop solar PV accounting for about 9 GW, from T. Ha, "Renewables are booming in Vietnam. Will the upswing last?" Eco-Business, 13 April 2021, https://www.eco-business.com/news/renewables-are-booming-in-vietnam-will-the-upswing-last; and Vietnam had 4,898 MW in operation at the end of 2019 and an estimated 16,504 MW at the end of 2020, from IRENA, op. cit. note 1. **Figure 27** based on historical global and country-specific data from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; and on country-specific data and sources provided throughout this section.

48 Information for 2019 from, for example: E. A. Gunther, "Vietnam rooftop solar records major boom as more than 9GW installed in 2020", PV-Tech, 6 January 2021, https://www.pv-tech.org/vietnam-rooftop-solar-records-major-boom-as-more-than-9gw-installed-in-2020; GlobalData Energy, "Vietnam's solar drive", Power Technology, 30 July 2019, https://www.power-technology.com/comment/vietnam-solar-drive; S. Djunisic, "B. Grimm brings online 677 MW of solar in Vietnam", Renewables Now, 17 June 2019, https://renewablesnow.com/news/bgrimm-brings-online-677-mw-of-solar-in-vietnam-658285; Maisch, op. cit. note 47; T. Kenning, "Close to 90 solar projects 'sprinting' for Vietnam's June FiT deadline", PV-Tech, 20 May 2019, https://www.pv-tech.org/news/close-to-90-solar-projects-sprinting-for-vietnams-june-fit-deadline; developments in 2020 from Vietnam Electricity (EVN) and the Viet Nam Energy Partnership Group, cited in Gunther, op. cit. this note. The rooftop market accelerated throughout 2020 and saw a sharp rise in December to qualify for the FIT2 tariff (USD 0.0838/kWh over 20 years for rooftop systems) before it expired at year's end, from idem.

49 Number of rooftop systems added in 2020 (82,900) and year-end rooftop solar PV capacity of 9.7 GW, from EVN / National Load Dispatch Centre of Vietnam (NLDC), provided by H. T. Tran, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Hanoi, personal communication with REN21, 11 April 2021; rooftop installations increased from a base of 378 MW_{DC} at the end of 2019 to 9,583 MW at end of 2020, with 6,708 GW connected in December alone; at year's end, total operating capacity was 16,449 GW_{DC} (13,160 GWAC), all from Vietnam Ministry of Industry and Trade, notice dated 31 December 2020, cited in Gunther, op. cit. note 48. Vietnam had installed a total of more than 101,939 rooftop systems with capacity of 9.3 GW as of 4 January 2021, from Electricity of Vietnam, "Vietnam to be the world's top 3 PV market with installed capacity exceeding 10GW", Nangluon Vietnam, 18 March 2021, http://nangluongvietnam.vn/news/en/nuclear-renewable/vietnam-to-be-the-worlds-top-3-pv-market-with-installed-capacity-exceeding-10gw.html. Note that total capacity at end-2020 was 19,400 MW_{DC}, from EVN, "Rooftop solar power boom is underway with a total installed capacity reaching nearly 9,300 MWp", press release (Hanoi: 1 January 2021), https://en.evn.com.vn/d6/news/Rooftop-solar-power-boom-is-underway-with-a-total-installed-capacity-reaching-nearly-9300-MWp-66-142-2169.aspx; was 18.5 GW at the end of 2020, from EVN/NLDC and provided by Tran, op. cit. this note, and increased from 106 MW_{DC} in 2018 to 19.4 GW_{DC} at the end of 2020, from L. Stoker, "Unravelling the past, present and future of solar policy in Vietnam", PV-Tech, 17 March 2021, https://www.pv-tech.org/unravelling-the-past-present-and-future-of-solar-policy-in-vietnam.

50 To meet rising demand and figure of 10% from E. Bellini, "Vietnam introduces auction scheme for large-scale PV", pv magazine, 5 December 2019, https://www.pv-magazine.com/2019/12/05/vietnam-introduces-auction-scheme-for-large-scale-pv; population growth and economic expansion from GlobalData Energy, op. cit. note 48; ensure energy security and reduce carbon emissions from Ha, op. cit. note 47.

51 Ha, op. cit. note 47.

52 Rankings based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Japan had its best year since 2015, when the country added 10,811 MW, based on data from IEA PVPS, *Trends in Photovoltaic Applications 2021*, p. 85.

53 Four years of contraction based on data from IEA PVPS, *Trends in Photovoltaic Applications 2021*, p. 85, and from data of feed-in tariff scheme, Japanese Ministry of Economy, Trade and Industry (METI), provided by H. Matsubara, ISEP, Tokyo, personal communication with REN21, 14 April 2020; additions in 2020 and year-end total from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; increase based on 2019 additions from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit.note 1, p. 85. Figure of 8.2 GW_{DC} (6.3 GWAC) also from RTS Corporation, cited in A. Bhambhani, "RTS Corporation says in 2020, Japan grew annual solar PV capacity by 17% to around 8.2 GW_{DC} reaching cumulative of 71.7 GW_{DC}", TaiyangNews, 20 January 2021, http://taiyangnews.info/markets/japan-installed-8-gw-dc-new-solar-capacity-in-2020.

54 M. Hall, "Japan's struggle to drive down renewables costs", pv magazine, 20 August 2020, https://www.pv-magazine.com/2020/08/20/japans-struggle-to-drive-down-renewables-costs; SolarPower Europe, op. cit. note 9, p. 80.

55 I. Kaizuka, "Agricultural PV emerges as Japan's next opportunity", pv magazine, 2 June 2020, https://www.pv-magazine.com/2020/06/02/agricultural-pv-emerges-as-japans-next-opportunity.

56 ISEP, op. cit. note 12. Shares include self-consumption.

57 Half of 2019 additions based on 10 GW added in 2019 from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1; lowest in five years from U. Gupta, "Tracking rooftop solar trends in India", pv magazine, 5 January 2021, https://www.pv-magazine.com/2021/01/05/tracking-rooftop-solar-trends-in-india. Investments fell 66% relative to 2019, to USD 2.8 billion (nearly USD 1.19 billion for utility-scale and USD 356 million for rooftop), from R. Ranjan, "Investments in the Indian solar sector declined by 66% in 2020", Mercom India, 1 March 2021, https://mercomindia.com/investments-indian-solar-declined-2020.

58 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 10.

59 Based on preliminary data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. IEA PVPS and Becquerel Institute use official estimates (in AC) for ground-mounted capacity with a multiplier of 1.3 for conversion of centralised capacity to DC; rooftop and off-grid capacity are assumed to be in DC, from IEA PVPS and Becquerel Institute, op. cit. note 1, 23 April 2020. India added 3,865.48 MW in 2020 based on end-2019 capacity of 34,675.75MW and end-2020 capacity of 38,541.23 MW (all a mix of AC and DC), from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2019-20 & cumulative upto Dec, 2019", https://mnre.gov.in/physical-progress-achievements, viewed 9 January 2020, and data at end 2020 from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2020-21 & cumulative upto Dec, 2020", https://mnre.gov.in/physical-progress-achievements, viewed 3 February 2021. India's year-end solar power capacity was 37,464.6 MW (probably all in AC, although this is not specified), from Government of India, Ministry of Power, Central Electricity Authority (CEA), "All India installed capacity (in MW) of power stations (as on 31.12.2020) (utilities)", https://cea.nic.in/wp-content/uploads/installed/2020/12/installed_capacity.pdf. Totals from MNRE and CEA are for all solar power, including off-grid solar PV, and also include some concentrating solar thermal power (CSP) capacity; India's CSP capacity is an estimated 225 MW (see Concentrating Solar Thermal Power section in this chapter for more details and sources). The top states for total capacity at end-2020 were Karnataka (7.3 GW), Rajasthan (5.4 GW) and Tamil Nadu (4.3 GW) (probably all in AC),

from Government of India, MNRE, "State-wise installed capacity of grid interactive renewable power as on 31.12.2020", https://mnre.gov.in/img/documents/uploads/file_s-1612163907504.xlsx, viewed 3 February 2021. India added 3.2 GW of solar PV capacity in 2020, from N. T. Prasad, "Solar generation in Q4 2020 9% higher from previous quarter, up 26% annually", Mercom India, 8 February 2021, https://mercomindia.com/solar-generation-up-26-percent-annually. (Mercom India data were confirmed to be provided in AC by S. Prateek, Mercom India, New Delhi, personal communication with REN21, May 2019.)

60 For example, see R. Ranjan, "India adds 3.2 GW of solar in 2020, a 56% decline as COVID takes a toll", Mercom India, 23 February 2021, https://mercomindia.com/india-adds-3-2-gw-of-solar-in-2020.

61 From, for example, MNRE cited in R. Ranjan, "Committee on Energy skeptical about India's chances of meeting its 2022 solar target", Mercom India, 24 March 2020, https://mercomindia.com/committee-energy-india-chances-solar-target; R. Ranjan, "Transmission infrastructure crucial to support growing solar capacity", Mercom India, 12 April 2021, https://mercomindia.com/transmission-infrastructure-crucial-solar-capacity; U. Gupta, "Solar industry in 2020", pv magazine, https://www.pv-magazine-india.com/2020/12/28/solar-industry-in-2020; "750 MW of solar projects in Andhra Pradesh face serious delays", Mercom India, 27 August 2020, https://mercomindia.com/solar-projects-andhra-pradesh-delays; A. Parikh, "MNRE addresses transmission infrastructure delays facing solar & wind developers", Mercom India, 11 March 2020, https://mercomindia.com/mnre-transmission-delays-solar-wind-developers; N. T. Prasad, "1.4 GW of ISTS solar projects awarded by NTPC stand canceled", Mercom India, 30 January 2020, https://mercomindia.com/ists-solar-projects-ntpc-canceled; P. Mints, SPV Market Research, *The Solar Flare*, 4 September 2020, p. 10.

62 Rooftop market based on 3,505.61 MW of rooftop capacity and 1,076.63 MW equivalent (assumed to be all in DC) of off-grid capacity at the end of 2020, from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2020-21 & cumulative upto Dec, 2020", op. cit. note 59, viewed 3 February 2021, and on 2,333.23 MW of rooftop capacity and 945.22 MW of off-grid capacity at the end of 2019, from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2019-20 & cumulative upto Dec, 2019", op. cit. note 59, viewed 9 January 2020. Inconsistent policy and restrictions from R. Ranjan, "Rooftop solar cannot thrive in a restrictive policy environment", Mercom India, 14 April 2021, https://mercomindia.com/rooftop-solar-cannot-thrive-restrictive-environment; pandemic from N. T. Prasad, "Cost of large-scale and rooftop solar projects rose slightly in Q3 2020", Mercom India, 24 November 2020, https://mercomindia.com/cost-large-scale-rooftop-solar; N. T. Prasad, "Top developments that influenced the rooftop solar segment in 2020", Mercom India, 31 December 2020, https://mercomindia.com/top-developments-influenced-rooftop-solar; H. Shukla, "Where does India's rooftop solar market stand since COVID-19 lockdown?" Mercom India, 14 December 2020, https://mercomindia.com/where-does-india-rooftop-solar; grid usage charges and net metering from Bridge to India, op. cit. note 17. For more on the rooftop sector and influences in 2020, see Prasad, "Top developments that influenced the rooftop solar segment in 2020", op. cit. this note.

63 Prasad, "Cost of large-scale and rooftop solar projects rose slightly in Q3 2020", op. cit. note 62; Prasad, "Top developments that influenced the rooftop solar segment in 2020", op. cit. note 62; Shukla, op. cit. note 62; Ranjan, op. cit. note 61. See also Ranjan, "Committee on Energy skeptical about India's chances of meeting its 2022 solar target", op. cit. note 60.

64 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, provided by A. Detollenaere, Brussels, personal communication with REN21, 22 March and 20 April 2021. As of September 2020, several projects ranging in size from 5 MW to 61 MW had secured licences in the Philippines, from E. Bellini, "Three 1.2 GW solar projects under development in the Philippines", pv magazine, 4 September 2020, https://www.pv-magazine.com/2020/09/04/three-1-2-gw-solar-projects-under-development-in-the-philippines; by end-2020, more than 1 GW of solar projects under PPAs were planned for installation in 2021 by a single developer, from E. Bellini, "Philippines to host 1 GW of solar under PPAs", pv magazine, 9 December 2020, https://www.pv-magazine.com/2020/12/09/philippines-to-host-1-gw-of-solar-under-ppas.

65 Based on data for 2020 from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; rankings for 2019 from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 9, and from Becquerel Institute, op. cit. note 1, 10 April 2020.

66 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Turkey connected an estimated 672 MWAC to the grid in 2020 for total of 6,667.4 MWAC,from Turkish grid operator TEIAS, cited in E. Bellini, "Turkey added 672 MW (AC) of PV capacity in 2020", pv magazine, 14 January 2021, https://www.pv-magazine.com/2021/01/14/turkey-added-672-mw-ac-of-pv-capacity-in-2020; but industry leaders believe the actual figure is 10-20% higher, from discrepancy with industry estimates from H. Karacaoglan, KRC Consulting (Germany), cited in idem.

67 Bellini, op. cit. note 66.

68 R. Nair, "Solar auction in Kazakhstan sees tariff dip to $0.034/kWh", Mercom India, 15 December 2020, https://mercomindia.com/solar-auction-in-kazakhstan. Pakistan completed a 75 MW and a 20 MW project, from idem.

69 America's share based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, from Becquerel Institute, op. cit. note 1, from National Renewable Energy Laboratory (NREL), provided by Masson, op. cit. note 1, 25 May 2021, and from Solar Energy Industries Association (SEIA) and Wood Mackenzie, *U.S. Solar Market Insight – 2020 Year in Review – Executive Summary* (Washington, DC: 2021), p. 5, https://www.seia.org/research-resources/solar-market-insight-report-2020-year-review. **Figure 28** based on IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, on Becquerel Institute, op. cit. note 1, and on country-specific data and sources provided throughout this section.

70 The United States added 19.2 GW for a total of 95.5 GW (all in DC), from NREL, op. cit. note 69. The United States added 19,221.11 MW in 2020, and increase over previous record year based on 15,103 MW installed in 2016, all from SEIA, "Solar industry research data", https://www.seia.org/solar-industry-research-data, viewed 16 March 2021; up over 2019 from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; total year-end capacity was 97.7 GW, from SEIA, "U.S. solar market insight", https://www.seia.org/us-solar-market-insight, updated 16 March 2021, and was 97.2 GW, from SEIA, "Solar data cheat sheet", https://www.seia.org/research-resources/solar-data-cheat-sheet, updated 16 March 2021. Note that these data are all provided in DC. The United States added an estimated 14,889.9 MW (4,510 MW of small-scale plus 10,379.9 MW of utility-scale facilities) of solar PV capacity in 2020, for a year-end total of 73,813.7 MW at end-2020, from US EIA, *Electric Power Monthly with Data for December 2020* (Washington, DC: February 2021), Table 6.1, https://www.eia.gov/electricity/monthly/archive/february2021.pdf. These data omit capacity from facilities with a total generator nameplate capacity less than 1 MW, from idem. In addition, the US EIA reports solar PV capacity in AC because US electricity operations and sales generally are conducted on an AC basis, from Marcy, op. cit. note 1. Finally, note that total US solar PV capacity exceeded 76 GW at the end of 2019, from SEIA and Wood Mackenzie, *U.S. Solar Market Insight, 2019 Year in Review – Executive Summary* (Washington, DC: March 2020), p. 5, https://www.woodmac.com/research/products/power-and-renewables/us-solar-market-insight.

71 SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 6.If counting only capacity additions, solar PV accounted for 42.2% based on total solar PV capacity additions of 14,889.9, followed by wind power (14,172.9 MW), natural gas (6,022.6 MW), hydropower (173.3 MW), geothermal (31.8 MW) and biopower (8.8 MW), all from US EIA, op. cit. note 70, Table 6.1. Note that these figures do not account for more than 13 GW of capacity taken offline in 2020, most of which was conventional steam coal, from idem.

72 SEIA and Wood Mackenzie, op. cit. note 69, pp. 6, 8. California added 3,904 MW, followed by Texas (3,425 MW) and Florida (2,822 MW); Virginia was fourth, adding 1,406 MW, and all of these states saw increases relative to 2019, from idem, p. 8.

73 Calculated based on solar PV net generation in 2020 from utility-scale systems (87,743 GWh) and from small-scale systems (41,740 GWh), both from US EIA, op. cit. note 70, Table 1.1.A, and on total utility-scale facility net generation of 4,009,085 GWh (plus previously noted small-scale solar PV generation), from idem, Table 1.3.B.

74 Based on 8.4 GW of utility-scale capacity added in 2019, from SEIA and Wood Mackenzie, op. cit. note 70, p. 9, and 14 GW added in 2020, from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; total of 59,772 MW, from SEIA, "Solar Industry Research Data", op. cit. note 70.

75 SEIA and Wood Mackenzie, op. cit. note 69, p. 5. The solar investment tax credit was extended and will remain at 26% for projects that begin construction in 2021 and 2022; it will fall to 22% in 2023 and 10% in 2024 for commercial projects (and the residential credit will end), from D. Wagman, " US to extend Investment Tax Credit for solar to 2024", pv magazine, 22 December 2020, https://www.pv-magazine.com/2020/12/22/us-to-extend-investment-tax-credit-for-solar-to-2024. As of early 2021, another 11.2 GW was already under construction, from SEIA and Wood Mackenzie, op. cit. note 69, p. 14. Investment tax credit details, from SEIA, "Solar Investment Tax Credit (ITC)", https://seia.org/initiatives/solar-investment-tax-credit-itc, viewed 28 April 2021. The ITC, established in 2005, provided a 30% investment tax credit for projects that began construction by the end of 2019. The credit stepped down to 26% in 2020, and it was scheduled to drop to 22% in 2021 and 10% from 2022 onwards for commercial and utility projects, and residential systems owned by companies. However, at the end of 2020, the 26% credit was extended for two years. It will decline to 22% in 2023, and, in 2024, will fall to 10% for commercial and utility-scale systems and to zero for residential installations owned by homeowners.

76 SEIA and Wood Mackenzie, op. cit. note 69, p. 5.

77 Ibid., p. 14.

78 Third consecutive year, 4% decline relative to 2019, and non-residential installations of 2.1 GW (2,074 MW) in 2020, all from SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 13. Total non-residential capacity at end-2020, from SEIA, "Solar industry research data", op. cit. note 70. The non-residential market faced the worst pandemic-related delays of any US segment and struggled with development timelines, interconnections, permitting and approval processes at the local level, from SEIA and Wood Mackenzie, op. cit. note 69, pp, 5, 12.

79 The US residential sector installed 3,194 MW of capacity in 2020, from SEIA and Wood Mackenzie, op. cit. note 69, p. 5; year-end total of 19,078.5 MW, from SEIA, "Solar industry research data", op. cit. note 7.

80 E. F. Merchant, "The highs and lows for solar in 2020", Greentech Media, 30 December 2020, https://www.greentechmedia.com/articles/read/the-highs-and-lows-for-solar-in-2020. The SEIA said 65,000 jobs had been lost as of May, or the equivalent of five years of growth, and in June roofer and solar installer PetersenDean filed for Chapter 11 bankruptcy, from idem. Layoffs and bankruptcies were due largely to the inability to find customers through traditional door-to-door sales, from E. F. Merchant, "A new response to coronavirus: Giving solar away for free", Greentech Media, 23 April 2020, https://www.greentechmedia.com/articles/read/one-response-to-the-coronavirus-giving-solar-away-for-free. Shifting to online and price cuts also from idem; E. F. Merchant, "How the coronavirus pandemic has impacted US solar so far", Greentech Media, 28 September 2020, https://www.greentechmedia.com/articles/read/how-the-coronavirus-pandemic-has-already-reshaped-u.s-solar; E. F. Merchant, "SunPower halts all global manufacturing, cuts employee workweek", Greentech Media, 20 April 2020, https://www.greentechmedia.com/articles/read/sunpower-halts-production-cuts-employee-workweek. Sunrun, the leading US installer, had a limited-time lease contract offer of no money upfront and USD 1 per month for the first six months, from Merchant, "A new response to coronavirus", op. cit. this note. New customer acquisition models required additional investment but also enabled companies to reach a broader, larger audience, from SEIA and Wood Mackenzie, op. cit. note 69, p. 17.

81 See, for example, A. Proudlove, North Carolina State University's Clean Energy Technology Center, cited in E. F. Merchant, "New year, same solar net metering battles", Greentech Media, 12 January 2021, https://www.greentechmedia.com/squared/the-lead/new-year-same-solar-net-metering-battles; H. K. Trabish, "Amid rising rooftop solar battles, emerging net metering alternatives could shake up the sector", Utility Dive, 18 March 2021, https://www.utilitydive.com/news/rooftop-solar-battles-emerging-net-metering-alternatives-duke-energy/596676.

82 SEIA and Wood Mackenzie, op. cit. note 69, pp. 5, 6.

83 P. Mints, SPV Research, *The Solar Flare*, 22 December 2020, p. 6; S. Kim, "Why is California having rolling blackouts?" Newsweek, 19 August 2020, https://www.newsweek.com/california-heat-wave-rolling-blackouts-power-outage-electricity-shortage-1526144.

84 SEIA, "Solar industry research data", op. cit. note 70. Behind-the-meter systems were up from under 5% in 2019, from idem. See also E. Zindler, *BCSE Sustainable Energy in America Factbook* (Washington, DC: Bloomberg Finance L. P., February 2021), https://bcse.org/wp-content/uploads/2021-Sustainable-Energy-in-America-Factbook-Executive-Summary.pdf. One in five US residential solar PV installations included battery storage in 2020, from "New survey shows solar installer confidence increased 60% in 2020", Renewable Energy World, 29 March 2021, https://www.renewableenergyworld.com/solar/new-survey-shows-solar-installer-confidence-increased-60-in-2020.

85 For example, Nevada had three large solar-plus-storage projects under development in 2020, from "Nevada goes big on solar-plus-storage", Windpower Monthly, September 2020, p. 31, https://www.windpowermonthly.com/article/1692957/read-windpower-monthly-online. Utilities brought plants into operation, from Saur News Bureau, "Duke Energy brings online its largest solar project in Texas", Saur Energy International, 8 July 2020, https://www.saurenergy.com/solar-energy-news/duke-energy-brings-online-its-largest-solar-project-in-texas; solicitations from T. Sylvia, "Solar-plus-storage replaces coal plant in New Mexico, makes carbon-capture retrofit moot", pv magazine, 12 October 2020, https://pv-magazine-usa.com/2020/10/12/solar-plus-storage-replaces-coal-plant-in-new-mexico-makes-carbon-capture-retrofit-moot, and from T. Sylvia, "US utility issues tender for 1 GW of renewables", pv magazine, 5 May 2020, https://www.pv-magazine.com/2020/05/05/us-utility-issues-tender-for-1-gw-of-pv. In New Mexico, a utility was in the process of replacing a large coal-fired generator (and plans for carbon capture) with solar PV-plus-storage capacity, from T. Sylvia, "Solar-plus-storage replaces coal plant in New Mexico, makes carbon-capture retrofit moot", pv magazine, 12 October 2020, https://pv-magazine-usa.com/2020/10/12/solar-plus-storage-replaces-coal-plant-in-new-mexico-makes-carbon-capture-retrofit-moot.

86 "US solar-storage builders thrive as risks recede", Reuters Events, 2 December 2020, https://www.reutersevents.com/renewables/solar-pv/us-solar-storage-builders-thrive-risks-recede.

87 See, for example, "US hybrid wind rush highlights tax credit impact", Reuters Events, 13 January 2021, https://www.reutersevents.com/renewables/wind/us-hybrid-wind-rush-highlights-tax-credit-impact.

88 ABSOLAR, "Energia solar fotovoltaica no Brasil – Infográfico ABSOLAR", no. 31 (4 May 2021), https://www.absolar.org.br/mercado/infografico. Challenging economic conditions (among top solar installers) in Argentina and Brazil, in particular, from I. Sagardoy, Fundacion Bariloche, personal communication with REN21, April 2020; F. Sabadini, RWTH – Aachen, personal communication with REN21, 1 April 2020; abundance of solar resources from M. Dorothal, "Top 30 Latin American solar PV plants (2018 update)", Unlocking Solar Capital, 22 May 2018, https://lac.unlockingsolarcapital.com/news-english/2018/5/22/top-30-latin-american-solar-pv-plants-2018-update; cost/price reductions are driving decisions, from E. Cruz, Climate Finance Solutions, personal communication with REN21, 13 April 2020. Note that in 2019, Mexico cancelled its fourth long-term auction, which had already been announced, as well as tenders to two transmission lines; 2019 medium-term auctions were cancelled as well, from IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), p. 17, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf. The priority of taking actions related to the pandemic led to delays in the discussion in Brazil of a legal framework for distributed generation in 2020, from Baitelo, op. cit. note 17, 31 March 2021.

89 Brazil added 3,145 MW in 2020, based on 7,740 MW at end-2020 and 4,595 MW at end-2019, from ABSOLAR, op. cit. note 87; Mexico added 1.5 GW, Chile added 790 MW and Argentina added around 320 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 14. Chile also from ACERA, op. cit. note 12, pp. 3, 5.

90 Mexico ended 2020 with an estimated 5,001 MW, from IEA PVPS, Snapshot of Global PV Markets 2021, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Figure of 7.7 GW in Brazil, from ABSOLAR, op. cit. note 87.

91 Figure of 68.6% from ABSOLAR, op. cit. note 87.

92 Ibid.

93 Ibid.

94 Ibid.

95 BNAmericas, "Brazil due to hold 8 power generation tenders in 2021", Renewables Now, 9 December 2020, https://www.bnamericas.com/en/news/brazil-due-to-hold-8-power-generation-tenders-in-2021.

96 J. R. Martín, "COVID-19 brings 'indefinite' delays for Brazil's solar-friendly auctions", PV-Tech, 31 March 2020, https://www.pv-tech.org/indefinite-delays-for-brazils-solar-friendly-auctions-amid-covid-19-row.

97 Sonnedix, "Sonnedix and Collahuasi sign a 100%-renewable PPA", press release (Iquique, Chile: 29 July 2020), https://www.sonnedix.com/news/sonnedix-and-collahuasi-sign-a-100-renewable-ppa; A. Bhambhani, "Sonnedix to supply 150 GWh solar power annually to Chilean copper miner Collahuasi from 170 MW Sonnedix Atacama solar project In Chile", TaiyangNews, 4 August 2020, http://taiyangnews.info/business/chilean-copper-miner-to-procure-solar-power.

98 First Solar, "First Solar power plant in Chile is world's first to deliver grid services", press release (Tempe, AZ: 20 August 2020), https://investor.firstsolar.com/news/press-release-details/2020/First-Solar-Power-Plant-in-Chile-is-Worlds-First-to-Deliver-Grid-Services/default.aspx.

99 Chile's year-end capacity was 3,484 MW, with another 3,695 MW under construction and 15,520 MW approved, from ACERA, op. cit. note 12, pp. 3, 5.

100 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

101 Installations were up 11% over 2019, based on additions of 18.2 GW in 2020, from SolarPower Europe, op. cit. note 4, p. 3; and were up 23.7% in 2020 based on additions of 19.3 GW in 2020, from IEA PVPS and Becquerel Institute, op. cit. note 1, 6 May 2021, and additions of 15.9 GW in EU-27 and the United Kingdom in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, p. 23, less the 0.3 GW installed in the United Kingdom in 2019, from UK BEIS, "Solar photovoltaics deployment in the UK", https://www.gov.uk/government/statistics/solar-photovoltaics-deployment, updated 30 January 2020.

102 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

103 Figure of 0.5 GW (545 MW) added and year-end total of 13.9 GW (13,873 MW), based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Figure of 4.1 GW in 2015, based on cumulative installed capacity of 5,528 MW at end-2014 and 9,601 MW at end-2015, from UK BEIS, "Renewable electricity capacity and generation", Table 6.1. Renewable electricity capacity and generation, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, viewed 16 April 2021. The country added 545 MW for a total of 13.9 GW in 2020, from Solar Energy UK, cited in M. Hall, "UK added 545 MW of solar last year to hit 13.9 GW", pv magazine, 21 January 2021, https://www.pv-magazine.com/2021/01/21/uk-added-545-mw-of-solar-last-year-to-hit-13-9-gw; added 217 MW in 2020 (down from 273 MW in 2019), from UK BEIS, op. cit. note 13, p. 16; and added 166 MW for a year-end total of 13,516 MW, from UK BEIS, op. cit. note 101, Table 1, viewed 16 April 2021. Note that the official statistics in the BEIS table are based on incomplete datasets that do not include unsubsidised systems with capacity below 1 MW that are not registered on the UK Microgeneration Certification Scheme database, from idem. About 60% of new capacity in 2020 was in large-scale ground-mounted projects, and the remainder was in rooftop (mostly commercial) systems, from Solar Energy UK, cited in Hall, op. cit. this note.

104 Additional large-scale projects from J. Parnell, "UK lifts block on new onshore wind and solar", Greentech Media, 2 March 2020, https://www.greentechmedia.com/articles/read/uk-lifts-block-on-new-onshore-wind-and-solar; "UK solar developers deploy storage to capture peak returns", Reuters Events, 5 May 2020, https://analysis.newenergyupdate.com/solar/uk-solar-developers-deploy-storage-capture-peak-returns; "UK urged to set 2035 net zero target; Enel to install 15 GW renewables by 2023", Reuters Events, 2 December 2020, https://www.reutersevents.com/renewables/solar-pv/uk-urged-set-2035-net-zero-target-enel-install-15-gw-renewables-2023.

105 Parnell, op. cit. note 104.

106 Below expectations and second-best from SolarPower Europe, op. cit. note 4, p. 3. Additions in 2019 were 16.2 GW and the best year yet was 2011, when 21.4 GW was added, from idem, p. 5. Note that the 21.4 GW added in 2011 included installations in the United Kingdom, but the country added only an estimated 0.9 GW in 2011, based on data from REN21, *Renewables Global Status Report 2012* (Paris: 2012). More new power capacity, from M. Schmela, SolarPower Europe, interview with Z. Brustik, "Spirit of optimism in European PV markets", The Smarter E Podcast, 28 January 2021, https://www.intersolar.de/podcast/en/spirit-of-optimism-in-european-pv-markets.

107 Around 19.3 GW added for a total of 140.5 GW and total capacity up more than 15%, based on data from IEA PVPS and Becquerel Institute, op. cit. note 1, 6 May 2021. An estimated 19.6 GW was added in 2020, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 6; an estimated 18.2 GW was brought online, raising cumulative capacity by 15% to 137.2 GW, from SolarPower Europe, op. cit. note 4, pp. 3, 5.

108 EurObserv'ER, op. cit. note 30, p. 15. The year 2019 saw the first major projects commissioned in Europe that were without direct subsidies and outside of volumes allocated for auctions (under PPAs), from idem, p. 11.

109 See, for example, SolarPower Europe, op. cit. note 4; SolarPower Europe, *EU Market Outlook for Solar Power, 2019-2023* (Brussels: 2019), pp. 6, 12, 82-83, https://www.solarpowereurope.org/eu-market-outlook-for-solar-power-2019-2023; C. Gilligan, "A new era of sustained growth", pv magazine, 16 January 2020, https://www.pv-magazine.com/2020/01/16/a-new-era-of-sustained-growth; Schmela, op. cit. note 106.

110 All challenges except land availability from Gilligan, op. cit. note 109; land availability from, for example, "Your guide to solar market growth in the global 'gigawatt club'", pv magazine, 18 January 2020 https://pv-magazine-usa.com/2020/01/18/your-guide-to-solar-market-growth-in-the-global-gigawatt-club; land availability and grid constraints from SolarPower Europe, op. cit. note 109, pp. 50, 76; Solarplaza, *Dutch Solar Energy Market Seeking Space to Grow Further*, prepared for The Solar Future NL, Utrecht, 8-9 July 2020, https://thesolarfuture.nl/nieuws-source/2020/3/2/dutch-solar-energy-market-seeking-space-to-grow-further; Mints, *The Solar Flare*, no. 5, op. cit. note 25, p. 28.

111 SolarPower Europe, op. cit. note 4, p. 5. However, this share was down from 79% installed in the top five countries in 2019, from idem.

112 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 6. France added 0.9 GW, from idem. Additions were the Netherlands (2.8 GW), Spain (2.6 GW), Poland (2.2 GW) and France (0.9 GW), from SolarPower Europe, op. cit. note 4, p. 5. Belgium became a gigawatt market for the first time in 2020, from R. Rossi, SolarPower Europe, Brussels, personal communication with REN21, 25 May 2021.

113 SolarPower Europe, op. cit. note 4, p. 20, and based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Italy added 0.8 GW for a year-end total of 21.7 GW, from Becquerel Institute, op. cit. note 1.

114 Increase relative to 2019 based on Germany added 3,835 MW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 85; added 4,885 MW for a total of 53,932 MW in 2020, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Germany added 4.8 GW in 2020 for total of 54.6 GW, from SolarPower Europe, op. cit. note 4, pp. 5, 20. In 2020, Germany added 4.88 GW for total of 53.6 GW; by comparison, annual additions were 3.94 GW in 2019, 2.96 GW in 2018 and 1.75 GW in 2017, from German federal network agency, the Bundesnetzagentur, cited in S. Enkhardt, "Germany installed 4.88 GW of solar in 2020", pv magazine, 1 February 2021, https://www.pv-magazine.com/2021/02/01/germany-installed-4-88-gw-of-solar-in-2020, and Germany added 4,801 MW for a year-end total of 53,848 MW, based on 49,047 MW at the end of 2019 and 53,848 MW at the end of 2020, from BMWi and AGEE-Stat, op. cit. note 12, p. 7.

115 Commercial share based on 2020 additions of 2,887 MW (up 6% over 2019 additions), from Bundesverband Solarwirtschaft e. V. (BSW-Solar), "Solar boom on private rooftops", 2 February 2021, https://www.solarwirtschaft.de/en/2021/02/02/solar-boom-on-private-rooftops.

116 Ibid. Share of annual market based on additions of 867 MW, from idem. Note that solar PV won nearly all auctioned capacity

in technology-neutral tenders during the year, from SolarPower Europe, "Spotlight on GW EU solar markets: Germany comes out on top despite new EEG revision changing support policy framework", 2 February 2021, https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-germany-on-top-despite-new-eeg-revision-changing-the-support-policy-framework.

117 BSW-Solar, op. cit. note 115. Homeowners added 1,131 MW of capacity in systems up to 10 kW, from idem.

118 Roughly half from BSW-Solar, "Statistical Figures of the German Solar Power Industry (Storage / Mobility)" (Berlin: 2021), https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW_Faktenblatt_Stromspeicher_Update_2020.pdf, and more than 90% of residential rooftop systems were installed with battery storage in 2020, from SolarPower Europe, *European Market Outlook for Residential Battery Storage 2020-2024* (Brussels: October 2020), p. 3, https://www.solarpowereurope.org/european-market-outlook-for-residential-battery-storage. The storage market was up 50% for third consecutive year, from BSW-Solar, "Solar battery boom", 18 February 2021, https://www.solarwirtschaft.de/en/2021/02/18/solar-battery-boom. Estimated total solar battery storage capacity of 1.9 GWh, based on data from EUPD Research (2020), *Energiewende im Kontext von Atom- und Kohleausstieg – Update 2020*, Berlin, cited in BSW-Solar, "Statistical Figures of the German Solar Power Industry (Storage/Mobility)", op. cit. this note; about 88,000 systems installed in 2020 for a total of 272,000 units, from idem; estimated total battery storage capacity at year's end was around 2.4 GWh, from BSW-Solar, "Solar battery boom", op. cit. this note. Residential storage linked to solar PV is supported in Germany with rebates, from P. Hannen, "Germany has 270,000 residential batteries linked to PV", 19 February 2021, https://www.pv-magazine.com/2021/02/19/germany-has-270000-residential-batteries-linked-to-pv.

119 Removed in July and Germany's capacity passed the 52 GW level in August 2020, from S. Enkhardt, "Germany breaches 52 GW mark with 409 MW of new solar in August", pv magazine, 1 October 2020, https://www.pv-magazine.com/2020/10/01/germany-breaches-52-gw-mark-with-409-mw-of-new-solar-in-august. The government pledged in September 2019 to lift the cap, but its removal was not official until July 2020. This delay is believed to have slowed installations of smaller rooftop systems in August (as Germany approached the 52 GW mark), the weakest month of 2020 (at least as of end-September), from idem. The revised feed-in law, which was enacted in December, maintains the feed-in payment for systems up to 300 kW and owners of systems 300-750 kW have two options: to receive the payment (at half the level of smaller systems) with permission to self-consume the electricity generation, or to build the project under the tender scheme for utility-scale solar PV and without the ability to self-consume, from Enkhardt, op. cit. note 114; S. Enkhardt, "Germany introduces new renewable energy law", pv magazine, 17 December 2020, https://www.pv-magazine.com/2020/12/17/germany-introduces-new-renewable-energy-law.

120 H. Shukla, "Germany's new Climate Action Plan focuses on augmenting solar and wind capacities", Mercom India, 24 September 2020, https://mercomindia.com/germany-new-climate-action-plan; N. T. Prasad, "Germany's solar tender oversubscribed, lowest tariff dips to €0.049/kWh", Mercom India, 29 October 2020, https://mercomindia.com/germany-solar-tender-oversubscribed.

121 C. Menke, "Photovoltaics – the key to the energy transition", BSW-Solar, https://www.solarwirtschaft.de/en/topics-of-interest/photovoltaics, viewed 24 March 2021.

122 Figure of 50.6 TWh (gross generation) in 2020 (up from 46.4 TWh in 2019), from BMWI and AGEE-Stat, op. cit. note 12, p. 6; share of generation from Fraunhofer ISE, op. cit. note 12. Solar PV share of net generation for public electricity supply was 10%, from Bundesnetzagentur, cited in BSW-Solar (2021), "Statistical Figures of the German Solar Power Industry (Photovoltaics)", Berlin, https://www.solarwirtschaft.de/datawall/uploads/2021/02/BSW_Faktenblatt_Photovoltaik_Update_2020-1.pdf. Solar PV generation was up from 45.8 TWh in 2018 and 46.4 TWh in 2019, from idem.

123 Steady growth from Dutch New Energy, N*ationaal Solar Trendrapport 2021*, cited in E. Bellini, "Netherlands deployed 2.93 GW of solar in 2020", pv magazine, 21 January 2021, https://www.pv-magazine.com/2021/01/21/netherlands-deployed-2-93-gw-of-solar-in-2020. In 2020, 2.93 GW added, up from 2.57 GW in 2019, 1.69 GW in 2018, 853 GW in 2017, for total of more than 10.1 GW, from idem. Drivers from SolarPower Europe, op. cit. note 4, p. 11.

124 The Netherlands added 3,036 MW for a total of 10,213 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; nearly half from SolarPower Europe, op. cit. note 4, p. 11. The year-end total was 9.2 GW, from idem, p. 20, and it was more than 10.1 GW, from Dutch New Energy, op. cit. note 123. Residential installations totalled 1.09 GW at end-2020, up from 873 GW in 2019, from idem. About 16 GW of additional capacity was under construction in the Netherlands at year's end, from idem.

125 SolarPower Europe, op. cit. note 4, p. 11.

126 Dutch New Energy, op. cit. note 123.

127 Spain added 2,806 MW in 2020 for a total of 12,716 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. This was down 40% based on additions of 4,751 MW in 2019, from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 85, and down 18% based on 3,256 MW added in 2020 and 3.97 GW added in 2019, from APPA Renovables, cited in P. Sanchez Molina, "Spain installed 3.2 GW of solar last year", pv magazine, 15 February 2021, https://www.pv-magazine.com/2021/02/15/spain-installed-3-2-gw-of-solar-last-year. Spain had 8,914 MWAC at end of 2019 and 11,547 MW_{AC} at the end of 2020, for a net increase of $2{,}633_{AC}$, from Red Eléctrica de España (REE), "Potencia instalada nacional (MW)", as of 31 December 2020, https://www.ree.es/es/datos/publicaciones/series-estadisticas-nacionales. Added 3,256 MW, including 623 MW distributed and 2,633 MW utility-scale projects, for a year-end total of about 11 GW (it is not known if these data are in AC or DC), from APPA Renovables, cited in Sanchez Molina, op. cit. this note.

128 SolarPower Europe, op. cit. note 4, p. 13. Private PPAs lacked direct government support, from Sanchez Molina, op. cit. note 127.

129 SolarPower Europe, "Spotlight on GW EU solar markets: Spain leads PPA subsidy-free market growth", 29 January 2021, https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-spain-leads-ppa-subsidy-free-market-growth.

130 The residential sector experienced unprecedented growth in 2020, and figure of 30% growth in self-consumption market, based on data from Unión Española Fotovoltaica, cited in P. Sanchez Molina, "Solar for self-consumption keeps growing in Spain", pv magazine, 29 January 2021, https://www.pv-magazine.com/2021/01/29/solar-for-self-consumption-keeps-growing-in-spain. The self-consumption market in 2020 was 596 MW, up from 459 MW in 2019; the industrial sector had the largest portion (56%), followed by commercial (23%) and residential (19%), from idem. The market grew less than expected because the small to medium enterprise sector was significantly affected by the pandemic, from SolarPower Europe, op. cit. note 4, pp. 13, 84.

131 REE, "The Spanish Electricity System – End of Year Forecast 2020" (Madrid: December 2020), with estimated data as of 11 December 2020, https://www.ree.es/en/datos/publications/annual-system-report/spanish-electricity-system-preliminary-report-2020.

132 Poland added 2,636 MW for a total of 3,936 MW, from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Added 1,850 MW in 2020 for year-end total of 3,150 MW (or 3.6 GW), from SolarPower Europe, op. cit. note 4, pp. 20, 54. Drivers from idem, p. 13; SolarPower Europe, "Spotlight on GW EU solar markets: Poland sees growing micro-installations and positive policy developments", 22 January 2021, https://www.solarpowereurope.org/spotlight-on-gw-eu-solar-markets-poland-sees-growing-micro-installations-and-positive-policy-developments. Favourable policies included net metering and feed-in tariffs, from idem.

133 For example, see M. Willuhn, "Statkraft greens Polish steel with 10-year PPA", pv magazine, 21 January 2021, https://www.pv-magazine.com/2020/01/21/statkraft-greens-polish-steel-with-10-year-ppa; J. R. Martín, "Polish coal giant doubles down on 2.5GW solar push despite business retrenchment", PV-Tech, 15 April 2020, https://www.pv-tech.org/news/polish-coal-giant-doubles-down-on-2.5gw-solar-push-despite-business-retrenc.

134 Switzerland from D. Stickelberger, "Rekordzubau bei der Schweizer Photovoltaik 2020", Swissolar, 3 March 2021, https://www.swissolar.ch/services/medien/news/detail/n-n/rekordzubau-bei-der-schweizer-photovoltaik-2020. Switzerland's market grew at least 30% relative to 2019, to record levels with

estimated additions of at least 430-460 MW, from idem. Denmark from Z. Shahan, "400,000+ solar co-owners in giant community solar park initiative In Denmark & Poland", CleanTechnica, 5 December 2020, https://cleantechnica.com/2020/12/05/400000-solar-co-owners-in-giant-community-solar-park-initiative-in-denmark-poland. Five parks were in operation by the end of 2020 and the rest were expected in 2021 and 2022; the initiative is a partnership of Danish pension fund Industriens Pension and Better Energy (Denmark), from idem. R. Withlock, "Lithuania welcomes world's first online consumer platform for purchasing remote solar panels", Renewable Energy Magazine, 25 March 2020, https://www.renewableenergymagazine.com/pv_solar/lithuania-welcomes-worlda-s-first-online-consumer-20200325. In addition, what is believed to be Europe's largest rooftop system (12 MW) went online in October at an Audi factory in Győr, Hungary, from Z. Shahan, "Largest rooftop solar system in Europe goes online… on Audi factory", CleanTechnica, 9 October 2020, https://cleantechnica.com/2020/10/09/largest-rooftop-solar-system-in-europe-goes-online-on-audi-factory.

135 Clean Energy Regulator, cited in Australian Energy Council, *Solar Report* (Melbourne: January 2021), p. 3, https://www.energycouncil.com.au/media/jv4blk2l/final-pdf-australian-energy-council-solar-report_-jan-2021.pdf; B. Church, "End of year forecast for the Australian PV solar market (2020)", Sunwiz, https://www.sunwiz.com.au/end-of-year-forecast-for-the-australian-pv-solar-market-2020, viewed 16 March 2021. Additions in the Northern Territory were down 17%, but by small amounts in terms of actual capacity, with 28.88 MW added in 2019 and 24 MW installed in 2020, from Australian Energy Council, op. cit. this note, p. 5. Rank based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1.

136 M. Maisch, "Australia's renewables pipeline continues to grow at record speed led by solar PV", pv magazine, 23 July 2020, https://www.pv-magazine-australia.com/2020/07/23/australias-renewables-pipeline-continues-to-grow-at-record-speed-led-by-solar-pv.

137 P. Crossley, University of Sydney, Sydney, Australia, personal communication with REN21, 9 April 2021; M. Lewis, "Bushfire recovery – more than just new poles", Energy Networks Australia, 30 January 2020, https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/bushfire-recovery-more-than-just-new-poles.

138 Based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Australia added somewhere in the range of 4,105 MW (reported) and 4,376 MW (estimated) based on end-2019 reported capacity of 16,094 MW and end-2020 reported capacity of 20,199 MW and end-2020 estimated capacity of 20,469 MW, from APVI, APVI Solar Map, funded by ARENA, https://pv-map.apvi.org.au/analyses, viewed 8 March 2021.

139 Increase over 2019 based on generation data in 2019 (solar total of 18,126 GWh) from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne, March 2020), p. 9, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf; 2020 data (solar total of 22,510 GWh) from Clean Energy Council, op. cit. note 12, p. 9; shares of Australia's total electricity generation from idem, p. 9; generation from small-scale solar PV overtook hydropower as Australia's second largest generator of renewable electricity (after hydropower), from idem, pp. 9, 70.

140 D. Carroll, "Australia deployed 2.6 GW of rooftop PV in 2020", pv magazine, 8 February 2021, https://www.pv-magazine.com/2021/02/08/australia-deployed-2-6-gw-of-rooftop-pv-in-2020.

141 Based on the following: Australia's rooftops saw 2,642 MW added in 2020 (up from 2,355 MW added in 2019) for a year-end total of 12,895 MW, from IEA PVPS, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. If we assume that all off-grid capacity is also under 100 kW, then 2,662 MW was added in 2020 (up from 2,380 MW in 2019), for a year-end total of 13,199 MW, from idem (both sources). About 2.6 GW was added (in 333,978 installations) in 2020, up from 2.2 GW (in 284,000 installations) in 2019, from Clean Energy Regulator, cited in Australian Energy Council, op. cit. note 135, p. 3; note that final installations could be higher because consumers have up to a year to register their new systems, from idem. Just under 3 GW was added in 2020, up from 2.1 GW in 2019, from *Sunwiz Annual Report*, cited in J. Sykes, "What is driving record rooftop solar volumes in Australia?" Renewable Energy World, 3 February 2021, https://www.renewableenergyworld.com/solar/what-is-driving-record-rooftop-solar-volumes-in-australia. Australia added 3,043 MW of rooftop solar PV capacity (in 378,451 systems) in 2020 (up from 2.2 GW in 2019) for a year-end total of 13,415 MW, from Clean Energy Council, op. cit. note 12, pp. 7, 17.

142 Clean Energy Council, op. cit. note 12, pp. 8, 62. Batteries were installed at 22,661 households in 2019, from idem, p. 62.

143 J. Deign, "What other countries can learn from Australia's roaring rooftop solar market", Greentech Media, 3 August 2020, https://www.greentechmedia.com/articles/read/what-the-us-can-learn-from-australias-roaring-rooftop-solar-market; Australian Energy Council, op. cit. note 135, p. 3; B. Matich, "Forget toilet paper, Australians are panic-buying PV", pv magazine, 19 March 2020, https://www.pv-magazine.com/2020/03/19/forget-toilet-paper-australians-are-panic-buying-pv; Sykes, op. cit. note 141. Residential solar prices continued a decade-long downwards trend in Australia during 2020, down 13.2%, from Solar Choice Price Index, cited in idem.

144 Figure of 2.7 million from Clean Energy Council, op. cit. note 12, p. 74; more than 2.66 million from Clean Energy Regulator, cited in Australian Energy Council, op. cit. note 135, p. 3.

145 APVI, op. cit. note 138.

146 First to face zero operational demand from G. Parkinson, "South Australia fast-tracks energy plan to dodge blackouts and meet 100% renewables goal", RenewEconomy, 19 June 2020, https://reneweconomy.com.au/south-australia-fast-tracks-energy-plan-to-dodge-blackouts-and-meet-100-renewables-goal-43196; other information from J. Deign, "How South Australia is dealing with rampant solar growth", Greentech Media, 21 September 2020, https://www.greentechmedia.com/articles/read/how-south-australia-is-dealing-with-rampant-solar-growth. See also Clean Energy Council, op. cit. note 12, pp. 18, 71. Rooftop solar PV met more than 70% of South Australia's electricity demand at times during 2020 and, in October, became the world's first major jurisdiction to be powered entirely by solar power for one hour; 77% of this was from rooftop systems, from idem, pp. 18, 71.

147 Clean Energy Council, op. cit. note 12, p. 34; N. Harmsen, "Power granted to switch off household solar in SA to prevent statewide blackout", ABC News (Australia), 18 June 2020, https://www.abc.net.au/news/2020-06-19/solar-boom-puts-sa-at-risk-of-another-statewide-blackout/12372558. Energy authorities in South Australia used their power to switch off residential solar systems remotely for the first time in March 2021, from D. Keane, N. Harmsen and S. Tomevska, "Solar panels switched off by energy authorities to stabilise South Australian electricity grid", ABC News (Australia), 17 March 2021, https://www.abc.net.au/news/2021-03-17/solar-panels-switched-off-in-sa-to-stabilise-grid/13256572. Several states (including Victoria, Western Australia and New South Wales) also announced a number of large battery storage projects in 2020, from Clean Energy Council, op. cit. note 12, p. 56.

148 See, for example, B. Matich, "Small-scale utility solar thriving on path of least resistance", pv magazine, 28 February 2020, https://www.pv-magazine-australia.com/2020/02/28/small-scale-utility-solar-thriving-on-path-of-least-resistance.

149 Grid challenges from, for example, J. Scully, "1GW of Australian solar at risk of curtailment following system strength warning", PV-Tech, 28 July 2020, https://www.pv-tech.org/system-strength-issues-in-north-queensland-could-result-in-1gw-of-solar-cur; S. Vorrath, "Grid problems now the biggest turnoff for renewable energy investment in Australia", RenewEconomy, 29 July 2020, https://reneweconomy.com.au/grid-problems-now-the-biggest-turnoff-for-renewable-energy-investment-in-australia-73144; lack of policy and target clarity, and regulatory risks, from T. Gunaratna, Clean Energy Council, Australia, personal communication with REN21, 11 April 2021, and from M. Maisch, "Renewables investment collapses due to network woes and policy uncertainty", pv magazine, 1 February 2020, https://www.pv-magazine-australia.com/2020/02/01/renewables-investment-collapses-due-to-network-woes-and-policy-uncertainty; barriers to investment, delayed and cancelled projects from G. Parkinson, "Victoria's biggest solar farm starts sending power to grid after long delays", RenewEconomy, 9 September 2020, https://reneweconomy.com.au/victorias-biggest-solar-farm-starts-sending-power-to-grid-after-long-delays-80694. See also P. Hannam, "'Murray Five' solar farms get approval to resume full energy output", *Sydney Morning Herald*, 24 April 2020, https://www.smh.com.au/business/markets/murray-five-solar-farms-get-approval-to-resume-full-energy-output-20200424-p54n2b.html.

150 Matich, op. cit. note 148; M. Maisch, "Victoria decides to go it alone on transmission to unlock more large-scale renewables and batteries", pv magazine, 19 February 2020, https://www.pv-magazine-australia.com/2020/02/19/victoria-decides-to-go-it-alone-on-transmission-to-unlock-more-large-scale-renewables-and-batteries.

151 N. Filatoff, "The weekend read: The plan to REZurrect Australia's large-scale segment", pv magazine, 17 October 2020, https://www.pv-magazine-australia.com/2020/10/17/the-weekend-read-the-plan-to-rezurrect-australias-large-scale-segment. The government of New South Wales was the first to call for interest in a proposed 3 GW REZ; after receiving 27 GW of bids, the state announced an additional 8 GW REZ, from idem. See also Clean Energy Council, op. cit. note 12, p. 7.

152 Matich, op. cit. note 148.

153 New Zealand from T. Niall, "Biggest solar farm in country installed on Auckland wastewater lake", stuff, 2 October 2020, https://www.stuff.co.nz/environment/climate-news/122936916/biggest-solar-farm-in-country-installed-on-auckland-wastewater-lake. Solar PV and electricity storage are advancing on the Cook Islands, from E. Bellini, "Solar-plus-storage for the Cook Islands", pv magazine, 7 September 2020, https://www.pv-magazine.com/2020/09/07/solar-plus-storage-for-the-cook-islands; the Fijian government-owned utility signed an agreement with the International Finance Corporation (IFC) for a 15 MW solar PV project to reduce reliance on imported fuels, from J. S. Hill, "Fiji set to build biggest solar project in Pacific Islands", RenewEconomy, 28 October 2020, https://reneweconomy.com.au/fiji-set-to-build-biggest-solar-project-in-pacific-islands-37084, and has seen rapid growth in behind-the-meter commercial rooftop systems since 2015, with about 4 MW installed by early 2020 and many more systems planned, from R. D. Prasad and A. Raturi, *Solar Energy for Power Generation in Fiji: History, Barriers and Potentials*, in A. Singh, ed., *Translating the Paris Agreement into Action in the Pacific. Advances in Global Change Research*, vol. 68 (January 2020), https://link.springer.com/chapter/10.1007/978-3-030-30211-5_8. Micronesia launched a tender for utility-scale solar-plus-storage capacity, from E. Bellini, "Micronesia launches tender for utility scale solar-plus-storage", pv magazine, 12 May 2020, https://www.pv-magazine.com/2020/05/12/micronesia-launches-tender-for-utility-scale-solar-plus-storage. New Caledonia aims for 100% renewable electricity by 2030 and was developing an agricultural-solar PV project in 2020, from P. Zubrinich, "Agrivoltaics in New Caledonia", pv magazine, 28 February 2020, https://www.pv-magazine-australia.com/2020/02/28/agrivoltaics-in-new-caledonia; the country also saw the completion of a 16 MW solar PV plant with 10 MW of storage in late 2019, to which another solar-plus-storage facility will be added, from idem. Papua New Guinea launched a pilot scheme allowing businesses to install and operate grid-connected rooftop systems as part of the country's effort to achieve 100% renewable energy by 2050, from "PNG's first rooftop solar trial officially begins in Port Moresby", PNG Power, Ltd., 4 December 2019, https://www.pngpower.com.pg/index.php/news/view/pngs-first-rooftop-solar-trial-officially-begins-in-port-moresby. Tonga aims for 70% renewable electricity by 2030 and signed contracts in 2020 for more solar-plus-storage projects to provide 24-hour-a-day electricity access, from J. S. Hill, "Tonga signs more solar/storage projects as it aims for 70 pct renewables", RenewEconomy, 21 April 2020, https://reneweconomy.com.au/tonga-signs-more-solar-storage-projects-as-it-aims-for-70-pct-renewables-49782.

154 Commercial rooftop systems from Prasad and Raturi, op. cit. note 153; in 2020 from IFC, "EFL and IFC sign agreement for Pacific's largest solar project", press release (Suva, Fiji: 21 October 2020), https://pressroom.ifc.org/all/pages/PressDetail.aspx?ID=17784, and from Hill, op. cit. note 153.

155 Bellini, op. cit. note 153.

156 Based on 4.1 GW added for a total of around 24 GW, from Becquerel Institute, op. cit. note 1, 26 May 2021; and on 4.3 GW of solar additions across the Middle East and North Africa region in 2020, from BloombergNEF, cited in MESIA, "MESIA Solar Outlook Report 2021 – Did a challenging year open up future opportunities for solar?" 19 January 2021, https://mesia.com/2021/01/19/mesia-solar-outlook-report-2021-did-a-challenging-year-open-up-future-opportunities-for-solar. In 2019, additions were an estimated 6.8 GW (up from 3.1 GW in 2018), from SolarPower Europe, op. cit. note 9, p. 18; and 2019 additions were an estimated 6.7 GW in 2019, for a year-end total of 15.1 GW, from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 9, and from Becquerel Institute, op. cit. note 9, 10 April 2020. In 2018, the regions added an estimated 2,556 MW in 2018 for a total of 6,716 MW, from Becquerel Institute, op. cit. note 1, April 2019. Another source estimates that about 3.6 GW was added in 2018, up from less than 1 GW in 2017, from IHS Markit, cited in J. Berg, "MENA PV additions quadrupled in 2018", pv magazine, 17 January 2019, https://www.pv-magazine.com/2019/01/17/mena-pv-additions-quadrupled-in-2018.

157 T. Smith, "Net-metering gaining favour throughout Middle East and Africa", ESI Africa, 12 August 2020, https://www.esi-africa.com/industry-sectors/generation/solar/net-metering-gaining-favour-throughout-middle-east-and-africa; Egypt from MESIA, op. cit. note 13, p. 5.

158 MESIA, op. cit. note 13, p. 5; E. Bellini, "Israel launches 300 MW solar-plus-storage tender", pv magazine, 24 January 2020, https://www.pv-magazine.com/2020/01/24/israeal-launches-tender-for-300-mw-of-solar-plus-storage; E. Bellini, "Israel's plan to recover from Covid-19 crisis includes 2 GW of new solar", pv magazine, 29 April 2020, https://www.pv-magazine.com/2020/04/29/israels-plan-to-recover-from-covid-19-crisis-includes-2-gw-of-new-solar; T. Smith, "Malawi gets new solar power plant to fill critical energy gap", ESI Africa, 6 November 2020, https://www.esi-africa.com/industry-sectors/generation/solar/malawi-gets-new-solar-power-plant-to-fill-critical-energy-gap; B. Groenendaal, "Malawi: 46MW Nkhotakota Solar Power Plant reaches financial close", GBA, 3 January 2020, https://www.greenbuildingafrica.co.za/malawi-46mw-nkhotakota-solar-power-plant-reaches-financial-close; Projects Today, "Nkhotakota Solar Power Plant receives USD 67 million subsidy", 11 November 2020, https://projectstoday.com/News/Nkhotakota-Solar-Power-Plant-receives-USD-67-million-subsidy; R. Ranjan, "Syria to develop 63 MW of solar projects", Mercom India, 27 May 2020; Tunisia and United Arab Emirates from MESIA, op. cit. note 13, p. 5; N. Pombo-van Zyl, "Zimbabwe opens tender for solar power plants", ESI Africa, 21 May 2020, https://www.esi-africa.com/industry-sectors/generation/solar/zimbabwe-opens-tender-for-solar-power-plants; Egypt cancelled a 200 MW tender for solar plants along the Nile basin because the pandemic reduced electricity demand, creating a surplus, from "Egypt cancels tenders for setting up solar plants along Nile basin", TRENDSNAFRICA, 7 August 2020, http://trendsnafrica.com/2020/08/07/egypt-cancels-tenders-for-setting-up-solar-plants-along-nile-basin; N. Pombo-van Zyl, "Egypt scraps West Nile solar tender as new PV assembly line is launched", PEI, 11 August 2020, https://www.powerengineeringint.com/renewables/solar/egypt-scraps-west-nile-solar-tender-as-new-pv-assembly-line-is-launched.

159 MESIA, op. cit. note 13, pp. 4, 9.

160 Ibid., pp. 4, 14.

161 Israel and Oman from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1; United Arab Emirates from "Mohammed bin Rashid Al Maktoum Solar Park launches third phase in Dubai", Gulf News, 12 December 2020, https://gulfnews.com/uae/mohammed-bin-rashid-al-maktoum-solar-park-launches-third-phase-in-dubai-1.75855508, from R. Ranjan, "Third phase of Dubai Solar Park with 800 MW of projects commissioned", 25 November 2020, https://mercomindia.com/dubai-solar-park-projects-commissioned, and from Dubai Electricity and Water Authority (DEWA), "Mohammed bin Rashid inaugurates DEWA Innovation Centre and 800MW 3rd phase of the Mohammed bin Rashid Al Maktoum Solar Park", 24 November 2020, https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2020/11/mohammed-bin-rashid-inaugurates-dewa-innovation-centre. The total operational capacity of the solar park by late 2020 was 1,013 MW, from DEWA, op. cit. this note.

162 UAE from Ibid., all sources; BELECTRIC, "BELECTRIC delivers utility-scale PV plant on mountainous site in Jordan", 7 April 2020, https://belectric.com/belectric-delivers-utility-scale-pv-plant-on-mountainous-site-in-jordan; U. Gupta, "Sterling and Wilson commissions 125 MW (DC) solar plant in Oman", pv magazine, 2 June 2020, https://www.pv-magazine-india.com/2020/06/02/sterling-and-wilson-commissions-125-mw-dc-solar-project-in-oman; Dubai and Oman also from MESIA, op. cit. note 13, pp. 5, 67.

163 Plans for solar and hydrogen project from E. Bellini, "Solar-powered hydrogen generation hub in Oman", pv magazine, 4 November 2020, https://www.pv-magazine.com/2020/11/04/

solar-powered-hydrogen-generation-hub-in-oman; M. Willuhn, "Shell to develop PV at Oman's Sohar Port and Freezone area", pv magazine, 26 April 2019, https://www.pv-magazine.com/2019/04/26/shell-to-develop-pv-at-omans-sohar-port-and-freezone-area; rooftop solar PV from MESIA, op. cit. note 13, p. 18, and from C. Prabhu, "Solar PV for first 1000 homes in Oman", Oman Observer, 24 April 2020, https://www.omanobserver.om/solar-pv-for-first-1000-homes-in-oman.

164 MESIA, op. cit. note 13, p. 18.

165 Ibid. Other countries in the region include Bahrain, Iraq, Jordan and Kuwait, from idem.

166 United Arab Emirates and Israel based on data from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Note that data are uncertain, particularly for the United Arab Emirates. Jordan ended 2020 with 1,545 MW, from Jordanian Ministry of Energy and Mineral Resources, provided by M. Mahmoud, Regional Center for Renewable Energy and Energy Efficiency (RCREEE), Cairo, personal communication with REN21, 28 May 2021.

167 For example, Algeria aims to become self-reliant for energy and to save petrochemical researched for local activities, from the Democratic Republic of Algeria, Governorate for Renewable energy and Energy Efficiency (CEREFE), "Transition énergétique en Algérie – Le mot du Premier Ministre sur le Premier Rapport du Commissariat sur la Transition Energétique", http://www.cerefe.gov.dz/fr/2020/11/29/transition-energetique-en-algerie, viewed 31 May 2021. Malawi aims to shift reliance away from hydropower (now more than 90% of the country's energy mix), which leaves the country vulnerable to frequent power supply cuts during droughts, from Smith, "Malawi gets new solar power plant to fill critical energy gap", op. cit. note 158; Groenendaal, op. cit. note 158; Projects Today, op. cit. note 158. Mali has similar concerns, from T. Smith, "Mali: New solar plant just the beginning", ESI Africa, 23 November 2020, https://www.esi-africa.com/industry-sectors/generation/solar/mali-new-solar-plant-just-the-beginning; B. Bungane, "Mali to host West Africa's largest solar farm with 50MW capacity", ESI Africa, 20 January 2020, https://www.esi-africa.com/industry-sectors/generation/mali-to-host-west-africas-largest-solar-farm-with-50mw-capacity. As does Zimbabwe from N. Pombo-van Zyl, "Zimbabwe opens tender for solar power plants", op. cit. note 158. In South Africa, several mining companies have installed or are planning their own solar PV plants to ensure a reliable supply of electricity, from E. Bellini, "South African mining sector wants solar", pv magazine, 31 January 2020, https://www.pv-magazine-australia.com/2020/01/31/south-african-mining-sector-wants-solar. The Algerian government aims to preserve domestic oil and gas resources while meeting rising domestic demand for energy and becoming a net exporter of competitively-priced electricity, from I. Magoum, "ALGERIA: 4000 MW Tafouk1 solar mega-project soon to be on track", Afrik21, 26 May 2020, https://www.afrik21.africa/en/algeria-4000-mw-tafouk1-solar-mega-project-soon-to-be-on-track; P. Largue, "Algeria announces 4GW plan to grow solar capacity ten-fold by 2025", ESI Africa, 25 May 2020, https://www.esi-africa.com/industry-sectors/generation/solar/algeria-announces-4gw-plan-to-grow-solar-capacity-ten-fold-by-2025. Batteries from, for example, SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 18; T. Smith, "Mali: Solar forecasting for energy stability at mine", ESI Africa, 29 July 2020, https://www.esi-africa.com/industry-sectors/generation/solar/mali-solar-forecasting-for-energy-stability-at-mine. See also Africa Solar Industry Association (AFSIA), *Africa Solar Outlook 2021 – A Country-by-Country Review of the Status of Solar in Africa* (Kigali, Rwanda: 2021), http://afsiasolar.com/wp-content/uploads/2021/02/AFSIA-Africa-Solar-Outlook-2021-final-2.pdf.

168 J. R. Martín, "African leaders enlist renewables to build future of energy resilience", PV-Tech, 20 April 2020, https://www.pv-tech.org/african-leaders-enlist-renewables-to-build-future-of-energy-resilience.

169 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 39. Financing tools and tenders from Institut Montaigne, cited in E. Bellini, "Unrealistic price signals and an explosion of tenders hinder African PV", pv magazine, 13 January 2020, https://www.pv-magazine.com/2020/01/13/unrealistic-price-signals-and-an-explosion-of-tenders-hinder-african-pv; financing and bankability in sub-Saharan Africa from Nyokabi, op. cit. note 15; fossil fuel subsidies from, for example, B. Publicover, "Solar is gaining traction in MENA region – but plenty of obstacles remain", pv magazine, 17 January 2020, https://www.pv-magazine.com/2020/01/17/mesia-outlines-past-progress-future-promise-in-sweeping-look-at-solar-across-middle-east-and-north-africa; subsidies as well as social and political unrest from Mints, op. cit. note 25,p. 12. See also G. Schwerhoff and M. Sy, "Where the sun shines: Renewable energy sources, especially solar, are ideal for meeting Africa's electrical power needs", International Monetary Fund, *Finance & Development*, vol. 57, no. 1 (March 2020), https://www.imf.org/external/pubs/ft/fandd/2020/03/powering-Africa-with-solar-energy-sy.htm.

170 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 18; AFSIA, op. cit. note 167, p. 27.

171 Smith, "Mali: New solar plant just the beginning", op. cit. note 167; Bungane, op. cit. note 167.

172 Egypt from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1; Ethiopia from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 15; B. Bungane, "Two solar plants to bring power to Ghana's Upper West Region", ESI Africa, 6 February 2020, https://www.esi-africa.com/industry-sectors/generation/two-solar-plants-to-bring-power-to-ghanas-upper-west-region; B. Bungane, "Ghana's president commissions 6.5MW Lawra solar power plant", ESI Africa, 12 October 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/ghanas-president-commissions-6-5mw-lawra-solar-power-plant; Somalia commissioned an 8 MW ground-mounted plant in Mogadishu, from Nextier Power, "New photovoltaic solar power plants in Mogadishu, Somalia", Nigeria Electricity Hub, 9 June 2020, https://www.nigeriaelectricityhub.com/2020/06/09/new-photovoltaic-solar-power-plant-in-mogadishu-somalia; Scatec, "Another 86 MW of Scatec Solar's 258 MW solar power complex in South Africa in commercial operation", 25 February 2020, https://scatec.com/2020/02/25/another-86-mw-of-scatec-solars-258-mw-solar-power-complex-in-south-africa-in-commercial-operation; Scatec, "Scatec Solar's 258 MW Upington project in South Africa completed", 6 April 2020, https://scatec.com/2020/04/06/scatec-solars-258-mw-upington-project-in-south-africa-completed.

173 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 110; MESIA, op. cit. note 13, pp. 18, 51.

174 Israel and Algeria from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, and from Becquerel Institute, op. cit. note 1. Egypt based on the following: 1.5 GW added for a total of 3.1 GW (and assumption that official data for the Benban complex are in AC), from idem, both sources, and from Masson, op. cit. note 1; 1,673 MW based on unofficial sources and cited in IRENA, op. cit. note 1; 1,623 MW, of which 1,465 MW is the Benban solar complex, from Egypt's New & Renewable Energy Authority (NREA), NREAmeter, January 2021, http://nrea.gov.eg/Media/New/1280, viewed 26 May 2021; and 1,720 MWp large-scale capacity plus 43.5 MW other, from AFSIA, op. cit. note 167, p. 32.

175 IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 12; Becquerel Institute, op. cit. note 1. The utility-scale share declined from 64.6% in 2019 to 59.6% in 2020, from idem, both sources.

176 Increase in new utility-scale capacity from IEA PVPS, *Snapshot of Global PV Markets 2021*, op. cit. note 1, p. 12.

177 See, for example, Clean Energy Council, op. cit. note 12, p. 77; G. Barbose and N. Darghouth, *Tracking the Sun, Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2019 Edition* (Berkeley, CA: LBNL, October 2019), p. 1, https://emp.lbl.gov/sites/default/files/tracking_the_sun_2019_report.pdf; E. Bellini, "Italy deployed 737 MW of solar in 2019", pv magazine, 21 April 2020, https://www.pv-magazine.com/2020/04/21/italy-deployed-737-mw-of-solar-in-2019. In Australia, for example, the average size of small-scale (up to 100 kW) rooftop systems was 8.04 kW in 2020, up from 1.97 kW in 2010, 4.99 kW in 2015, and 7.72 kW in 2019, from Clean Energy Council, op. cit. note 12.

178 Tendering from IEA PVPS, *Snapshot of Global PV Markets 2020*, op. cit. note 9, p. 11; tendering and PPAs from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 7, p. 25. It is easier to deploy large amounts of capacity when in utility-scale projects rather than distributed rooftop, which is why many countries with emerging markets start with tenders for large projects, from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 33; PPAs also from Wiki-Solar, "Utility-scale solar surges to yet another record year", 12 January 2021, https://wiki-solar.org/library/public/210112_Utility-scale_notches_up_another_record_year.pdf; reduce price through economies of scale from J. Petri, "Solar has finally gone off the

scale", Bloomberg, 28 February 2020, https://www.bloomberg.com/news/articles/2020-02-28/solar-power-has-finally-gone-off-the-scale-green-insight; "Iberdrola jumps from giant PV project to new build blitz", Reuters Events, 27 February 2020, https://analysis.newenergyupdate.com/pv-insider/iberdrola-jumps-giant-pv-project-new-build-blitz; "Texas solar owners face price risks after building boom", 17 February 2020, Reuters Events, https://www.reutersevents.com/renewables/solar-pv/texas-solar-owners-face-price-risks-after-building-boom.

179 Figures of about 80 plants, exceeding 21 GW, figure of 49 countries (and Mali and Oman), based on database provided by D. Lenardič, pvresources, Jesenice, Slovenia, personal communication with REN21, 31 March 2021. The total is at least 78 plants, not including three in Spain that were between 49 and 50 MW, from idem.

180 Based on data from Ibid., 31 March 2021 and 12 April 2021. Note that this includes some projects for which a portion of capacity was commissioned in previous years. This is down from an estimate of 35 in 2019, from Petri, op. cit. note 178.

181 Spain from "Iberdrola jumps from giant PV project to new build blitz", op. cit. note 178; Iberdrola, "Núñez de Balboa, operational: Iberdrola commissions Europe's largest photovoltaic plant", 6 April 2020, https://www.iberdrola.com/press-room/news/detail/nunez-balboa-operational-iberdrola-commissions-europe-s-largest-photovoltaic-plant; P. Sanjay, "With 2,245 MW of commissioned solar projects, world's largest solar park is now at Bhadla", Mercom India, 19 March 2020, https://mercomindia.com/world-largest-solar-park-bhadla; Saurabh, "2.2 gigawatt solar park in India's Rajasthan State now fully operational", CleanTechnica, 30 March 2020, https://cleantechnica.com/2020/03/30/2-2-gigawatt-solar-park-in-indias-rajasthan-state-now-fully-operational. Bhadla was still the world's largest at the end of 2020, as confirmed by Lenardič, op. cit. note 179, 31 March 2021. In late 2020, work began on India's Kutch hybrid renewable energy park in Gujarat, which is planned to have 41.5 GW of solar and wind power capacity when completed, from PSU Watch Bureau, "Work begins on world's largest hybrid RE park in Gujarat's Kutch. Know all about it here", PSU Watch, 15 December 2020, https://psuwatch.com/work-begins-world-largest-hybrid-re-park-gujarat-kutch.

182 See, for example: Hungary from E. Bellini, "100 MW solar park comes online in eastern central Europe", pv magazine, 14 December 2020, https://www.pv-magazine.com/2020/12/14/100-mw-solar-park-comes-online-in-eastern-central-europe; "Largest solar plant in Italy plugs into the grid", reNEWS, 25 June 2020, https://www.renews.biz/61222/largest-solar-plant-in-italy-plugs-into-the-grid; P. Sanchez Molina, "Large-scale solar deployment picks up in Spain", pv magazine, 11 September 2020, https://www.pv-magazine.com/2020/09/11/large-scale-solar-deployment-picks-up-in-spain; J. Parnell, "UK's largest solar project approved, will snub government subsidies", Greentech Media, 29 May 2020, https://www.greentechmedia.com/articles/read/uks-largest-solar-plus-storage-project-gets-greenlight-now-the-hard-work-starts; United States from Saur News Bureau, op. cit. note 85; "Invenergy fires up 160MW Southern Oak", reNEWS, 30 April 2020, https://renews.biz/60011/invenergy-starts-up-160mw-solar-plant; "Colorado Springs Utilities brings 60 MW of solar energy online", Renewable Energy World, 20 April 2020, https://www.renewableenergyworld.com/2020/04/20/colorado-springs-utilities-brings-60-mw-of-solar-energy-online; "Texas solar owners face price risks after building boom", op. cit. note 178; L. Morais, "Argentina's 300MW Cauchari solar farm begins commercial operation", Institute for Energy Economics and Financial Analysis (IEEFA), 28 September 2020, https://ieefa.org/argentinas-300mw-cauchari-solar-farm-begins-commercial-operation; "Chile's 123-MW Granja solar plant now operational", Renewable Energy World, 9 March 2020, https://www.renewableenergyworld.com/2020/03/09/chiles-123-mw-granja-solar-plant-now-operational; P. Sanchez Molina, "Neoen energizes 140 MW solar park linked to 3.2 MW/2.2 MWh of storage in El Salvador", pv magazine, 8 December 2020, https://www.pv-magazine.com/2020/12/08/neoen-energizes-140-mw-solar-park-linked-to-3-2-mw-2-2-mwh-of-storage-in-el-salvador; G. Parkinson, "Australia's biggest solar farm sends first output to the grid", RenewEconomy, 15 September 2020, https://reneweconomy.com.au/australias-biggest-solar-farm-sends-first-output-to-the-grid-95988; Mali from Smith, op. cit. note 167; South Africa from Bellini, op. cit. note 167; A. Parikh, "Scatec Solar's 86 MW solar project in South Africa begins operation", Mercom India, 4 March 2020, https://mercomindia.com/scatec-solar-86-mw-solar-project-south-africa; B. Bungane, "South Africa: 75MW Waterloo Solar begins commercial operations", ESI Africa, 27 November 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/south-africa-75mw-waterloo-solar-begins-commercial-operations; B. Bungane, "Two new solar plants now feeding 132MW into South Africa's grid", ESI Africa, 1 October 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/two-new-solar-plants-now-feeding-132mw-into-south-africas-grid; B. Bungane, "South Africa: Bokamoso Solar plant commences commercial operations", ESI Africa, 18 September 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/south-africa-bokamoso-solar-plant-commences-commercial-operations; NS Energy, "Sterling and Wilson commissions 125MW DC solar PV project in Oman", 3 June 2020, https://www.nsenergybusiness.com/news/sterling-wilson-solar-pv-oman; Power Technology, "Indian prime minister inaugurates 750MW solar project", 10 July 2020, https://www.power-technology.com/news/narendra-modi-inaugurates-750mw-solar-project-india; "Japanese consortium tees up 100MW Kanoya Osaki", reNEWS, 29 May 2020, https://renews.biz/60641/japanese-consortium-tees-up-100mw-kanoya-osaki; NS Energy, "Risen Energy connects 50MW solar plant to grid in Kazakhstan", 22 January 2020, https://www.nsenergybusiness.com/news/risen-energy-solar-plant; Bellini, "Three 1.2 GW solar projects under development in the Philippines", op. cit. note 64; Retail Asia, "Largest solar plant in Southeast Asia begins operating in Vietnam", 14 October 2020, https://www.retailnews.asia/largest-solar-plant-in-southeast-asia-begins-operating-in-vietnam; E. Bellini, "Albania launches 140 MW solar tender", pv magazine, 22 January 2020, https://www.pv-magazine.com/2020/01/22/albania-launches-tender-for-140-mw-of-solar.

183 Well-designed and -built from Rossi, op. cit. note 112, 25 May 2021, from SolarPower Europe, *Solar Sustainability: Best Practices Benchmark* (Brussels: May 2021), https://www.solarpowereurope.org/solar-sustainability-best-practices-benchmark, and from Bundesverband Neue Energiewirtschaft (bne) e.V., *Solarparks - Gewinne für die Biodiversität* (Berlin: November 2019), https://www.bne-online.de/fileadmin/bne/Dokumente/20191119_bne_Studie_Solarparks_Gewinne_fuer_die_Biodiversitaet_online.pdf. Concerns from, for example, P. Fairley, "The pros and cons of the world's biggest solar park", IEEE Spectrum, 22 January 2020, https://spectrum.ieee.org/energy/renewables/the-pros-and-cons-of-the-worlds-biggest-solar-park; S. M. Nir, "He set up a big solar farm. His neighbors hated it", *New York Times*, 18 March 2020, https://www.nytimes.com/2020/03/18/nyregion/solar-energy-farms-ny.html; J. McCurry, "Japan's renewable energy puzzle: Solar push threatens environment", *The Guardian* (UK), 19 April 2018, https://www.theguardian.com/world/2018/apr/19/japans-renewable-energy-puzzle-solar-push-threatens-environment; IEA PVPS, *Trends in Photovoltaic Applications 2018*, op. cit. note 9, p. 16. Land constraints already are becoming a problem in China, for example, particularly in the eastern part of the country along the coastline, from F. Haugwitz, AECEA, presentation for "PV Market Insights 2021", Daegu, Republic of Korea, 28-29 April, pvmi.co.kr/eng.

184 D. Renné, International Solar Energy Society, Boulder, CO, personal communication with REN21, April 2020.

185 BIPV progressing but slowly, and auto manufacturers, from Masson, op. cit. note 1, 20 February 2020 and 9 March 2021.

186 India from A. Upadhyay, "India's largest building integrated vertical solar system & the road ahead", CleanTechnica, 11 July 2020, https://cleantechnica.com/2020/07/11/indias-largest-building-integrated-vertical-solar-system-the-road-ahead; United States from for example, B. Ludt, "Philadelphia architecture firm installs wild solar project to maximize onsite power production", Solar Power World, 10 November 2020, https://www.solarpowerworldonline.com/2020/11/philadelphia-architecture-firm-installs-wild-solar-project-to-maximize-onsite-power-production; K. Misbrener, "All Energy Solar completes unusual Minnesota solar project meant to double as art installation", Solar Power World, 14 September 2020, https://www.solarpowerworldonline.com/2020/09/all-energy-solar-installs-solar-art-installation-minnesota; B. Ludt, "Wall-mounted solar mural depicts history of Texas school", 20 February 2020, https://www.solarpowerworldonline.com/2020/02/wall-mounted-solar-mural-depicts-history-of-texas-school. Europe from Swiss BIPV Competence Centre and Becquerel Institute, *Building Integrated Photovoltaics: A Practical Handbook for Solar Buildings' Stakeholders* (Canobbio, Switzerland: October 2020), https://solarchitecture.ch/wp-content/uploads/2020/11/201022_BIPV_web_V01.pdf.

187 Land and design innovations from N. Ford, "Floating solar design gains drive strong growth prospects", New Energy Update, 22 July 2020, https://analysis.newenergyupdate.com/pv-insider/floating-solar-design-gains-drive-strong-growth-prospects. See also World Bank, Energy Sector Management Assistance Program (ESMAP) and Solar Energy Research Institute of Singapore (SERIS), *Where Sun Meets Water: Floating Solar Handbook for Practitioners* (Washington, DC: World Bank, 2019),http://documents.worldbank.org/curated/en/418961572293438109/Where-Sun-Meets-Water-Floating-Solar-Handbook-for-Practitioners; IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, pp. 16-17.

188 New risks and higher costs from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 61, and from Wood Mackenzie Power & Renewables, cited in M. Cox, "The state of floating solar: Bigger projects, climbing capacity, new markets", Greentech Media, 19 September 2019, https://www.greentechmedia.com/articles/read/the-state-of-floating-solar-bigger-projects-and-climbing-capacity; benefits from SolarPower Europe, op. cit. this note, and from World Bank, ESMAP and SERIS, op. cit. note 187. In 2020, a new Dutch study showed no significant benefit to solar panels from sunlight reflected off water or from reduced panel temperatures, and it found that bird droppings can affect the panels' performance; in addition, the study found no significant benefits to water-quality and temperatures, from Delft University of Technology, "Innovative floating bifacial photovoltaic solutions for inland water areas", *Progress in Photovoltaics*, cited in E. Bellini, "New study debunks several myths about floating PV", pv magazine, 15 December 2020, https://www.pv-magazine.com/2020/12/15/new-study-debunks-several-myths-about-floating-pv.

189 Wood Mackenzie Power & Renewables, op. cit. note 188.

190 Countries with projects in Asia include China, the Republic of Korea, Malaysia, the Philippines, Singapore, Thailand, Vietnam and others, from the following sources: CEC, "World's largest floating solar plant connected in China", press release, http://english.cec.org.cn/No.106.1755.htm, viewed 25 March 2020; T. Kenning, "World's largest floating solar plant connected in China", PV-Tech, 20 March 2019, https://www.pv-tech.org/news/worlds-largest-floating-solar-plant-connected-in-china; GCL System, "Floating solar: Philippines switches on its first hybrid floating photovoltaic hydro power project", pv magazine, 16 July 2019, https://www.pv-magazine-australia.com/press-releases/floating-solar-philippines-switches-on-its-first-hybrid-floating-photovoltaic-hydro-power-project; M. Patel, "Floating solar power plants: An idea whose time has come", *Economic Times*, 22 May 2019, https://energy.economictimes.indiatimes.com/energy-speak/floating-solar-power-plants-an-idea-whose-time-has-come/3582; E. Bellini, "New alliance to expand floating PV in Southeast Asia", pv magazine, 8 August 2019, https://www.pv-magazine.com/2019/08/08/new-alliance-to-expand-floating-pv-in-southeast-asia; A. A. Hadi, "World's largest floating solar energy systems installed in Maldives", Sun, 26 August 2019, https://en.sun.mv/55072. African countries include Malawi and the Seychelles, from J. Martín, "France powers up Europe's self-styled largest floating PV project", PV-Tech, 21 October 2019, https://www.pv-tech.org/news/france-powers-up-europes-self-styled-largest-floating-pv-project, and from BizCommunity, "Seychelles floating solar energy project moves into next phase", 13 June 2019, https://www.bizcommunity.com/Article/189/640/191942.html. Countries in Europe include France, Portugal and the Netherlands, from the following sources: J. Martín, "World Bank, SERIS take aim at floating PV hurdles with standardisation push", PV-Tech, 4 November 2019, https://www.pv-tech.org/news/world-bank-seris-take-aim-at-floating-pv-hurdles-with-standardisation-push; Martín, "France powers up Europe's self-styled largest floating PV project", op. cit. this note; E. Barbiroglio, "A new floating solar farm shows that renewables can be easy", *Forbes*, 7 November 2019, https://www.forbes.com/sites/emanuelabarbiroglio/2019/11/07/a-new-floating-solar-farm-shows-that-renewables-can-be-easy; M. Osborne, "BayWa r.e planning over 100MW of floating solar projects in Europe for 2020", PV-Tech, 5 November 2019, https://www.pv-tech.org/news/baywa-r.e-planning-over-100mw-of-floating-solar-projects-in-europe-for-2020. Countries in the Americas include Brazil, from Martín, "France powers up Europe's self-styled largest floating PV project", op. cit. this note; P. Sanchez Molina, "Chile connects first floating PV plant to grid under net billing scheme", pv magazine, 16 September 2020, https://www.pv-magazine.com/2020/09/16/chile-connects-first-floating-pv-plant-to-grid-under-net-billing-scheme; T. Sylvia, "America's largest floating solar project completed", pv magazine, 23 October 2019, https://pv-magazine-usa.com/2019/10/23/americas-largest-floating-solar-project-completed. Most of the largest floating solar plants are in Asia (outside of Asia, most floating solar PV plants are on the scale of several megawatts), from "Floating solar design gains drive strong growth prospects", Reuters Events, 22 July 2020, https://analysis.newenergyupdate.com/pv-insider/floating-solar-design-gains-drive-strong-growth-prospects, C. Gilligan and C. Beadle, "Asian buoyancy floats solar", pv magazine, 4 June 2020, https://www.pv-magazine.com/2020/06/04/asian-buoyancy-floats-solar.

191 MESIA, op. cit. note 13, p. 26.

192 Z. Shahan, "Largest floating solar park in Europe connected to grid in Netherlands", CleanTechnica, 1 August 2020, https://cleantechnica.com/2020/08/01/largest-floating-solar-park-in-europe-connected-to-grid-in-netherlands; Blauwvinger Energie, "Zonnepark Bomhofsplas gekocht, https://blauwvingerenergie.nl/zonnepark-bomhofsplas-gekocht, viewed 31 March 2021; G. Deboutte, "First unit of 250 MW floating PV project comes online in Ghana", pv magazine, 15 December 2020, https://www.pv-magazine.com/2020/12/15/first-unit-of-250-mw-floating-pv-project-comes-online-in-ghana; Chile from Sanchez Molina, op. cit. note 190. Other examples include: "Sembcorp signs 25-year power purchase deal to build floating solar system", *Reuters*, 11 May 2020, https://www.reuters.com/article/singapore-oil-sembcorp-inds/sembcorp-signs-25-year-power-purchase-deal-to-build-floating-solar-system-idUSL4N2CT3NE; E. Bellini, "Vietnam sees 70 MW of floating PV come online", pv magazine, 6 January 2021, https://www.pv-magazine.com/2021/01/06/vietnam-sees-70-mw-of-floating-pv-come-online; N. Pombo-van Zyl, "Brazil to host floating solar PV at its Batalha hydropower dam", ESI Africa, 17 February 2020, https://www.esi-africa.com/industry-sectors/future-energy/brazil-to-host-floating-solar-pv-at-its-batalha-hydropower-dam; Sanchez Molina, op. cit. note 190; Acciona, "ACCIONA begins installing the first grid-connected floating photovoltaic plant in Spain, in Extremadura", 3 March 2020, https://www.acciona.com/pressroom/news/2020/march/acciona-begins-installing-the-first-grid-connected-floating-photovoltaic-plant-in-spain-in-extremadura; "EDP floating PV-hydro project shows market viability", Reuters Event, 28 October 2020, https://www.reutersevents.com/renewables/solar/edp-floating-pv-hydro-project-shows-market-viability; S. J. Ahmed and E. Hamdi, "IEEFA report: Volts from the blue – floating solar to generate 900% more electricity across Asia-Pacific", IEEFA, 30 June 2020, https://ieefa.org/ieefa-volts-from-the-blue-floating-solar-energy-to-generate-900-more-clean-electricity-across-asia-pacific-since-2019.

193 J. Scully, "Chenya Energy eyes floating PV growth after completing 181MWp offshore project", PV-Tech, 5 February 2021, https://www.pv-tech.org/chenya-energy-eyes-floating-pv-growth-after-completing-181mwp-offshore-project. The largest water-based project (with some arrays floating and some on stilts over water) was completed in Zhejiang province, China, in 2020, from "World's biggest floating solar farms", Power Technology, 19 February 2021, https://www.power-technology.com/features/worlds-biggest-floating-solar-farms. The Hangzhou Fengling Electricity Science Technology's solar farm was developed in two phases, with 200 MW completed in 2017 and the remainder in April 2020; the plant is built on the Changhe and Zhouxiang reservoirs in Cixi, from idem. See also E. Bellini, "Another 120 MW of solar aquaculture in China", pv magazine, 14 April 2020, https://www.pv-magazine.com/2020/04/17/another-120-mw-of-solar-aquaculture-in-china, and Kstar, "KSTAR 320MW (120MW+200MW) solar-water power plant", 18 April 2020, https://www.kstar.com/newinformation/17387.jhtml.

194 S. Hanley, "Europe puts focus on floating solar & agrivoltaics", CleanTechnica, 22 March 2020, https://cleantechnica.com/2020/03/22/europe-puts-focus-on-floating-solar-agrivoltaics; J. S. Murray, "Oil giants team up to float coastal solar vision", Business Green, 20 March 2020, https://www.businessgreen.com/news/4012807/oil-giants-team-float-coastal-solar-vision. In 2020, an 80 kW array was completed in the waters off the coast of the resort island of Nurai, Abu Dhabi (UAE), from S. Vorrath, "Open sea floating solar array set to power Abu Dhabi resort island", One Step Off The Grid, 13 February 2020, https://onestepoffthegrid.com.au/open-sea-floating-solar-array-set-to-power-abu-dhabi-resort-island, and fromMESIA, op. cit. note 13, p. 5. Bidders were selected for a 2.1 GW plant planned for an estuarine tidal flat off the coast of the

Republic of Korea. The plant to be built near Saemangeum is expected to generate enough electricity to serve the needs of 1 million homes, and is part of a planned renewable energy project of up to 3 GW, from "World's biggest floating solar farms", op. cit. note 193. Two fossil fuel companies (Norway's Equinor and Italy's Saipem) partnered to develop a technological solution for near-shore applications, from Hanley, op. cit. this note; Murray, op. cit. this note.For a further offshore related development in early 2021, see B. Willis, "The race is on for commercial deployment of solar in open seas", Greentech Media, 27 January 2021, https://www.greentechmedia.com/articles/read/race-on-for-commercial-deployment-of-solar-in-open-seas.

195 See sources provided for this paragraph. Bifacial systems from Renné, op. cit. note 184, 11 April 2020.

196 "Agri-PV builders trial crop, technology in yield-boosting plants", Reuters Events, 19 August 2020, https://analysis.newenergyupdate.com/solar/agri-pv-builders-trial-crop-technology-yield-boosting-plants; *SolarPower Europe, Agrisolar: Best Practices Guidelines Version 1.0* (Brussels: May 2021), https://www.solarpowereurope.org/agrisolar-best-practice-guidelines.

197 Costs are higher due to specialized equipment and more expensive installation methods, from "Agri-PV builders trial crop, technology in yield-boosting plants", op. cit. note 196. Studies from, for example: SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 61; SolarPower Europe, op. cit. note 196; "US agri-PV teams build data for commercial roll-out", Reuters Events, 16 December 2020, https://www.reutersevents.com/renewables/solar-pv/us-agri-pv-teams-build-data-commercial-roll-out; "Agri-PV builders trial crop, technology in yield-boosting plants", op. cit. note 196; L. Freehill-Maye, "Sheep, ag and sun: Agrivoltaics propel significant reductions in solar maintenance costs", Utility Dive, 4 August 2020, https://www.utilitydive.com/news/sheep-ag-and-sun-agrivoltaics-propel-significant-reductions-in-solar-main/581879; E. Bellini, "Food crops do better in the shade of solar panels", pv magazine, 3 September 2019, https://www.pv-magazine.com/2019/09/03/food-crops-do-better-in-the-shade-of-solar-panels; P. Lal, "India prepares to embrace agrivoltaics", pv magazine, 27 September 2019, https://www.pv-magazine-india.com/2019/09/27/india-prepares-to-embrace-agrivoltaics; T. Tsanova, "German agro PV trial shows up to 186% land use efficiency", Renewables Now, 15 April 2019, https://renewablesnow.com/news/german-agro-pv-trial-shows-up-to-186-land-use-efficiency-650768. Improved yields and additional income from SolarPower Europe, *Global Market Outlook for Solar Power, 2019-2023*, op. cit. note 7, p. 51, and from IEA PVPS, *Trends in Photovoltaic Applications 2019*, op. cit. note 5, p. 17. Prevention of wind and soil erosion, and shade for livestock, from Lal, op. cit. this note; reduced evaporation and rainwater harvesting from Tsanova, op. cit. this note. In Europe, studies have found that solar PV installations in vineyards can aid in hail and frost protection and can enable control of alcohol content in grapes, from Energiezukunft, "Himbeeren unter Solarmodulen statt unter Folientunneln", 9 March 2020, https://www.energiezukunft.eu/erneuerbare-energien/solar/himbeeren-unter-solarmodulen-statt-unter-folientunneln.

198 Japan from Matsubara, op. cit. note 53; and Japan, Republic of Korea and India from Haugwitz, op. cit. note 29, 13 April 2021. India active programmes from Renné, op. cit. note 184, 5 April 2020; see also Lal, op. cit. note 197. Elsewhere from, for example, "Agri-PV builders trial crop, technology in yield-boosting plants", op. cit. note 96; "First dual-use agricultural PV system in Massachusetts now operational", Renewable Energy World, 20 October 2020, https://www.renewableenergyworld.com/2020/10/20/first-dual-use-agricultural-pv-system-in-massachusetts-now-operational; "US agri-PV teams build data for commercial roll-out", op. cit. note 197. Israel from B. Matich, "Orchardvoltaics – it's just ripe", pv magazine, 15 January 2021, https://www.pv-magazine.com/magazine-archive/orchardvoltaics-its-just-ripe. China from Masson, op. cit. note 1, 9 March 2021.

199 China as dominant producer and supplier from Z. Jianhua, Director of NEA, speaking at press conference: "The State Council Information Office held a press conference on China's renewable energy development", 30 March 2021, http://www.nea.gov.cn/2021-03/30/c_139846095.htm (using Google Translate); P. Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 16. Chinese factories comprise at least 73% of global capacity in every step of the solar PV supply chain, from BloombergNEF, cited in "China's solar giants slash prices as virus curbs demand", Bloomberg, 31 May 2020, https://www.bloomberg.com/news/articles/2020-05-31/china-s-solar-giants-forced-to-cut-prices-as-virus-curbs-demand; Chinese factories manufacture about 70% of the global supply of solar panels plus Chinese companies throughout Southeast Asia, from H. Bahar, "The coronavirus pandemic could derail renewable energy's progress. Governments can help." IEA, 4 April 2020, https://www.iea.org/commentaries/the-coronavirus-pandemic-could-derail-renewable-energy-s-progress-governments-can-help. See also "China solar giants get bigger as glut ignites battle for share", Bloomberg, 4 March 2020, https://www.bloomberg.com/news/articles/2020-03-04/china-solar-giants-get-bigger-as-glut-ignites-battle-for-share. Closures in the entire industry from E. F. Merchant, "Solar industry waits to assess ripple effects from China's coronavirus outbreak", Greentech Media, 31 January 2020, https://www.greentechmedia.com/articles/read/solar-industry-waits-to-assess-ripple-effects-from-coronavirus-impact, but China rebounded quickly, from "Coronavirus is starting to slow the solar energy revolution", Bloomberg, 27 February 2020, https://www.bloomberg.com/news/articles/2020-02-27/coronavirus-is-starting-to-slow-the-solar-energy-revolution. The timing of the worst impacts of COVID-19 in China coincided with the Lunar New Year, so material delays were already incorporated into supply-management schedules, from E. Crouse and D. Conner, "Opinion: Distressed supply chains uniquely impact renewable energy", Seattle Business News, 20 April 2020, https://www.bizjournals.com/seattle/news/2020/04/20/distressed-supply-chains-uniquely-impacts-energy.html.

200 "COVID-19 sends price risk warning to dispatch-only renewables", Reuters Events, 20 May 2020, https://newenergyupdate.com/pv-insider/covid-19-sends-price-risk-warning-dispatch-only-renewables; "Solar, wind investors adapt PPAs for post-COVID pickup", Reuters Events, 6 May 2020, https://www.reutersevents.com/renewables/pv-insider/solar-wind-investors-adapt-ppas-post-covid-pickup; P. M. Shea, "Coronavirus spurs 'domino effect' of wind, solar delays", Energywire, 10 March 2020, https://www.eenews.net/energywire/stories/1062562335/; EurObserv'ER, op. cit. note 30, p. 15.

201 IEA, "Renewables 2020: Covid-19 and the resilience of renewables", https://www.iea.org/reports/renewables-2020/covid-19-and-the-resilience-of-renewables, viewed 15 May 2021. See also, for example, M. Osborne, "SMA Solar's inverter shipments rebound in Q3 after COVID-19 hit", PV-Tech, 12 November 2020, https://www.pv-tech.org/sma-solars-inverter-shipments-rebound-in-q3-after-covid-19-hit; M. Mercure, "SEIA: solar rebounds for pandemic in Q3", Solar Industry, 15 December 2020, https://solarindustrymag.com/seia-solar-rebounds-from-pandemic-in-q3; E. Bellini, "JinkoSolar posts significant shipment growth in Q3", pv magazine, 26 November 2020, https://www.pv-magazine-australia.com/2018/11/26/jinkosolar-posts-significant-shipment-growth-in-q3.

202 Mints, op. cit. note 83, pp. 6, 25; Becquerel Institute, BI Newsletter December 2020, received via email 17 December 2020. Accidents at polysilicon factories included an explosion at GCL Poly's facility in Xinjiang (China) and flooding of Tongwei's facility in Sichuan (China), which took about 11% of global production capacity offline, from SEIA, "Solar Market Insight Report 2020 Q4", https://www.seia.org/research-resources/solar-market-insight-report-2020-q4, viewed 13 April 2021, and from C. Chen, "Consolidation continues for polysilicon makers", pv magazine, 20 July 2020, https://www.pv-magazine.com/2020/08/20/consolidation-continues-for-polysilicon-makers. China has 90% of solar glass production capacity, from P. Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 13. Between June 2020 and February 2021, prices increased dramatically for glass (up 80% per square metre), polysilicon (up 64%) and silver (up 55%), from B. S. Nagaraj, "Solar module prices to remain high until second half of 2021: Chinese manufacturers", Mercom India, 26 April 2021, https://mercomindia.com/solar-module-prices-high-second-half-of-2021. Glass pricing and related information in endnote from the following: Becquerel Institute, op. cit. this note; Masson, op. cit. note 1, 9 March 2021; Soby Photovoltaic Network, "The shortage of photovoltaic glass is expected to alleviate the relevant departments to actively promote three measures", Polaris Power Exhibition Network, 4 November 2020, http://ex.bjx.com.cn/html/20201104/36640.shtml (using Google Translate). Prices also were up because of increasingly diverse sizes of modules, which requires stocking a variety of glass sizes and can lead to a mismatch of resources, from idem. Rising demand due to rapidly

increasing production of solar modules and also to growth in demand for bifacial panels, which increase glass requirements, from "Glass shortage threatens solar panels needed for climate fix", Bloomberg, 4 November 2020, https://www.bloomberg.com/news/articles/2020-11-05/a-glass-shortage-is-threatening-china-s-solar-power-ambitions. The Chinese government forbade increases in production capacity in 2018 because the industry is energy-intensive and highly-polluting and it was facing over-capacity issues, from idem. Global prices for solar glass saw steady rise starting in 2018, but jumped up over 70% from July to November, from idem.

203 See information and sources throughout this section.

204 Germany extended completion deadlines by up to six months for awarded capacity, from M. Schachinger, "Module Price Index: 2020 – Taking the time to say 'thanks'...", pv magazine, 20 January 2021, https://www.pv-magazine.com/2021/01/20/module-price-index-2020-taking-the-time-to-say-thanks. S. Enkhardt and C. Rollet, "Germany and France modify solar tenders because of Covid-19", pv magazine, 25 March 2020, https://www.pv-magazine.com/2020/03/25/germany-and-france-modify-solar-tenders-because-of-covid-19. India announced in March an extension of commissioning deadlines for projects under construction and extended a waiver for inter-state transmission charges for projects commissioned up to mid-2023, from U. Gupta, "Solar industry in 2020", pv magazine, 28 December 2020, https://www.pv-magazine-india.com/2020/12/28/solar-industry-in-2020; J. Pyper, "How India's renewable energy sector survived and thrived in a turbulent 2020", Greentech Media, 6 January 2021, https://www.greentechmedia.com/articles/read/india-solar-energy-transition-pandemic-2020; N. T. Prasad, "COVID-19 lockdown: MNRE extends deadline for all renewable projects under construction", Mercom India, 27 March 2020, https://mercomindia.com/covid-19-lockdown-mnre-deadline-renewable-under-construction.The United States extended various tax credit deadlines for acquiring components and completing projects, from P. Mints, SPV Market Research, *The Solar Flare*, 30 April 2020, p. 20; but the federal government also ended a two-year rent holiday for wind and solar power projects on federal lands, sending out retroactive bills in May, some for millions of dollars, from N. Groom, "Trump admin slaps solar, wind operators with retroactive rent bills", *Reuters*, 18 May 2020, https://www.reuters.com/article/us-usa-interior-renewables/trump-admin-slaps-solar-wind-operators-with-retroactive-rent-bills-idUSKBN22U0FW.

205 Spain from Mints, op. cit. note 204, p. 19, and from B. Willis, "New laws eye 'massive' deployment of renewables in Spain", PV-Tech, 24 June 2020, https://www.pv-tech.org/new-laws-eye-massive-deployment-of-renewables-in-spain; M. Agravante, "Italy's Relaunch Decree helps homeowners install solar photovoltaic systems for free", Inhabitat, 27 May 2020, https://inhabitat.com/italys-relaunch-decree-helps-homeowners-install-solar-photovoltaic-systems-for-free; India from Pyper, op. cit. note 204. India's national and several state governments also launched additional tenders and financially supporting power DISCOMs so they had liquidity to pay producers, from idem. Note, however, that implementation of India's "must-run" status was lax during the year and curtailment continued to threaten both solar PV and wind power generators, from R. Ranjan, "Curtailment of solar and wind for commercial reasons continues to be a threat", Mercom India, 10 December 2020, https://mercomindia.com/curtailment-solar-wind-commercial-threat.

206 Disrupted supply chains from sources throughout related text that follows. See also, for example, E. Bellini, "Covid-19 and dependence on China's PV supply chain", pv magazine, 30 March 2020, https://www.pv-magazine.com/2020/03/30/covid-19-and-dependence-on-chinas-pv-supply-chain.

207 Existing import tariffs from N. Young, "These are the tariffs still impacting the U.S. solar industry", Solar Power World, 24 March 2020, https://www.solarpowerworldonline.com/2020/03/these-are-the-tariffs-still-impacting-the-u-s-solar-industry; E. J. Williams, A. D. Schurle and M. A. Lund, "The status of solar and wind tax credits and tariffs as we enter 2021", Solar Power World, 7 December 2020, https://www.solarpowerworldonline.com/2020/12/the-status-of-solar-and-wind-tax-credits-and-tariffs-as-we-enter-2021. See also E. F. Merchant, "Trump moves to increase solar import tariffs, kill bifacial exemption", Greentech Media, 12 October 2020, https://www.greentechmedia.com/articles/read/presidential-proclamation-to-increase-extend-section-201-tariffs. Bifacial developments from Mints, op. cit. note 204; Mints, op. cit. note 83, p. 29; E. F. Merchant, "Trump administration removes tariff exemption for bifacial solar panels — again", Greentech Media, 17 April 2020, https://www.greentechmedia.com/articles/read/trump-admin-removes-tariff-exemption-for-bifacial-solar-panels-again; X. Sun, "Why US solar tariffs almost worked, and why they don't now", Greentech Media, 23 July 2020, https://www.greentechmedia.com/articles/read/why-us-solar-tariffs-almost-worked-and-why-they-dont-now; B. Pickerel, "Bifacial solar panels lose their Section 201 tariff exemption", Solar Power World, 19 November 2020, https://www.solarpowerworldonline.com/2020/11/bifacial-solar-panels-lose-their-section-201-tariff-exemption.

208 R. Nair, "After Kazakhstan, US imposes 47.54% duty on silicon from Bosnia-Herzegovina & Iceland", Mercom India, 10 December 2020, https://mercomindia.com/us-imposes-duty-on-silicon; "U.S. silicon metal producers welcome duties on imports of silicon metal from Kazakhstan", Bloomberg, 1 December 2020, https://www.bloomberg.com/press-releases/2020-11-30/u-s-silicon-metal-producers-welcome-duties-on-imports-of-silicon-metal-from-kazakhstan. Critics say that US import tariffs have raised costs and hampered domestic deployment, from M. Willson, "Biden's 'Buy America' plan may hit a solar wall", E&E News, 1 March 2021, https://www.eenews.net/stories/1063726219/print. According to Wood Mackenzie, "Tariffs have made solar modules artificially more expensive in the U.S. The cost is about 79 percent higher than in major European markets, 75 percent higher than Japan, and about 85 percent higher than in China. Without the tariffs, U.S. solar system prices could be nearly 30 percent lower", from Sun, op. cit. note 207.

209 Promotion of self-reliance through duties from R. Ranjan, "Technological upgrades imperative for India's solar manufacturing to take-off", Mercom India, 31 August 2020, https://mercomindia.com/technological-upgrades-india-solar-manufacturing, from Ranjan, op. cit. note 60, and from R. Ranjan, "2020 a look back: Developments that shaped the solar sector", Mercom India, 29 December 2020, https://mercomindia.com/2020-look-back-developments-solar. Safeguard duty from Ranjan, "Technological upgrades imperative for India's solar manufacturing to take-off", op. cit. this note; N. T. Prasad, "India set to extend levy of safeguard duty on solar imports by another year", Mercom India, 20 July 2020, https://mercomindia.com/india-extend-sgd-solar-imports; R. Ranjan, "DGTR imposes countervailing duty of 9.71% on solar glass imports from Malaysia", Mercom India, 21 December 2020, https://mercomindia.com/dgtr-countervailing-duty-solar-glass-malaysia. India imports more than 80% of its solar cells and modules from China, domestic manufacturers have struggled to compete, from A. Upadhyay, "India completes world's largest solar tender, aims to reduce Chinese solar imports", CleanTechnica, 22 June 2020, https://cleantechnica.com/2020/06/22/india-completes-worlds-largest-solar-tender-aims-to-reduce-chinese-solar-imports.

210 "Make in India" from Mints, op. cit. note 204, p. 18; launched tenders for solar projects linked to cell and module manufacturing capacity, from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 77; IEA, "Solar PV", in *Renewables 2020: Analysis and Forecast to 2025* (Paris: November 2020), https://www.iea.org/reports/renewables-2020/solar-pv#abstract; in late 2020, incentives linked to production were announced to attract manufacturers to build facilities in India for domestic use and export, from Mints, op. cit. note 83, p. 16.

211 SolarPower Europe, op. cit. note 4, p. 29, and from Mints, op. cit. note 83, p. 22. For more information, see SolarPower Europe, "Solar Manufacturing Accelerator: Accelerating the deployment of solar PV manufacturing projects in Europe", https://www.solarpowereurope.org/campaigns/manufacturing-accelerator, viewed 25 April 2021; European Solar Manufacturing Council, https://esmc.solar, viewed 25 April 2021.

212 Masson, op. cit. note 1, 9 March 2021.

213 "Egypt, China discuss cooperation on sand-to-cell manufacturing", ZAWYA, 2 November 2020, https://www.zawya.com/mena/en/business/story/Egypt_China_discuss_cooperation_on_sandtocell_manufacturing-SNG_188840258; "Egypt-based Enara Energy pens deal with Chint Electric for solar project", ZAWYA, 29 December 2020, https://www.zawya.com/mena/en/projects/story/Egyptbased_Enara_Energy_pens_deal_with_Chint_Electric_for_solar_project-SNG_196359277; R. Mahmoud, "Egypt to begin project to convert sand into solar panels" Al-Monitor, 3 February 2021, https://www.al-monitor.com/originals/2021/02/egypt-china-local-manufacture-sand-solar-panels-energy.html.

A cooperation agreement was signed between Enara (Egypt) and Chint (China) to establish the project, and it will be implemented in coordination with Egypt's Ministry of Military Production, from idem.

214 IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit.note 1, p. 30. See, for example, E. Bellini, "Algeria's first mounting system manufacturer, pv magazine, 25 June 2020, https://www.pv-magazine.com/2020/06/25/algerias-first-mounting-system-manufacturer.

215 E. Bellini, "China will extend duties on US and South Korean polysilicon for another five years", pv magazine, 21 January 2020, https://pv-magazine-usa.com/2020/01/21/china-will-extend-duties-on-us-and-south-korean-polysilicon-for-another-five-years; Chen, op. cit. note 202.

216 China's shares in 2010 and 2020 from IHS Markit, cited in A. Swanson and C. Buckley, "Chinese solar companies tied to use of forced labor", *New York Times*, 8 January 2021, https://www.nytimes.com/2021/01/08/business/economy/china-solar-companies-forced-labor-xinjiang.html.

217 Figure of 45% from Mints, personal communication with REN21, op. cit. note 1. Xinjiang's share of production was 40%, from J. Chase, BloombergNEF, cited in https://www.nytimes.com/2021/01/08/business/economy/china-solar-companies-forced-labor-xinjiang.html. Producers drawn to region from Mints, *Photovoltaic Manufacturer Capacity, Shipments*, op. cit. note 1, p. 14. About 237 million tonnes of polysilicon are produced in Xinjiang, another 215 million tonnes elsewhere in China, and 116 million tonnes in Europe, the Republic of Korea, the United States and elsewhere, making the Xinjiang share nearly 42% of the total, from idem.

218 See, for example, Institute for Energy Research, "Chinese solar panel production issues are mounting", 18 November 2020, https://www.instituteforenergyresearch.org/renewable/solar/chinese-solar-panel-production-issues-are-mounting; M. Copley, "Human rights allegations in Xinjiang could jeopardize solar supply chain", S&P Global, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/human-rights-allegations-in-xinjiang-could-jeopardize-solar-supply-chain-60829945; WION, "Chinese solar companies tied to use of forced labor", 9 January 2021, https://www.msn.com/en-in/news/world/chinese-solar-companies-tied-to-use-of-forced-labor/ar-BB1cBmFq; A. Hernández-Morales et al., "Fears over China's Muslim forced labor loom over EU solar power", Politico, 10 February 2021, https://www.politico.eu/article/xinjiang-china-polysilicon-solar-energy-europe; E. F. Merchant, "Solar industry pushed to examine supply chain after reports of forced labor in China", Greentech Media, 19 January 2021, https://www.greentechmedia.com/articles/read/solar-industry-pushed-to-examine-supply-chain-after-reports-of-forced-labor-in-china; Swanson and Buckley, op. cit. note 216.

219 Chinese government and industry from, for example, PVTIME, "Lu Jinbiao: Leading Chinese photovoltaic enterprises may be targets of Solar Energy Industry Association's anti-'forced labor' alliance", 7 February 2021, http://www.pvtime.org/lu-jinbiao-leading-chinese-photovoltaic-enterprises-may-be-targets-of-solar-energy-industry-associations-anti-forced-labor-alliance, and M. Copley, "Chinese solar group blasts US calls to avoid supplies from Xinjiang", S&P Global, 8 February 2021, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/chinese-solar-group-blasts-us-calls-to-avoid-supplies-from-xinjiang-62496859. Groups in United States and Europe from, for example, SolarPower Europe, "Abiding by Human Rights Standards" (Brussels: 2021), https://www.solarpowereurope.org/wp-content/uploads/2021/04/Statement-on-Human-Rights.pdf; SEIA, "Solar industry call to action: Forced labor has no place in the solar supply chain", 10 December 2020, https://www.seia.org/news/solar-industry-call-action-forced-labor-has-no-place-solar-supply-chain; K. Misbrener, "SEIA asks solar companies to sign pledge against forced labor in supply chain", Solar Power World, 10 December 2020, https://www.solarpowerworldonline.com/2020/12/seia-asks-solar-companies-sign-pledge-against-forced-labor-in-supply-chain; SEIA, "Ensuring an Ethical & Sustainable Solar Supply Chain" (Washington, DC: November 2020), https://www.seia.org/sites/default/files/SEIA-Backgrounder-Supply-Chain-Ethics-Sustainability.pdf. Australia and Japan from P. Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 13.

220 SEIA, "Solar industry call to action", op. cit. note 219. As of early 2021, 175 companies involved in the industry in the United States, including leading Chinese solar manufacturers, had signed a pledge demanding increased transparency efforts, from D. Murtaugh, "Solar firms eye supply tracing as China forced labor debated", Bloomberg, 4 February 2021, https://www.bloomberg.com/news/articles/2021-02-04/solar-firms-eye-supply-tracing-as-china-forced-labor-in-focus.

221 SolarPower Europe, op. cit. note 219.

222 Masson, op. cit. note 1, 9 March 2021.

223 Prices for large-quantity buyers from P. Mints, SPV March Research, *The Solar Flare*, 26 February 2021, p. 11, and from P. Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 15. Another source estimates that module prices were USD 0.2 per watt at the end of 2020, from A. McCrone, "Energy, transport, sustainability – 10 predictions for 2021", Bloomberg, 19 January 2021, https://about.bnef.com/blog/energy-transport-sustainability-10-predictions-for-2021. According to the IEA, module prices rose from July 2020 to April 2021 due to rising commodity prices (such as glass and polysilicon) and supply chain complications. The accidents in polysilicon plans in Xinjiang almost halved China's output, pushing prices up 60% in September, from IEA, "Renewable electricity", op. cit. note 1.

224 Polysilicon prices rose due to shortages in China, pushing up wafer and cell prices, from Mints, op. cit. note 223, p. 9; solar glass prices were up more than 20% by late 2020; higher glass and polysilicon prices could not be passed along to consumers by module manufacturers, from idem, p. 11.

225 Figure considers fixed-axis utility-scale systems, from BloombergNEF, "Scale-up of solar and wind puts existing coal, gas at risk", 28 April 2020, https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk. Regarding variations in energy costs, see, for example: IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit.note 1, pp. 59-60; I. Kaizuka, IEA PVPS, "Photovoltaic Market and Industry Trends 2020" webinar, 4 February 2021; Barbose and Darghouth, op. cit. note 177. For example, US solar PV system costs declined in all sectors from 2019 to the end of 2020, thanks to declining module prices, from M. Cox, "Key 2020 US solar PV cost trends and a look ahead", Greentech Media, 17 December 2020, https://www.greentechmedia.com/articles/read/key-2020-us-solar-pv-cost-trends-and-a-look-ahead. See also SEIA and Wood Mackenzie, op. cit. note 69, p. 17; SEIA, "Solar industry research data", op. cit. note 70. See also NREL, "Documenting a decade of cost declines for PV systems", 10 February 2021, https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html, and D. Feldman et al., *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020* (Golden, CO: NREL, January 2021), p. vi, https://www.nrel.gov/docs/fy21osti/77324.pdf. In Brazil, by contrast, system prices for distributed generation rose 20% due to high logistical costs and devaluation of the Brazilian real, following several years of steady decline, from Greener, cited in E. Bellini, "Brazil's PV module demand reached almost 5 GW in 2020", pv magazine, 10 February 2021, https://www.pv-magazine.com/2021/02/10/brazils-pv-module-demand-reached-almost-5-gw-in-2020. Japan continues to see module prices well above the global average, from IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit.note 1, pp. 57-58. Factors influencing price from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, pp. 21-22.

226 Mints, op. cit. note 61.

227 "PV trends of 2020: Part 2", pv magazine, 25 December 2020, https://www.pv-magazine.com/2020/12/25/pv-trends-of-2020-part-2. Abu Dhabi's lowest bid, at USD 13.5 per MWh, was for a 1.2 GW project with a 30-year PPA that should come online in 2022, and Qatar's lowest was just under USD 15.7 per MWh with a 25-year PPA in an auction for the country's first utility-scale project (800 MW), from idem.

228 Capacity and winning bid in USD from Mints, op. cit. note 61, p. 25. The bid was approximately EUR 11.14 per MWh and for second solar auction, from "PV trends of 2020: Part 2", op. cit. note 227; 10 MW project from "Portugal sets record-low global solar price; California probes power mix after heatwave woes", Reuters Events, 2 September 2020, https://analysis.newenergyupdate.com/solar/portugal-sets-record-low-global-solar-price-california-probes-power-mix-after-heatwave-woes. Power purchase agreement period of 15 years from A. Bhambhani, "700 MW solar power auction finally launched in Portugal; DGEG to accept bids till July 31, 2020 for projects in Alentejo & Algarve regions", TaiyangNews, 10 June 2020, http://taiyangnews.info/markets/portugal-launches-countrys-second-solar-auction. Storage requirement and compensation from "PV trends of 2020: Part 2", op. cit. note 227. The auction was for a total of 700 MW

under three different remuneration modalities that are linked to the market regime and included a new remuneration modality for solar PV plus storage, from Portuguese Renewable Energy Association, Lisbon, personal communication with REN21, May 2021.

229 Mints, op. cit. note 83, p. 18; U. Gupta, "Solar industry in 2020", pv magazine, 28 December 2020,https://www.pv-magazine-india.com/2020/12/28/solar-industry-in-2020.

230 IEA, op. cit. note 210; "India's stunning solar bid rides on 12 boosters", Bloomberg, 26 November 2020, https://www.bloomberg.com/professional/blog/indias-stunning-solar-bid-rides-on-12-boosters; U. Gupta, "India sets new record-low solar tariff of Rs2.36/kWh", pv magazine, 1 July 2020, https://www.pv-magazine-india.com/2020/07/01/india-sets-new-record-low-solar-tariff-of-rs-2-36-kwh; U. Gupta, "Clarify basic customs duty on solar modules as Change in Law, NSEFI writes to SECI", pv magazine, 7 February 2020, https://www.pv-magazine-india.com/2020/02/07/clarify-basic-customs-duty-on-solar-modules-as-change-in-law-nsefi-writes-to-seci; A. Gupta, "Record low tariff bidding for new solar projects, due to chance coming together of many positives", EQ International, 4 July 2020, https://www.eqmagpro.com/record-low-tariff-bidding-for-new-solar-projects-due-to-chance-coming-together-of-many-positives. Support policies included the waiving of development fees and protection from future import duties. India's low bid ceilings have been a major cause of undersubscription in auctions, leading the national government to announce in March the removal of ceilings for future auctions, from IEA, op. cit. note 210.

231 Firstgreen, "Tariff renegotiations of Solar PPAs. Can we really bring foreign investments with this level of regulatory uncertainty?" 20 August 2020, https://www.firstgreen.co/tariff-renegotiations-of-solar-ppas-can-we-really-bring-foreign-investments-with-this-level-of-regulatory-uncertainty; Ranjan, op. cit. note 60. The Indian states of Andhra Pradesh, Gujarat, Uttar Pradesh and Telangana all have attempted to renegotiate prices, Jharkhand renegotiated prices with developers of 1,200 MW of solar projects, and several other states attempted to do the same, from idem. Such attempts have discouraged investors due to regulatory uncertainty and concerns that contracts will not be honored.

232 N. Pombo-van Zyl, "Eskom keen to renegotiate PPA contracts with IPPs", ESI Africa, 22 May 2020, https://www.esi-africa.com/industry-sectors/generation/eskom-keen-to-renegotiate-ppa-contracts-with-ipps; T. Creamer, "Controversial plan to renegotiate IPP tariffs is proceeding, De Ruyter confirms", Engineering News, 21 May 2020, https://www.engineeringnews.co.za/article/controversial-plan-to-renegotiate-of-ipp-tariffs-is-proceeding-de-ruyter-confirms-2020-05-21/rep_id:4136.

233 M. Hall, "Saudi Arabia commissioned no solar projects last year", pv magazine, 11 January 2021, https://www.pv-magazine.com/2021/01/11/saudi-arabia-commissioned-no-solar-projects-last-year. Saudi Arabia increased its renewable energy target for 2023 from 9.5 GW to 27.3 GW, with solar providing most of this, up from 5.9 GW to 20 GW, from Global Data, cited in idem.

234 Masson, op. cit. note 1, 9 March 2021; Y. Rack, "Developers risk 'eating their own margin' in solar's race to the bottom", S&P Global, 1 October 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/developers-risk-eating-their-own-margin-in-solar-s-race-to-the-bottom-60543744.

235 Masson, op. cit. note 1, 9 March 2021; J. Deign, "Key to those record-low solar bids? Rosy merchant income assumptions", Greentech Media, 9 August 2019, https://www.greentechmedia.com/articles/read/merchant-income-is-key-in-latest-record-solar-bids.

236 Masson, op. cit. note 1, 9 March 2021.

237 Rose in 2020 after falling continuously from T. Sylvia, "Average PPA prices rose in US market in 2020", pv magazine, 14 January 2021, https://www.pv-magazine.com/2021/01/14/average-ppa-prices-rose-in-us-market-in-2020. Average fourth quarter prices were up 11.5% (to USD 30.56 per MWh) relative to the same period in 2019, from idem. Reasons for increase from E. Holbrook, "New report shows power purchase agreement prices rising across North America", Environment + Energy Leader, 21 October 2020, https://www.environmentalleader.com/2020/10/new-report-shows-power-purchase-agreement-prices-rising-across-north-america; E. Holbrook, "Report: North American PPA prices rose throughout 2020", Environment + Energy Leader, 20 January 2021, https://www.environmentalleader.com/2021/01/report-north-american-ppa-prices-rose-throughout-2020; T. Sylvia, "Solar PPA prices in the US rise for the second consecutive quarter — after 18 months of decline", pv magazine, 16 October 2020, https://pv-magazine-usa.com/2020/10/16/after-18-months-of-decline-solar-ppa-prices-rise-for-the-second-consecutive-quarter.

238 I. Gheorghiu, "El Paso Electric sees record low solar prices as it secures New Mexico project approvals", Utility Dive, 18 May 2020, https://www.utilitydive.com/news/el-paso-electric-sees-record-low-solar-prices-as-it-secures-new-mexico-proj/578113. The projects and prices are a 100 MW solar PV plant with PPA price of USD 15 per MWh, and a 100 MW solar PV plus 50 MW storage facility of USD 21 per MWh, from idem. Four solar-plus-storage plants to replace a large coal-fired power plant, from T. Sylvia, "Solar-plus-storage replaces coal plant in New Mexico, makes carbon-capture retrofit moot", pv magazine, 12 October 2020, https://pv-magazine-usa.com/2020/10/12/solar-plus-storage-replaces-coal-plant-in-new-mexico-makes-carbon-capture-retrofit-moot.

239 Pexapark cited in S. Enkhardt, "Rollercoaster for the European PPA market in 2020", pv magazine, 21 January 2021, https://www.pv-magazine.com/2021/01/21/rollercoaster-for-the-european-ppa-market-in-2020.

240 Prices in Germany averaged EUR 41.61 per MWh, from Ibid.; Denmark and Sweden from H. Edwardes-Evans, "PPA prices dip in Q4 2020 as developers absorb COVID impacts: LevelTen", S&P Global, 13 January 2021, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/011321-ppa-prices-dip-in-q4-2020-as-developers-absorb-covid-impacts-levelten; Holbrook, "New report shows power purchase agreement prices rising across North America", op. cit. note 237.

241 Down in first half from Mints, op. cit. note 83, pp. 7, 14; up 7% for entire year from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 13. Capacity increased from 123.5 GWpeak to 131.7 GWpeak, from idem.

242 Mints, Photovoltaic Manufacturer Capacity, op. cit. note 1, pp. 17, 22. In 2020, China alone accounted for 67% of global cell production capacity, 59% of module assembly capacity and 67% of global shipments, from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 16. China is the top global supplier of polysilicon (58%), silicon wafers (93%), cells (75%) and modules (73%), from Jianhua, op. cit. note 199. The United States was the leader in global solar PV shipments until 1996, and had a 1% share in 2020, from Mints, op. cit. note 223, pp. 16-17.

243 Based on data from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, pp. 43, 105. Total shipments were 131.7 GWp, with shipment shares as follows: LONGi (11%), Tongwei (9%), JA Solar (8%), Aiko Solar (8%), Trina Solar (7%), Jinko Solar (7%), Canadian Solar (Canada/China – 6%), Zhongli (6%), Suntech (5%) First Solar (4%), and all others 29% (including Hanwha Q-Cells (Republic of Korea), at 4%), based on shipments from in-house production of crystalline and thin-film cells shipped to first buyer, from idem.

244 Thin films accounted for about 5% of global shipments in 2020, down from 14% in 2011, from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, pp. 19, 70. First Solar accounted for 4% of total shipments, or about 80% of thin film shipments, based on data from idem, p. 17.

245 Based on information and sources throughout this text. Much of the expansion outside of China was by Chinese-based companies building new facilities or expanding in other countries, especially in Asia. For example, Suntech (China) began operations at an integrated cell (500 MW) and module (500 MW) manufacturing facility in Indonesia in September with plans to expand capacity to 1 GW by year's end, from H. Shukla, "Daily news wrap-up: Suntech's 1 GW integrated solar cell and module facility opens", Mercom India, 18 September 2020, https://mercomindia.com/daily-news-wrap-up-suntech-facility.

246 J. Zarco, "Production begins at 500 MW Mexican solar panel fab", pv magazine, 25 November 2020, https://www.pv-magazine.com/2020/11/25/production-begins-at-500-mw-mexican-solar-panel-fab; J. C. Machorro, "México busca la autosuficiencia en insumos para la industria solar", Periodismo y Ambiente, 4 December 2020, http://www.periodismoyambiente.com.mx/2020/12/04/mexico-busca-la-autosuficiencia-en-insumos-para-la-industria-solar (using Google Translate). Stantec Turkey, *Market Report for Turkey's Photovoltaic Panel Manufacturing*, November 2020, cited in S. Inal, K. Goytan and A. Ozden "Turkish PV manufacturer report reveals country's annual

production capacity is 5,610 MW/year", pv magazine, 19 January 2021, https://www.pv-magazine.com/2021/01/19/turkish-pv-manufacturer-report-reveals-countrys-annual-production-capacity-is-5610-mw-year. The Kalyon plant increased Turkey's annual manufacturing capacity to 5.6 GW, with all but two manufacturers being domestic companies; Turkey exports about one fourth of its production, mostly to Europe and the Middle East, all from idem.

247 Crystalline and thin-film cell capacity increased from 153.1 GWp in 2019 to 203.7 GWp in 2020, and module assembly capacity increased from 185 GWp in 2019 to 248.6 GWp, from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, pp. 13, 15. Commercial cell production capacity, including thin film and crystalline cells, increased from 153 GW in 2019 to nearly 191 GW in 2020, and module assembly capacity increased to about 230 GW in 2020, all from Mints, op. cit. note 223, pp. 6-7; module assembly capacity in 2019 was 185 GW, from Mints, *The Solar Flare*, no. 4, op. cit. note 15, pp. 15, 25, 29.

248 Based on data from Mints, op. cit. note 223, p. 6. China accounted for about 67% of global shipments in 2020, followed by Malaysia (10%) and Vietnam (9%), from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 31.

249 See, for example, I. Kaizuka, IEA PVPS, "Photovoltaic Market and Industry Trends 2020" webinar, 4 February 2021. Other examples from "Solar module manufacturers ZNShine and Trina to expand production capacity", Mercom India, 14 August 2020, https://mercomindia.com/solar-module-manufacturers-znshine-trina; "Trina Solar expands 15 GW new module capacity", CleanTechnica, 30 September 2020, https://cleantechnica.com/2020/09/30/trina-solar-expands-15-gw-new-module-capacity; M. Osborne, "Tongwei investing US$2.86 billion in new 30GW solar cell manufacturing hub in China", PV-Tech, 11 February 2020, https://www.pv-tech.org/news/tongwei-investing-us2.86-billion-in-new-30gw-solar-cell-manufacturing-hub-i; D. Ayemba, "World's largest solar modules production plant to be constructed in China", Construction News, 8 April 2020, https://constructionreviewonline.com/2020/04/worlds-largest-solar-modules-production-plant-to-be-constructed-in-china; "China solar giants get bigger as glut ignites battle for share", op. cit. note 199; Z. Shahan, "JinkoSolar begins construction on 20 gigawatt solar cell factory", CleanTechnica, 23 January 2021, https://cleantechnica.com/2021/01/23/jinkosolar-begins-construction-on-20-gigawatt-solar-cell-factory; J. Parnell, "5 would-be European giga-scale solar manufacturers", Greentech Media, 14 October 2020, https://www.greentechmedia.com/articles/read/5-would-be-giga-scale-solar-manufacturers; J. Zarco, "Production begins at 500 MW Mexican solar panel fab", pv magazine, 25 November 2020, https://www.pv-magazine.com/2020/11/25/production-begins-at-500-mw-mexican-solar-panel-fab.

250 In addition to sources in previous endnote, see Trinasolar, "Trina Solar to expand ultra-high-power module production capacity by 15 GW with latest 3 billion Yuan investment", 23 September 2020, https://www.trinasolar.com/en-apac/resources/newsroom/aptrina-solar-expand-ultra-high-power-module-production-capacity-15gw-latest-3; "The solar-powered future is being assembled in China", Bloomberg, 14 September 2020, https://www.bloomberg.com/features/2020-china-solar-giant-longi.

251 Tongwei from P. Mints, SPV Market Research, *The Solar Flare*, 28 February 2020, p. 23, and from M. Osborne, "Tongwei investing US$2.86 billion in new 30GW solar cell manufacturing hub in China", PV-Tech, 11 February 2020, https://www.pv-tech.org/news/tongwei-investing-us2.86-billion-in-new-30gw-solar-cell-manufacturing-hub-i. Tongwei also announced plans to expand polysilicon production capacity more than three-fold by 2023; Tongwei's goal is to increase polysilicon production capacity from 80 billion tonnes to 290 billion tonnes by 2023, from idem. In addition, GCL-System Integration was considering increasing its modules manufacturing capacity (7.2 GW as of May) by building a new 60 GW per year factory, from "China's solar giants slash prices as virus curbs demand", op. cit. note 199, from EurObserv'ER, op. cit. note 30, p. 14, and from D. Ayemba, "World's largest solar modules production plant to be constructed in China", Construction News, 8 April 2020, https://constructionreviewonline.com/2020/04/worlds-largest-solar-modules-production-plant-to-be-constructed-in-china.

252 Masson, op. cit. note 1, 4 May 2020, and examples and sources in this paragraph.

253 Ecosolifer AG from E. Bellini, "A commercial bifacial HJT solar cell with 24.1% efficiency", pv magazine, 3 March 2020, https://www.pv-magazine.com/2020/03/03/a-commercial-bifacial-hjt-solar-cell-with-24-1-efficiency; Hevel Group, "Hevel Group launches HJT solar cell production based on M2+ wafers", pv magazine, 14 April 2020, https://www.pv-magazine.com/press-releases/hevel-group-launches-hjt-solar-cell-production-based-on-m2-wafers; Meyer Burger shift to HJT, from Mints, op. cit. note 204, p. 22; M. Osborne, "Meyer Burger to start exclusive heterojunction solar module manufacturing in the first half of 2021", PV-Tech, 19 June 2020, https://www.pv-tech.org/meyer-burger-to-start-exclusive-heterojunction-solar-module-manufacturing-i; S. Hanley, "Meyer Burger plans 10 gigawatts of floating solar for North Rhine-Westphalia", CleanTechnica, 4 May 2020, https://cleantechnica.com/2020/05/04/meyer-burger-plans-10-gigawatts-of-floating-solar-for-north-rhine-westpahlia; plans to scale up by 2026 from Parnell, op. cit. note 249. The company also announced (early 2021) plans to enter the US market to start selling cells in H2 2021, from H. Shukla, "Meyer Burger reports a net loss of CHF 64.47 million in 2020", 15 March 2021, https://mercomindia.com/meyer-burger-reports-net-loss-2020. In addition, 3Sun (owned by utility Enel, Italy), had plans to expand a Sicilian cell and module facility that opened in 2019, from Parnell, op. cit. note 249, and panel manufacturer REC (US) was planning to build a new factory in France to make modules compliant with the country's low-carbon rules for large-scale plants, from J. Spaes, "REC identifies location for 4 GW solar module factory in France", 18 November 2020, https://www.pv-magazine.com/2020/11/18/rec-identifies-location-for-4-gw-solar-module-factory-in-france.

254 P. Sanchez Molina, "Another solar module factory in North Africa", pv magazine, 24 July 2020, https://www.pv-magazine.com/2020/07/24/another-solar-module-factory-in-north-africa.

255 Mints, op. cit. note 61, p. 11. By one estimate, about 180 Chinese manufacturers exited the industry or went bankrupt over the previous four years, from Y. Jiang, BloombergNEF, cited in "The solar-powered future is being assembled in China", op. cit. note 250. Consolidation also continued in China's polysilicon industry, from Chen, op. cit. note 202.

256 Jiang, cited in "The solar-powered future is being assembled in China", op. cit. note 250.

257 Borrowing and rising prices from Ibid.; Yingli entered restructuring in June 2020 after falling into bankruptcy, from Mints, op. cit. note 204, p. 25; brought under government control and renamed from Mints, op. cit. note 83, pp. 6, 33.

258 Ended partnership from Willson, op. cit. note 208, and from F. Lambert, "Tesla and Panasonic end solar deal at Gigafactory New York ahead of battery event", Electrek, 26 February 2020, https://electrek.co/2020/02/26/tesla-panasonic-end-solar-deal-gigafactory-new-york-battery. Panasonic stopped manufacturing modules in the United States to streamline global operations, from idem (both sources). Panasonic entered the solar sector in 2008 by purchasing pieces of Sanyo Solar, and completed acquisition in 2010, from Mints, op. cit. note 223, p. 30; pandemic and pricing from idem, p. 31; end all production from idem, p. 29.

259 N. Huang and A. Hwang, "Invetec subsidiary ends solar cell production", DigiTimes, 19 August 2020, https://www.digitimes.com/news/a20200819PD208.html; Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, pp. 8, 33.

260 SunPower, "Company history", https://us.sunpower.com/company/history, viewed 12 April 2021; SunPower, "SunPower and Maxeon Solar Technologies close spin-off transaction", 27 August 2020, https://newsroom.sunpower.com/2020-08-27-SunPower-and-Maxeon-Solar-Technologies-Close-Spin-Off-Transaction; SunPower, "SunPower Corporation to close manufacturing facility in Hillsboro, Oregon", 7 January 2021, https://newsroom.sunpower.com/2021-01-07-SunPower-Corporation-to-Close-Manufacturing-Facility-in-Hillsboro-Oregon; SunPower, "SunPower expands SunPower Residential Installation (SPRI) across six states", 26 January 2021, https://newsroom.sunpower.com/2021-01-26-SunPower-Expands-SunPower-Residential-Installation-SPRI-Across-Six-States.

261 Mints, op. cit. note 61, p. 28; "New US clean energy jobs plummet; First Solar sells O&M division to NovaSource", Reuters Events, 19 August 2020, https://analysis.newenergyupdate.com/solar/new-us-clean-energy-jobs-plummet-first-solar-sells-om-division-novasource; E. F. Merchant, "First Solar sells off majority of development pipeline", Greentech Media, 25 January 2021, https://www.greentechmedia.com/articles/read/first-solar-sells-off-majority-of-development-pipeline.

262 Vivint Solar, "Sunrun announces definitive agreement to acquire Vivint Solar for an enterprise value of $3.2 billion", 7 June 2020, https://www.vivintsolar.com/newsroom/press-releases/sunrun-difinitive-agree-ment-to-aquire-vivint-solar; I. Penn, "Solar deal would create a new industry giant", *New York Times*, 6 July 2020, https://www.nytimes.com/2020/07/06/business/energy-environment/sunrun-vivint-solar.html; P. Eavis and I. Penn, "Home solar is growing, but big installers are still losing money", *New York Times*, 4 January 2021, https://www.nytimes.com/2021/01/04/business/energy-environment/rooftop-solar-installers.html; largest consolidation from R. Ranjan, "In the largest rooftop solar acquisition, Sunrun to acquire Vivint Solar for $3.2 billion", Mercom India, 7 July 2020, https://mercomindia.com/sunrun-acquire-vivint-solar.

263 J. St. John, "Hanwha Q Cells to buy storage software startup Geli to tackle C&I market", Greentech Media, 6 August 2020, https://www.greentechmedia.com/articles/read/hanwha-q-cells-buys-geli-to-tap-into-north-american-ci-solar-storage-market; Geli, "Geli to be acquired by Q Cells, expanding Q Cells' offerings in Integrated Energy Storage Solutions", 6 August 2020, https://geli.net/2020/08/geli_to_be_acquired_by_q_cells.

264 See sources throughout this paragraph. See also Wind Power section in this chapter.

265 J. Deign, "The solar industry's new power player: Oil majors", Greentech Media, 26 February 2020, https://www.greentechmedia.com/articles/read/the-solar-industrys-new-power-player-oil-majors; Total, "Spain: Total to enter into the solar market with a pipeline of 2 GW of projects", 11 February 2020, https://www.total.com/media/news/press-releases/spain-total-enter-solar-market-pipeline-2-gw-projects; "Midwest leads drop in US solar prices; European fund buys into giant Canadian merchant project", Reuters Events, 12 February 2020, https://www.reutersevents.com/renewables/pv-insider/midwest-leads-drop-us-solar-prices-european-fund-buys-giant-canadian-merchant-project. Companies include BP (UK), Eni (Italy), Equinor (Norway), Galp Energia (Portugal), Repsol (Spain), Shell (Netherlands) and Total (France).

266 J. Parnell, "BP links with JinkoPower to bring clean energy to China's companies", Greentech Media, 6 July 2020, https://www.greentechmedia.com/articles/read/bp-and-jinko-buddy-up-on-ci-solar-in-china; P. Sanchez Molina, "Hydrogen production coupled to solar and storage to debut in Spain", pv magazine, 2 March 2020, https://www.pv-magazine.com/2020/03/02/hydrogen-production-coupled-to-solar-and-storage-to-debut-in-spain.

267 The company has been working on perovskite cells for several years; in 2020 its cells exceeded several International Electrotechnical Commission durability thresholds, from Hunt, "Hunt achieves key milestone in perovskite technology development", 12 February 2020, https://huntperovskite.com/wp-content/uploads/2020/08/20200212-Hunt-Perovskite-Technologies-Press-Release-Final.pdf; "Hunt Perovskite Technologies reports 18% efficiency with its ink-based solar cell process", Perovskite Info, 13 February 2020, https://www.perovskite-info.com/hunt-perovskite-technologies-reports-18-efficiency-its-ink-based-solar-cell. See also C. Helman, "Why a famed Texas oil family is hunting for cheap solar power from 'Perovskites'", *Forbes*, 25 February 2020, https://www.forbes.com/sites/christopherhelman/2020/02/25/why-a-famed-texas-oil-family-is-hunting-for-cheap-solar-power-from-perovskites; T. Casey, "Super secret perovskite solar cell company bursts out of stealth mode", CleanTechnica, 29 February 2020, https://cleantechnica.com/2020/02/29/super-secret-perovskite-solar-cell-company-bursts-out-of-stealth-mode; PR Newswire, "Hunt Energy announces Scott Burton as new CEO of Hunt Perovskite Technologies", 19 August 2020, https://www.prnewswire.com/news-releases/hunt-energy-announces-scott-burton-as-new-ceo-of-hunt-perovskite-technologies-301114937.html; patents from Hunt, "Hunt Perovskite Technologies adds another key patent in perovskite durability via Ink Chemistry", 2 November 2020, https://huntperovskite.com/wp-content/uploads/2020/11/Hunt-Perovskite-Technologies-Press-Release.pdf.

268 Pyper, op. cit. note 204; R. Ranjan, "Coal India to set up integrated solar wafer manufacturing facility", Mercom India, 29 December 2020, https://mercomindia.com/coal-india-to-set-up.

269 Solar cells and modules, value chain from Schmela, op. cit. note 1, 12 May 2020. See also information and related sources throughout this section.

270 See, for example, "JinkoSolar claims world record for bifacial solar module efficiency", Power Engineering International, 21 January 2020, https://www.powerengineeringint.com/2020/01/21/jinkosolar-claims-world-record-for-bifacial-solar-module-efficiency; E. Bellini, "Solar modules from Sharp with half-cut technology exceed 19.5% efficiency", pv magazine, 14 January 2020, https://pv-magazine-usa.com/2020/01/14/solar-modules-from-sharp-with-half-cut-technology-exceed-19-5-efficiency; R. Ranjan, "Panasonic claims highest conversion efficiency of 16.09% for perovskite solar panel", Mercom India, 14 February 2020, https://mercomindia.com/panasonic-claims-conversion-efficiency-perovskite-solar-panel; S. Enkhardt, "German scientists develop solar facade with 50% higher yield", pv magazine, 3 March 2020, https://www.pv-magazine.com/2020/03/03/german-scientists-develop-solar-facade-with-50-higher-yield; C. June, "Urban solar energy: Solar panels for windows hit record 8% efficiency", Michigan Engineer News Center, 17 August 2020, https://news.engin.umich.edu/2020/08/urban-solar-energy-solar-panels-for-windows-hit-record-8-efficiency; R. Ranjan, "Canadian Solar says it has achieved a record solar cell efficiency of 23.81%", Mercom India, 19 March 2020, https://mercomindia.com/canadian-solar-achieved-solar-cell-efficiency; Sonnenseite, "World record: Efficiency of perovskite silicon tandem solar cell jumps to 29.15 per cent", 24 February 2020, https://www.sonnenseite.com/en/science/world-record-efficiency-of-perovskite-silicon-tandem-solar-cell-jumps-to-29.15-per-cent.html; R. Ranjan, "New perovskite CIGS tandem cell achieves record efficiency of 24.16%", Mercom India, 29 April 2020, https://mercomindia.com/new-perovskite-cigs-tandem-cell-efficiency; H. Shukla, "Weekly news wrap-up: Jinko's solar cell efficiency at 24.79%, Sungrow launches new ESS", Mercom India, 14 August 2020, https://mercomindia.com/news-wrap-up-jinko-solar; Renewable Energy Magazine, "Oxford PV hits new world record for solar cell", 21 December 2020, https://www.renewableenergymagazine.com/pv_solar/oxford-pv-hits-new-world-record-for-20201221; M. Hutchins, "The state of the art in perovskite tandems", pv magazine, 7 January 2021, https://www.pv-magazine.com/2021/01/07/the-state-of-the-art-in-perovskite-tandems.

271 Lost and regained lead from Mints, *The Solar Flare*, no. 6 (23 December 2019), pp. 6, 12; S. Dutta, "Global module suppliers Trina and Canadian Solar announce world record efficiencies", Mercom India, 31 May 2019, https://mercomindia.com/trina-and-canadian-solar-record-efficiencies; J. Chase et al., "On prices, technology and 2019 trends", pv magazine, 6 September 2019, https://www.pv-magazine-australia.com/2019/09/06/on-prices-technology-and-2019-trends. Share of global shipments from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 15; expansions were monocrystalline, from SolarPower Europe, *Global Market Outlook for Solar Power 2019-2023*, op. cit. note 7, p. 49; SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 55; P. Mints, SPV Market Research, *The Solar Flare*, 31 October 2020, p. 19. For information on mono- v. multi-/poly-crystalline technologies, see, for example, Evergreen Solar, "January 2020 best type of solar panels", https://evergreensolar.com/types, viewed 20 March 2020; Gold Coast Solar Power Solutions, "Mono crystalline or poly/multi crystalline solar panels – does it matter?" https://gold-coast-solar-power-solutions.com.au/posts/mono-crystalline-or-poly-multi-crystalline-solar-panels-does-it-matter, viewed 20 March 2020; "Monocrystalline and polycrystalline solar panels: What you need to know", Energy Sage, 12 December 2019, https://www.energysage.com/solar/101/monocrystalline-vs-polycrystalline-solar-panels.

272 "The solar-powered future is being assembled in China", op. cit. note 250; SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 55; Mints, op. cit. note 271, p. 19.

273 See sources below. The main reason for enlarging wafers has been to continue with PERC for as long as possible because this is less costly than investing in new cell production equipment for new cell technology, from Schmela, op. cit. note 1, 26 May 2021.

274 Increasing size to optimise costs from "PV trends of 2020: Part 3", pv magazine, 28 December 2020, https://www.pv-magazine.com/2020/12/28/pv-trends-of-2020-part-3, and from M. Hutchins, "The weekend read: Big, and then bigger", pv magazine, 12 December 2020, https://www.pv-magazine.com/2020/12/12/the-weekend-read-big-and-then-bigger. Increase power from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 55. See also M.

Hutchins, "The weekend read: Big, and then bigger", pv magazine, 12 December 2020, https://www.pv-magazine.com/2020/12/12/the-weekend-read-big-and-then-bigger.

275 By 2020 increasing sizes, from "PV trends of 2020: Part 3", op. cit. note 274; SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 55. For many years the traditional wafer size was 156 millimetres, or M0, which was overtaken by 156.75 (M2) in 2017; M2 was already being displaced in 2020, and many manufacturers were shifting from M6 (166 millimetres, mm), first introduced in 2019, to M10 (182 mm) and M12 (210 mm), from idem, both sources. Most major module manufacturers from "PV trends of 2020: Part 3", op. cit. note 274. The size changes require that the downstream sectors also adjust to different physical and electrical characteristics of the new modules, from idem.

276 Left behind from R. Ranjan, "Changing wafer sizes will cost cell and solar module manufacturers", Mercom India, 20 January 2021, https://mercomindia.com/changing-wafer-sizes-cost-module-manufacturers. Indian manufacturers, for example, were still transitioning to the M6 wafer size in 2020, from idem. Increased costs from R. Ranjan, "Technological upgrades imperative for India's solar manufacturing to take-off", op. cit. note 209, and from T. Sylvia, "Manufacturers call for module size standardization", pv magazine, 5 January 2021, https://www.pv-magazine.com/2021/01/05/manufacturers-call-for-module-size-standardization.

277 Sylvia, op. cit. note 276.

278 Steer a shift from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 57; cell shipments from P. Mints, SPV Market Research, *The Solar Flare*, April 2021, p. 12. Monocrystalline PERC provides increase in efficiency (by 0.5-1 percentage points) with little increase in the cost of production and has become the new standard cell, from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 57. PERC cells produce 6-12% more energy than conventional solar panels, from Sunpower, "What is PERC solar cell technology?" https://us.sunpower.com/solar-resources/what-perc-solar-cell-technology, viewed 17 March 2021.

279 PERC from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 57. Shifting from idem, pp. 57-58; Schmela, op. cit. note 1, 26 May 2021; J. P. de Villiers, Soventix South Africa, cited in "Surprising trends influencing solar PV technology", ESI Africa, 25 November 2020,https://www.esi-africa.com/industry-sectors/renewable-energy/surprising-trends-influencing-solar-pv-technology; Mints, op. cit. note 278, p. 12; IEA PVPS, *Trends in Photovoltaic Applications 2020*, op. cit. note 1, pp. 7, 42-43. Most cell capacity added in 2020 and early 2021 was basically PERC-based, from Schmela, op. cit. note 1, 26 May 2021. However, manufacturers are shifting to n-Type production capacity, especially HJT (as noted), TOPCon and n-PERC, from Mints, op. cit. note 278. For information on n-type cell technologies, see K. Pickerel, "The different between n-type and p-type solar cells", Solar Power World, 2 July 2018, https://www.solarpowerworldonline.com/2018/07/the-difference-between-n-type-and-p-type-solar-cells.

280 TOPCon from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 57. PERC production lines can be upgraded to TOPCon (passivated contact cells), which many consider to be the next generation of solar cell after PERC, from K. S. Chan, "What is a TOPCON solar cell?" KSChan, 21 November 2019, https://www.kschan.com/what-is-a-topcon-solar-cell. HJT from SolarPower Europe, *Global Market Outlook for Solar Power 2019-2023*, op. cit. note 7, p. 49; converting factories from, for example, S. Chunduri, "Heterojunction solar technology 2019 report. TaiyangNews' first report on heterojunction technology (HJT) explores if this promising high-efficiency silicon cell species is the next big thing in solar cell/module manufacturing", TaiyangNews, 20 March 2019, http://taiyangnews.info/reports/heterojunction-solar-technology-2019-report; Recom Solar, "Heterojunction technology: The solar cell of the future", https://recom-solar.com/innovation, viewed 29 April 2019; low temperatures and fewer steps from G. Roters et al., *Heterojunction Technology: The Solar Cell of the Future* (Gwatt, Switzerland: Meyer Burger, undated), https://www.meyerburger.com/user_upload/dashboard_news_bundle/da4c7a0b7c33e8e21ccddace78c76513b12cc727.pdf. See also "Risen Energy introduces 3 new high-power modules with 440W, 450W & 500W based on different technologies, incl. HJT, M12", TaiyangNews, 13 December 2019, http://taiyangnews.info/technology/risen-energy-announces-500-w-hjt-modules, and K. Pickerel, "What are heterojunction technology (HJT) solar panels?" Solar Power World, 4 November 2019, https://www.solarpowerworldonline.com/2019/11/what-are-heterojunction-technology-hjt-solar-panels. In 2020, a number of China-based companies were actively looking into HJT, and some brought additional production lines into operation from for example, "EnergyTrend survey on solar PV prices across supply chain In China; Jinnergy goes M6, CSI setting up 250 MW HJT line", TaiyangNews, 9 July 2020, http://taiyangnews.info/markets/china-pv-snippets-price-update-hjt-news; Jinergy, "Jinergy HJT cell efficiency to reach 24.2% by the end of 2020", 28 October 2020, https://en.prnasia.com/releases/apac/jinergy-hjt-cell-efficiency-to-reach-24-2-by-the-end-of-2020-296427.shtml; "China's GS-Solar claims 25.2% as 'highest efficiency' for mass produced heterojunction solar cells, certified by Germany's TÜV Nord", TaiyangNews , 19 February 2021, http://taiyangnews.info/technology/25-2-efficiency-for-gs-solar-hjt-solar-cell. China had almost 10 GW of HJT cell capacity in construction by late 2020, from Jinergy, op. cit. this note. See also J. Gifford, "Long read: Time is now for HJT", pv magazine, 19 September 2020, https://www.pv-magazine-australia.com/2020/09/19/long-read-time-is-now-for-hjt, and Pickerel, op. cit. this note.

281 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 57. At the current pace of development, with improvements of 0.5 to 0.6% annually, cell technologies will soon reach their practical efficiency limits, from idem.

282 Research dollars and increasing efficiencies, from, for example, US DOE, Office of Energy Efficiency & Renewable Energy (EERE), "Solar Energy Technologies Office Fiscal Year 2020 Perovskite Funding Program",https://www.energy.gov/eere/solar/solar-energy-technologies-office-fiscal-year-2020-perovskite-funding-program, viewed 28 April 2021; E. Wesoff, "VC funding in solar 2020: Perovskites, silicon and utility-scale foundations, plus lots of software", pv magazine, 16 December 2020, https://pv-magazine-usa.com/2020/12/16/vc-funding-in-solar-2020-perovskites-silicon-and-utility-scale-foundations-plus-lots-of-software; European Perovskite Initiative, *Perovskite-based Photovoltaics: A Unique Chance for European PV-Industry* (Warsaw: September 2019), p. 3, https://www.zsw-bw.de/uploads/media/EPKI_Perovskite_White_Paper_2019-09_01.pdf; T. Metcalfe, "Solar panels are reaching their limit. These crystals could change that." NBC News, 19 April 2021, https://www.nbcnews.com/science/environment/solar-panels-are-reaching-limit-crystals-change-rcna545.Reports of about 3% efficiency in 2006 to more than 25% in 2020, from US DOE, EERE, "Perovskite solar cells", https://www.energy.gov/eere/solar/perovskite-solar-cells, viewed 17 March 2021, and from European Perovskite Initiative, "Perovskite solar cells: A new paradigm in photovoltaics", PV-Tech, 17 October 2019, https://www.pv-tech.org/corporate-updates/perovskite-solar-cells-a-new-paradigm-in-photovoltaics; efficiency of 29.52% was achieved in a silicon-based tandem in 2020, M. Hutchins, "Oxford PV retakes tandem cell efficiency record", pv magazine, 21 December 2020, https://www.pv-magazine.com/2020/12/21/oxford-pv-retakes-tandem-cell-efficiency-record. Closer to commercialisation from "PV trends of 2020: Part 4", pv magazine, 29 December 2020, https://www.pv-magazine.com/2020/12/29/pv-trends-of-2020-part-4.

283 The efficiency record was certified by NREL, from Hutchins, op. cit. note 282; ramp up and launch from idem and from M. Gallucci, "Perovskite Solar out-benches rivals in 2021", IEEE Spectrum, 1 January 2021, https://spectrum.ieee.org/tech-talk/energy/renewables/oxford-pv-sets-new-record-for-perovskite-solar-cells. The company pushed back its launch of commercial production from 2021 to 2022 due to the pandemic and various delays.

284 A. Lydon, "Forget silicon. This material could be a game-changer for solar power", CNN, 14 October 2020, https://www.cnn.com/2020/10/14/energy/solar-energy-perovskites-spc-intl/index.html.

285 Research under way from, for example, US DOE, EERE, "Perovskite solar cells", op. cit. note 282; Y. Cholteeva, "Record-breaking solar perovskites", Power Technology, 6 May 2020, https://www.power-technology.com/features/record-breaking-solar-perovskites; "Perovskite solar cells made with peppermint oil and walnut aroma food additives, preventing lead leakage", *Science Daily*, 26 February 2020, https://www.sciencedaily.com/releases/2020/02/200226102144.htm; I. Fadelli, "Inverted perovskite solar cells with a power conversion efficiency of 22.3%", TechXplore, 20 February 2020, https://techxplore.com/

news/2020-02-inverted-perovskite-solar-cells-power.html; R. Sanders, "Blue diode illustrates limitations, promise of perovskite semiconductors", Berkeley News, 24 January 2020, https://news.berkeley.edu/2020/01/24/blue-diode-illustrates-limitations-promise-of-perovskite-semiconductors; NREL, "Researchers improve safety of lead-based perovskite solar cells", press release (Golden, CO: 19 February 2020), https://www.nrel.gov/news/press/2020/researchers-improve-safety-lead-based-perovskite-solar-cells.html; Sonnenseite, "Plants absorb lead from perovskite solar cells more than expected", 22 February 2020, https://www.sonnenseite.com/en/science/plants-absorb-lead-from-perovskite-solar-cells-more-than-expected.html; "Game-changer in future solar technology: New perovskite solar modules with greater size, power and stability", SciTech Daily, 27 January 2021, https://scitechdaily.com/game-changer-in-future-solar-technology-new-perovskite-solar-modules-with-greater-size-power-and-stability. Other companies working on perovskite technology include Energy Materials (US), Hunt Perovskite Technologies (US) and Microquanta Semiconductor (China), from Cholteeva, op. cit. this note; Evolar (Sweden) from L. Stoker, "Solar perovskite start-up Evolar bags new investment to target rapid commercialization", PV-Tech, 17 November 2020, https://www.pv-tech.org/solar-perovskite-start-up-evolar-bags-new-investment-to-target-rapid-commercialisation.

286 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 59, and sources provided throughout this paragraph.

287 Ibid., p. 59, and Schmela, op. cit. note 1, 26 May 2021. The industry average for all modules produced, as of October 2020, was 400 W, from Mints, op. cit. note 271, p. 19, and the average module wattage for all of 2020 was 435 W, from Mints, *Photovoltaic Manufacturer Capacity*, op. cit. note 1, p. 13. For example, in May, JinkoSolar launched what was then the most powerful panel (530 W) for utility-scale solar, from Jinko Solar, "JinkoSolar launches the world's most powerful utility solar panel", ESI Africa, 20 May 2020, https://www.esi-africa.com/industry-sectors/generation/solar/jinkosolar-launches-the-worlds-most-powerful-utility-solar-panel. It was passed by Trina Solar later in the year with a 600 W module and upgraded panels ranging from 635-660 W, from V. Shaw, "Trina reveals 600 W module", pv magazine, 20 July 2020, https://www.pv-magazine.com/2020/07/20/trina-reveals-600-w-module; E. Bellini, "New 635-660 W module series from Trina", pv magazine, 19 August 2020, https://www.pv-magazine.com/2020/08/19/new-635-660-w-module-series-from-trina. Trina also launched two 500 W PERC mono bifacial modules in early 2020, from E. Bellini, "Trina unveils two 500 W bifacial solar modules", pv magazine, 27 February 2020, https://www.pv-magazine.com/2020/02/27/trina-unveils-two-500-w-bifacial-solar-modules. JinkoSolar also announced its first panel specifically for residential rooftops, a 405 W n-type panel, from "Jinko enters the residential solar game with a bang", pv magazine, 12 March 2020, https://pv-magazine-usa.com/2020/03/12/jinko-enters-the-residential-solar-game-with-a-bang.

288 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 59; M. Hutchins, "The weekend read: Big, and then bigger", pv magazine, 12 December 2020, https://www.pv-magazine.com/2020/12/12/the-weekend-read-big-and-then-bigger; E. Bellini, "Jinko launches PV module with record output of 580 W", pv magazine, 18 May 2020, https://pv-magazine-usa.com/2020/05/18/jinko-launches-pv-module-with-record-output-of-580-w. It also means one more decision for project developers, from Hutchins, op. cit. this note.

289 L. Botti, "How to make the most of the bifacial solar module opportunity", Renewable Energy World, 10 March 2021, https://www.renewableenergyworld.com/blog/how-to-make-the-most-of-the-bifacial-solar-module-opportunity; gains in output also from SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 58; J. Crescenti, "Discussing bifacial project economics", pv magazine, 19 February 2020, https://www.pv-magazine.com/2020/02/19/discussing-bifacial-project-economics; potential for lower LCOE from P. Mints, SVP Market Research, *Photovoltaic Manufacturer Shipments: Capacity, Price & Revenues 2019/2020* (San Francisco: April 2020), p. 57.

290 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 58. Another source put the increase in energy yield from single-axis tracker bifacial systems as much as 35%, while also reducing the levelised cost of energy by 16% compared with conventional monofacial systems, from SERIS, cited in "Global PV costs fall 13% in 2019; Bifacial offers higher returns at over 93% of sites", Reuters Events, 10 June 2020, https://newenergyupdate.com/pv-insider/global-pv-costs-fall-13-2019-bifacial-offers-higher-returns-over-93-sites; an NREL study in 2019 revealed production gains of up to 9%, from NREL, "Bifacial solar advances with the times—and the sun", viewed 13 April 2021, https://www.nrel.gov/news/features/2020/bifacial-solar-advances-with-the-times-and-the-sun.html. A SolarPro study found bifacial yield increases of up to 11% for fixed-tilt systems and 27% for tracker systems compared with similarly rated traditional panels, from Botti, op. cit. note 289.

291 SolarPower Europe, *Global Market Outlook for Solar Power 2020-2024*, op. cit. note 9, p. 58. For some large projects using bifacial, see "Bifacial PV developer doubles gains using simple ground layer", Reuters Events, 5 May 2021, https://analysis.newenergyupdate.com/pv-insider/bifacial-pv-developer-doubles-gains-using-simple-ground-layer; "Giant bifacial PV plants act as springboard for growth", Reuters Events, 10 June 2020, https://newenergyupdate.com/pv-insider/giant-bifacial-pv-plants-act-springboard-growth. Bifacial modules have increased equipment and installation costs, from N. Lusson, "Bifacial modules: The challenges and advantages", pv magazine, 19 August 2020, https://www.pv-magazine.com/2020/08/19/bifacial-modules-the-challenges-and-advantages; and they require inverters that can respond to higher rates of current, from Botti, op. cit. note 289.

292 IEA, "Renewable electricity", op. cit. note 1; Schmela, op. cit. note 1, 26 May 2021.

293 Masson, op. cit. note 1, 9 March 2021. For example, solar PV's share of global polysilicon demand increased from 26% in 2000 to 84% in 2010, from IEA, "Share of PV in polysilicon demand (left) and polysilicon price (right), 1975-2010", 1 July 2020, https://www.iea.org/data-and-statistics/charts/share-of-pv-in-polysilicon-demand-left-and-polysilicon-price-right-1975-2010. Demand for polysilicon used in solar PV production has only risen since 2010.

294 Minerals and metals from K. Hund et al., *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition* (Washington, DC: World Bank, 2020), pp. 40-41, http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf.

295 More than doubled based on 1,546 tonnes used for solar PV production in 2010, from The Silver Institute, *World Silver Survey 2011* (Washington, DC: 2011), p. 62, https://www.silverinstitute.org/wp-content/uploads/2017/10/2011WorldSilverSurvey.pdf, and on 3,142 tons of silver used in 2020, from The Silver Institute, *World Silver Survey 2021* (Washington, DC: 2021), p. 48, https://www.silverinstitute.org/wp-content/uploads/2021/04/World-Silver-Survey-2021.pdf. Solar PV share of global silver demand based on above and on total global consumption of 27,333 tons in 2010, from The Silver Institute, World Silver Survey 2011, op. cit. this note, p. 10, and global consumption of 27,872 tons in 2020, from The Silver Institute, World Silver Survey 2021, op. cit. this note, p. 9. Figure of 80% from idem, p. 48. As of 2019, researchers found a close correlation between rising production of solar panels and an increase on the world price of silver, from University of Kent, "Solar panel demand causing spike in worldwide silver prices", Science Daily, 17 April 2019, https://www.sciencedaily.com/releases/2019/04/190417102750.htm. For more on silver demand and solar PV, see E. Bellini, "Silver prices expected to rise by 11% this year", pv magazine, 12 February 2021, https://www.pv-magazine.com/2021/02/12/silver-prices-expected-to-rise-by-11-this-year.

296 A solar PV system's useful lifetime is 25 to 40 years, from NREL, "Energy Analysis – Useful life", https://www.nrel.gov/analysis/tech-footprint.html, viewed 16 March 2021. Note that module manufacturers generally offer warranties of 25-30 years, from "Solar operators shun low-cost risks to extend lifespans", Reuters Events, 24 June 2020, https://newenergyupdate.com/pv-insider/solar-operators-shun-low-cost-risks-extend-lifespans, and from J. Gerdes, "US solar plants now expected to run for more than 30 years: Berkeley Lab", Greentech Media, 29 June 2020, https://www.greentechmedia.com/articles/read/solar-plants-expected-to-operate-30-years. Many solar plant operators count on lifespans over 35 years thanks to improvements in manufacturing processes; this longer assumed lifetime also helps in terms of assumptions about the LCOE of projects, from "Solar operators shun low-cost risks to extend lifespans", op. cit. this note; Gerdes, op. cit. this note.

297 Large volume of decommissioned panels from, for example, Md. S. Chowdhury et al., "An overview of solar photovoltaic panels' end-of-life material recycling", *Energy Strategy Reviews*, vol. 27 (January 2020), https://www.sciencedirect.com/science/article/pii/S2211467X19301245. US repowering, from E. Wesoff and B. Beetz, "Solar panel recycling in the US — a looming issue that could harm industry growth and reputation", pv magazine, 3 December 2020, https://pv-magazine-usa.com/2020/12/03/solar-panel-recycling-in-the-us-a-looming-issue-that-could-harm-growth-and-reputation. NREL estimates a cumulative 80 million tonnes by 2050, from G.A. Heath et al., "Research and development priorities for silicon photovoltaic module recycling to support a circular economy", *Nature Energy*, vol. 5 (July 2020), p. 502, https://www.nature.com/articles/s41560-020-0645-2.epdf.

298 A. M. Schmid, "Think before trashing: The second-hand solar market is booming", Solar Power World, 11 January 2021, https://www.solarpowerworldonline.com/2021/01/think-before-trashing-the-second-hand-solar-market-is-booming; Saur News Bureau, "Recycling, the coming challenge for solar panels", Saur Energy International, 1 September 2020, https://www.saurenergy.com/solar-energy-news/recycling-the-coming-challenge-for-solar-panels. See also "Longer solar lifespans test analytics, repowering gains", Reuters Events, 9 July 2020, https://www.reutersevents.com/renewables/pv-insider/longer-solar-lifespans-test-analytics-repowering-gains.

299 Second-hand panels from Schmid, op. cit. note 298. Major markets include Afghanistan, Djibouti, Ethiopia and Somalia, from idem. See also J. Deign, "Landfilling old solar panels likely safe for humans, new research suggests", Greentech Media, 2 April 2020, https://www.greentechmedia.com/articles/read/solar-panel-landfill-deemed-safe-as-recycling-options-grow. Most panels from the following: in the United States, for example, an estimated 90% of decommissioned panels were going to landfill as of 2018, from Recycle PV Solar, cited in idem, and nearly all were going to landfill as of end-2020, from Wesoff and Beetz, op. cit. note 297. Recycling facilities from S. K. Johnson, "Solar panel recycling has a long way to go, and silicon may be the key", Ars Technica, 15 July 2020, https://arstechnica.com/science/2020/07/solar-panel-recycling-has-a-long-way-to-go-and-silicon-may-be-the-key; Deign, op. cit. this note. Standard recycling facilities, which can extract the glass and aluminum, for example, do not recover valuable or environmentally harmful components, from Heath et al., op. cit. note 297. Regarding damaged or faulty, in Sub-Saharan Africa panels are frequently damaged during transit and installation or by extreme weather and mishandling; also, some panels becoming obsolete because of pace of technology advancement, from Greencape, "Solar Panel Waste Workshop at the Century City Conference Centre", Cape Town, 5 March 2019, https://www.greencape.co.za/assets/Solar-Panel-Waste-Workshop-Report-5Mar2020.pdf.

300 PV CYCLE (Belgium) estimates that 94.7% of a solar panel is recyclable, from Saur News Bureau, op. cit. note 298; do not cover the costs from Wesoff and Beetz, op. cit. note 297; M. Stone, "Solar panels are starting to die. What will we do with the megatons of toxic trash?" Grist, 13 August 2020, https://grist.org/energy/solar-panels-are-starting-to-die-what-will-we-do-with-the-megatons-of-toxic-trash.

301 J. Clyncke, PV CYCLE aisbl, Brussels, personal communication with REN21, 30 April and 3 May 2021. Note that markets for recycled materials (e.g., silver, glass, silicon) operate on the scale of tonnes for activities and pricing, which requires a large volume of solar panels, from idem.

302 Ibid.

303 Only Europe from G. Cañadas, "The state of PV recycling: building a solar circular economy", Rated Power, 15 March 2021, https://ratedpower.com/blog/pv-recycling; only the EU and Washington State have laws that mandate panel recycling, from Johnson, op. cit. note 299; New York state as of 2020 from D. Mulvaney and M. D. Bazilian, "The downside of solar energy", *Scientific American*, 1 December 2019, https://blogs.scientificamerican.com/observations/the-downside-of-solar-energy. In the EU, under the WEEE (Waste Electrical and Electronic Equipment) directive of 2012, installers are accountable for electronic waste (including solar panels and inverters) and producers must recycle; in Japan, project developers and owners are responsible for their own panel disposal and must pay into a decommissioning fund; and Washington state has a stewardship and takeback programme requiring every panel supplier to provide a plan for recycling by 2022, all from Wesoff and Beetz, op. cit. note 297.

304 Operators of all solar power generation facilities in Japan with an output of 10 kW or more installed under the FIT system, including existing facilities, will be required to set aside the equivalent of 5% of the total cost of the facilities as disposal costs to an external institution for 10 years after 2022, from Matsubara, op. cit. note 53. In Australia, Victoria, South Australia and the Australian Capital Territory had bans on electronic waste going to landfill, from J. Milbank, "Recycling solar", Renew, 19 November 2019, https://renew.org.au/renew-magazine/sustainable-tech/recycling-solar; Queensland also had an e-waste ban that includes solar PV panels, from Gunaratna, op. cit. note 149, 12 April 2021; in South Africa, electronic waste is banned from landfills as of August 2021 as part of a drive to develop alternatives, from Greencape, op. cit. note 299. Other countries – including India, Japan and the Republic of Korea – were developing requirements as of mid-2020, from Heath et al., op. cit. note 297. For India, see also U. Gupta, "Managing solar PV waste in India", pv magazine, 1 April 2021, https://www.pv-magazine.com/2021/04/01/managing-solar-pv-waste-in-india. For Washington state, see also SEIA, "Washington State passes bill that will improve solar recycling program", 10 March 2020, https://www.seia.org/news/washington-state-passes-bill-will-improve-solar-recycling-program. In the United States, California, New York and Washington have programmes to incentivise and regulate recycling, from A. Hobson, American Council of Renewable Energy, cited in Deign, op. cit. note 299; New Jersey and North Carolina passed laws in 2020 that require the study of end-of-life options, California has universal waste regulations, Hawaii had legislation pending in mid-2020 that would require a study of issues related to module recycling, and Rhode Island had legislation pending that would ensure reuse or recycling, all from NREL, "What it takes to realize a circular economy for solar photovoltaic system materials", 2 April 2021, https://www.nrel.gov/news/program/2021/what-it-takes-to-realize-a-circular-economy-for-solar-photovoltaic-system-materials.html.

305 Clyncke, op. cit. note 301. The treatment line is the result of an R&D project called PV MOREDE (2013-2016), which aims to deliver a Mobile Recycling Device. The line has an initial capacity of 1,800 tonnes per year, with an option to increase to 4,000 tonnes per year, and with a reported recovery rate of 95%, from idem. As of August 2020, the Veolia (France) facility was reportedly the only commercial-scale recycling facility for silicon panels; it launched solar PV recycling operations in 2018 and recovers 95% of materials, from Veolia, "Veolia opens the first European plant entirely dedicated to recycling photovoltaic panels", 5 July 2018, https://www.veolia.com/en/newsroom/news/recycling-photovoltaic-panels-circular-economy-france, viewed 18 March 2021; Waste360, "Veolia opens solar recycling plant in France", 26 June 2018, https://www.waste360.com/solar/veolia-opens-solar-recycling-plant-france. See also S. K. Johnson, "Solar panel recycling has a long way to go, and silicon may be the key", Ars Technica, 15 July 2020, https://arstechnica.com/science/2020/07/solar-panel-recycling-has-a-long-way-to-go-and-silicon-may-be-the-key; T. Sylvia, "NREL looks to tackle PV waste before it's too late", pv magazine, 20 July 2020, https://pv-magazine-usa.com/2020/07/20/nrel-looks-to-tackle-pv-waste-before-its-too-late. The number of facilities in Europe is limited, as is public information about economics and efficacy of recycling, from idem; Heath et al., op. cit. note 297.

306 Clyncke, op. cit. note 301.

307 Japan from Heath et al., op. cit. note 297, and from Clyncke, op. cit. note 301. Several organisations in Japan accept solar PV modules, but only one specialises in recycling modules and the process is limited, from idem. India from U. Gupta, "Establishing a solar module recycling system in India", pv magazine, 31 December 2020, https://www.pv-magazine.com/2020/12/31/establishing-a-solar-module-recycling-system-in-india. United States from Sylvia, op. cit. note 305. The SEIA is leading an industry-wide recycling initiative with five partners; by end-2020 there were 12 recycling locations across the country and three more were pending, from Wesoff and Beetz, op. cit. note 297. First Solar has long had a recycling programme that recovers up to 90% of its modules, from Deign, op. cit. note 299; First Solar, "First Solar recycling recovers up to 90% of materials", viewed 12 April 2021, https://www.firstsolar.com/en/Modules/Recycling.

308 Reclaim PV from N. Filatoff, "Australia's first large-scale PV recycling operation amps up 'waste' collection", pv magazine, 8 February 2021, https://www.pv-magazine.com/2021/02/08/australias-first-large-scale-pv-recycling-operation-amps-up-waste-collection; other companies in Australia – including Solar

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Recovery Corporation, PV Industries and Lotus Energy – are working on recycling and product stewardship, from Gunaratna, op. cit. note 149, 12 April 2021.

309 Saur News Bureau, op. cit. note 298.

310 E. Bellini, "South Korea introduces carbon footprint rules for solar modules", pv magazine, 29 May 2020, https://www.pv-magazine.com/2020/05/29/south-korea-introduces-carbon-footprint-rules-for-solar-modules; E. Bellini, "Playing by the carbon footprint rules", pv magazine, 2 April 2019, https://www.pv-magazine.com/magazine-archive/playing-by-the-carbon-footprint-rules.

311 K. Pickerel, "Influential solar panel players launch alliance to promote their low-carbon products", Solar Power World, 8 October 2020, https://www.solarpowerworldonline.com/2020/10/influential-solar-panel-players-launch-alliance-to-promote-their-low-carbon-products; Ultra Low-Carbon Solar Alliance, "Not all solar panels are created equal", https://ultralowcarbonsolar.org, viewed 26 April 2021. One of its members, First Solar, committed in 2020 to transition its US facilities to carbon-free electricity by 2026 and to power global manufacturing operations with renewable energy by 2028, from First Solar, "First Solar commits to powering 100% of global operations with renewable energy by 2028", press release (Tempe: 6 August 2020), https://investor.firstsolar.com/news/press-release-details/2020/First-Solar-Commits-to-Powering-100-of-Global-Operations-with-Renewable-Energy-by-2028/default.aspx.

CONCENTRATING SOLAR THERMAL POWER (CSP)

1 Data are compiled from the following sources: US National Renewable Energy Laboratory (NREL), "Concentrating solar power projects", https://solarpaces.nrel.gov, with the page and its subpages viewed on numerous dates leading up to 13 April 2021 (some subpages are referenced individually throughout this section) and references cited in the CSP section of Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2020 Global Status Report* (Paris: 2020), pp. 120-123, https://www.ren21.net/reports/global-status-report. In some cases, information from the above sources was verified against additional country-specific sources, as cited in the rest of the endnotes for this section. Global CSP data are based on commercial facilities only; demonstration and pilot facilities as well as facilities of 5 MW or less are excluded from capacity data, with the exception of certain plants in China that are described as "demonstration" plants by government but are nonetheless large- (utility-) scale, grid-connected plants that are operating or will operate commercially. Data discrepancies between REN21 and other reference sources are due primarily to differences in categorisation and thresholds for inclusion of specific CSP facilities in overall global totals.

2 Ibid. **Figure 29** from idem.

3 J. Fialka, "Futuristic solar plants plagued by glitches, poor training", Scientific American, 17 June 2020, https://www.scientificamerican.com/article/futuristic-solar-plants-plagued-by-glitches-poor-training; J. Lilliestam et al., "The near- to mid-term outlook for concentrating solar power: Mostly cloudy, chance of sun", *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 16, no. 1 (2021), pp. 23-41, https://www.tandfonline.com/doi/full/10.1080/15567249.2020.1773580.

4 See sources in endnote 1.

5 Ibid.

6 Ibid.

7 Ibid.

8 Ibid.

9 Ibid.

10 NREL, "Concentrating Solar Power Projects: Urat Royal Tech 100 MW", https://solarpaces.nrel.gov/urat-royal-tech-100mw-thermal-oil-parabolic-trough-project, updated 22 January 2020.

11 Ibid.

12 HelioCSP, "Three concentrated sola power projects of 335 MW rescued in China", 10 March 2020, http://helioscsp.com/three-concentrated-solar-power-projects-of-335-mw-rescued-in-china; China Solar Thermal Alliance, "Updated progress of Chinese 20 CSP demonstration projects", 3 April 2020, http://en.cnste.org/html/csp/2017/0727/282.html.

13 See sources in endnote 1.

14 P. Lague, "Dubai commissions world's tallest solar power tower", ESI Africa, 15 June 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/dubai-commissions-worlds-tallest-solar-power-tower.

15 NREL, "Concentrating Solar Power Projects in United Arab Emirates", https://solarpaces.nrel.gov/by-country/AE, page and its sub-pages viewed on various dates up to 31 March 2021.

16 NREL, "Concentrating Solar Power Projects: ISCC Duba 1", https://solarpaces.nrel.gov/iscc-duba-1, updated 31 January 2017.

17 See sources in endnote 1.

18 Ibid.

19 Ibid.

20 S. Djunisic, "Chile's Cerro Dominador CSP project lands new PPA", Renewables Now, 26 August 2020, https://renewablesnow.com/news/chiles-cerro-dominador-csp-project-lands-new-ppa-711312; reve, "The Cerro Dominador concentrated solar power plant, the first in Chile and Latin America, installs its solar receiver", 25 May 2020, https://www.evwind.es/2020/05/25/the-cerro-dominador-concentrated-solar-power-plant-the-first-in-chile-and-latin-america-installs-its-solar-receiver-at-a-height-of-220-meters/74854; S. Djunisic, "Chile's Cerro Dominador CSP project completes salt melting process", Renewables Now, 16 April 2020, https://renewablesnow.com/news/chiles-cerro-dominador-csp-project-completes-salt-melting-process-695284.

21 J. M. Takouleu, "ZAMBIA: Sinohydro to carry out work on Kalulushi CSP solar power plant", Afrik21, 16 July 2020, https://www.afrik21.africa/en/zambia-sinohydro-to-carry-out-work-on-kalulushi-csp-solar-power-plant.

22 "Botswana to build 200MW of CSP; Cubico buys 100 MW of CSP in Spain", Reuters Events, 13 January 2021, https://www.reutersevents.com/renewables/solar-thermal/botswana-build-200-mw-csp-cubico-buys-100-mw-csp-spain.

23 See sources in endnote 1.

24 Ibid.

25 CSP Focus, "The good solar thermal numbers in 2019 reinforce the importance of this technology", 2 March 2020, http://www.cspfocus.cn/en/market/detail_2702.htm; Agencia Estatal Boletin Oficial del Estado, "Orden TED/1161/2020, de 4 de diciembre, por la que se regula el primer mecanismo de subasta para el otorgamiento del régimen económico de energías renovables y se establece el calendario indicativo para el periodo 2020-2025", 5 December 2020, https://www.boe.es/diario_boe/txt.php?id=BOE-A-2020-15689; C. Farand, "Spain unveils climate law to cut emissions to net zero by 2050", Climate Home News, 18 May 2020, https://www.climatechangenews.com/2020/05/18/spain-unveils-climate-law-cut-emissions-net-zero-2050.

26 K. Chamberlain, "Abengoa to install first retrofit CSP storage pilot", *Reuters*, 10 June 2020, https://www.reutersevents.com/renewables/solar-thermal/abengoa-install-first-retrofit-csp-storage-pilot.

27 See sources in endnote 1.

28 Ibid. **Figure 30** from idem.

29 NREL, "Concentrating Solar Power Projects: Ashalim Plot B (Megalim)", https://solarpaces.nrel.gov/ashalim-plot-b, updated 12 April 2019.

30 See sources in endnote 1. See also Systems Integration chapter in this report.

31 See sources in endnote 1.

32 Ibid.

33 Ibid.

34 Ibid.

35 Ibid.

36 Ibid.

37 International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2020* (Abu Dhabi, 2021).

38 Ibid.

39 Cerro Dominador Concentrated Solar Power, "Projects", https://cerrodominador.com/en/projects, viewed 12 March 2021.

40 S. Kraemer, "Morocco pioneers PV with thermal storage at 800MW Midelt CSP project", SolarPACES, 25 April 2020, https://www.solarpaces.org/morocco-pioneers-pv-to-thermal-storage-at-800-mw-midelt-csp-project.

41 M. Rycroft, "CSP-PV hybrid power systems: An attractive future option", EE Publishers, 27 May 2019, https://www.ee.co.za/article/csp-pv-hybrid-power-systems-an-attractive-future-option.html; "Hybrid CSP-PV offers lowest cost for Chile; US DOE reopens loan program", *Reuters*, 11 March 2021, https://www.reutersevents.com/renewables/solar-thermal/hybrid-csp-pv-offers-lowest-cost-chile-us-doe-reopens-loan-program; B. Bedeshci, "Hybrid concentrated solar power - PV gains", Heliocsp, 15 August 2018, https://helioscsp.com/hybrid-concentrated-solar-power-pv-gains.

42 K. Chamberlain, "Abengoa to install first retrofit CSP storage pilot", *Reuters*, 10 June 2020, https://www.reutersevents.com/renewables/solar-thermal/abengoa-install-first-retrofit-csp-storage-pilot.

43 European Commission (EC), "Competitive solar power towers – CAPTure", https://cordis.europa.eu/project/id/640905, updated 27 August 2020; European Commission, "Modular high concentration Solar Configuration", updated 19 August 2020, https://cordis.europa.eu/project/id/727402; EC, "High temperature concentrated solar thermal power plan with particle receiver and direct thermal storage", https://cordis.europa.eu/project/id/727762, updated 1 September 2020.

44 Energy.gov, "Energy Department announces $130 million in solar technology projects", 12 November 2020, https://www.energy.gov/articles/energy-department-announces-130-million-solar-technology-projects; Energy.gov, "Concentrating solar power", https://www.energy.gov/sco2-power-cycles-renewable-energy-applications/concentrating-solar-power, viewed 12 March 2020.

SOLAR THERMAL HEATING

1 Revised gross additions for 2019 included in this GSR (26.1 GW_{th}) are significantly lower than those published in GSR 2020 (31.3 GW_{th}) for two reasons: First, the Chinese Solar Thermal Industry Federation (CSTIF) adjusted downwards its number for China's new additions in 2019, from 22.75 GW_{th} (a preliminary figure, available as of early 2020) to 20 GW_{th}. Second, data for new additions in China are based on produced collector area, rather than on annual installations in China; as a result, export volumes have been included in China's national statistics for 2020 and earlier years. In past editions of the GSR, this has resulted in a double counting of some collector area because the majority of coated vacuum tubes installed worldwide are purchased from China. The one exception is Turkey, which imposed a high import tax on Chinese vacuum tubes in July 2011, resulting in high national vacuum tube production capacities that supply most of national demand. To correct the newly added solar thermal capacity in China, newly added vacuum tube collector capacities in large solar thermal markets outside of China and Turkey were subtracted from the produced collector volume in China for 2019 and 2020. The result has been a further reduction to the number for China's additions during 2019 (relative to data in GSR 2020). Because China dominated global gross additions in 2019 and 2020, downwards adjustments to China's additions also had a downwards effect on the data published for annual global sales (see endnote 5), from M. Spörk-Dür, AEE – Institute for Sustainable Technologies (AEE INTEC), Austria, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), April 2020.

2 Increasing demand from residential customers during the pandemic was reported for India, Brazil and Turkey, from B. Epp, solrico, Bielefeld, Germany, personal communication with REN21, April 2021.

3 Changes to support policies increased demand significantly in Germany and the Netherlands in 2020, whereas the expiration of support policies in India, Poland and the United States resulted in strong declines in solar thermal capacity additions during the year, from Ibid.

4 Solarthermalworld.org reported on solar thermal sales activities in at least 134 countries worldwide during 2008-2020, from Ibid.

5 **Figure 31** based on the following sources: Global solar thermal capacity is based on the latest market data from the largest 20 solar thermal markets in terms of added capacity listed in order of their additions: China, Turkey, India, Brazil, United States, Germany, Australia, Mexico, Israel, Greece, Spain, Poland, South Africa, Italy, Netherlands, Cyprus, Austria, Morocco, Tunisia and Portugal, which represented 95% of cumulative installed capacity in operation in 2019. Added capacities in other countries for which new additions are available until 2019 (but not yet for 2020) were projected according to national trends over the 2018-2019 period. The rest of the world – meaning those countries without detailed solar thermal market information in 2019 and previous years – accounted for an estimated 5% of the global market volume excluding China in 2019 and 2020. Until 2018, the rest of the world was considered to be 5% of the global market including China, which overestimated its market share, from Spörk-Dür, op. cit. note 1; W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2019, Detailed Market Figures 2018* (Gleisdorf, Austria: International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC), 2020), http://www.iea-shc.org/solar-heatworldwide.

6 Spörk-Dür, op. cit. note 1. Equivalence of 407 terawatt-hours (TWh) and 239 million barrels of oil equivalent from Kyle's Converter, http://www.kylesconverter.com.

7 T. Ramschak, AEE INTEC, Austria, personal communication with REN21, April 2021; Weiss and Spörk-Dür, op. cit. note 5.

8 Epp, op. cit. note 2. Year-end total installations of concentrating collector technologies (linear Fresnel, parabolic trough and dish) were reported by aperture area and converted into solar thermal capacity using the internationally accepted convention for stationary collectors, 1 million m^2 = 0.7 GW_{th}.

9 The total installed capacity of air collectors declined to 1 GW_{th} at the end of 2020 (1.1 GW_{th} at the end of 2019) due to 0.05 GW_{th} of air collector technology that went out of operation in 2020 after a lifetime of 20 years, from Spörk-Dür, op. cit. note 1.

10 **Figure 32** based on the latest market data available for gross additions of glazed and unglazed water collectors (not including concentrating collectors), at the time of publication, for countries that together represent 96% of the world total. Data from original country sources include gross national additions and were provided to REN21 as follows: D. Ferrari, Sustainability Victoria, Melbourne, Australia; W. Weiss, AEE INTEC, Vienna, Austria; D. Johann, Brazilian Solar Thermal Energy Association (ABRASOL), São Paulo, Brazil; H. Cheng, Shandong SunVision Management Consulting, Dezhou, China (5% were subtracted from the Chinese additions reported by Cheng, because the figures included vacuum tube collectors that were manufactured in China and exported to other countries). The 5% subtracted represents the average share of China's produced vacuum tube collector area that was exported to other key markets in the years 2015 to 2019 (for countries where final new additions were available); P. Kastanias, Cyprus Union of Solar Thermal Industrialists (EBHEK), Nicosia, Cyprus; A. Liesen, BSW Solar, Berlin, Germany; C. Travasaros, Greek Solar Industry Association (EBHE), Piraeus, Greece; J. Malaviya, Solar Thermal Federation of India (STFI), Pune, India; E. Shilton, Elsol, Kohar-yair, Israel; F. Musazzi, ANIMA, the Federation of Italian Associations in the Mechanical and Engineering Industries, Milan, Italy; N. Jaeger, Holland Solar, Utrecht, Netherlands (preliminary estimation for the Netherlands, share of flat plate and vacuum tubes were applied as in 2019 – latest data available); T. Kousksou, University of Pau and the Pays de l'Adour, Pau, France (for Morocco; share of vacuum tube and flat plate collectors was not available); D. Garcia, Solar Thermal Manufacturers Organisation (FAMERAC), Mexico City, Mexico; P. Dias, Solar Heat Europe, Brussels, Belgium (for Portugal); J. Staroscik, Association of Manufacturers and Importers of Heating Appliances (SPIUG), Warsaw, Poland; K. Kritzinger, Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch, Stellenbosch, South Africa; P. Polo, Spanish Solar Thermal Association (ASIT), Madrid, Spain; A. Baccouche, ANME, Tunis, Tunisia; K. Ülke, Bural Heating, Kayseri, Turkey; B. Heavner, California Solar & Storage Association (CALSSA), Sacramento, California, United States, all personal communications with REN21, February-April 2021.

11 Global additions from Spörk-Dür, op. cit. note 1. For country additions, see endnote 10.

12 Epp, op. cit. note 2.

13 Global additions from Spörk-Dür, op. cit. note 1. For country additions, see endnote 10.

14 B. Epp, "China sees strong growth in demand for solar space heating", Solarthermalworld.org, 9 February 2021, https://www.solarthermalworld.org/news/demand-clean-space-heating-rebounds-germany.

15 Ibid. As per endnote 1 the new additions in 2020 and the decline rates in 2019 and 2020 were calculated by subtracting the exported vacuum tube collector area produced in China as reported from CSTIF in the years 2018, 2019 and 2020. As a preliminary correction for 2020, 5% of the produced volume in China was subtracted for exports, as this corresponds with the average export share for the last five years.

16 Total capacity in operation in China at the end of 2019 was calculated with a system lifetime of 11 years, instead of the 10-year lifetime assumed until 2018. China's total capacity at the end of 2020 was calculated with a system lifetime of 12 years, which increases the total in operation relative to data in previous GSRs, from Spörk-Dür, op. cit. note 1.

17 Epp, op. cit. note 14.

18 Ibid.

19 Ibid.

20 CSTIF, *Chinese Solar Thermal Industry Status Report 2020* (Beijing: 8 December 2020), https://mp.weixin.qq.com/s/3YOksFnzrMyUmrt79HTpGg.

21 Ibid.

22 Ibid.

23 Ibid.

24 K. Ülke, Bural Heating, Kayseri, Turkey, personal communication with REN21, March 2021.

25 Spörk-Dür, op. cit. note 1.

26 Ülke, op. cit. note 24.

27 B. Epp, "Opposing trends in India's solar thermal market 2020", Solarthermalworld.org, 20 April 2021, https://www.solarthermalworld.org/news/opposing-trends-indias-solar-thermal-market-2020.

28 Ibid.

29 Ibid.
30 J. Malaviya, STFI, Pune, India, personal communication with REN21, April 2021.
31 Ibid.
32 Epp, op. cit. note 27.
33 D. Johann, ABRASOL, São Paulo, Brazil, personal communication with REN21, April 2021.
34 Ibid.
35 Ibid.
36 Ibid.
37 Ibid.; B. Heavner, CALSSA, Sacramento, United States, personal communication with REN21, April 2021; D. Ferrari, Sustainability Victoria, Melbourne, Australia, personal communication with REN21, March 2021.
38 Johann, op. cit. note 33.
39 Ibid.
40 Ibid.
41 Ibid.
42 Heavner, op. cit. note 37.
43 Ibid.
44 Ibid.
45 Spörk-Dür, op. cit. note 1.
46 Ferrari, op. cit. note 37.
47 Ibid.
48 Ibid.
49 Ibid.
50 P. Dias, Solar Heat Europe, Brussels, Belgium, personal communication with REN21, March 2021.
51 Ibid.
52 Ibid.
53 Ibid.
54 B. Epp, "Demand for clean space heating rebounds in Germany", Solarthermalworld.org, 9 February 2021, https://www.solarthermalworld.org/news/demand-clean-space-heating-rebounds-germany.
55 The new German support scheme also covers 45% of the costs if a heat pump or a pellet boiler is installed instead of an oil boiler, from B. Epp, "High scrappage bonus for oil boilers", Solarthermalworld.org, 3 March 2020, https://www.solarthermalworld.org/news/high-scrappage-bonus-oil-boilers.
56 Epp, op. cit. note 54.
57 Spörk-Dür, op. cit. note 1.
58 C. Travasaros, EBHE, Piraeus, Greece, personal communication with REN21, February 2021.
59 Ibid.
60 P. Polo, ASIT, Madrid, Spain, personal communication with REN21, March 2021; J. Staroscik, SPIUG, Warsaw, Poland, personal communication with REN21, March 2021.
61 Staroscik, op. cit. note 60.
62 New plant in Tibet from R. Ge, Micoe Corporation, Lianyungang, China, personal communication with solrico, March 2021; solar district heating in Tibet in 2019 from B. Epp, "SDH system with parabolic troughs in Tibet", Solarthermalworld.org, 17 December 2019, https://www.solarthermalworld.org/news/sdh-system-parabolic-troughs-tibet; B. Epp, "Second Arcon-Sunmark SDH system up and running in Tibet", Solarthermalworld.org, 25 November 2019, https://www.solarthermalworld.org/news/second-arcon-sunmark-sdh-system-and-running-tibet; B. Epp, "Saga in Tibet tests solar heating in public buildings", Solarthermalworld.org, 25 March 2020, https://www.solarthermalworld.org/news/saga-tibet-tests-solar-heating-public-buildings.
63 CSTIF, op. cit. note 20.
64 Ibid.
65 P. Geiger, Solites – Steinbeis Forschungsinstitut für solare und zukunftsfähige thermische Energiesysteme, Stuttgart, Germany, personal communication with REN21, March 2021.
66 J. Berner, "Large-scale solar heat is cost-competitive in Germany", Solarthermalworld.org, 13 December 2019, https://www.solarthermalworld.org/news/large-scale-solar-heat-cost-competitive-germany.
67 Geiger, op. cit. note 65.
68 Ibid.
69 "Kommunale Klimaschutz-Modellprojekte", https://www.klimaschutz.de/modellprojekte, viewed 7 May 2021.
70 J. Berner, "Support for 90 Heat Network 4.0 feasibility studies", Solarthermalworld.org, 2 October 2019, https://www.solarthermalworld.org/news/support-90-heat-network-40-feasibility-studies.
71 Berner, op. cit. note 66.
72 B. Epp, "Danish SDH market reaches new milestone", Solarthermalworld.org, 1 September 2019, https://www.solarthermalworld.org/news/danish-sdh-market-reaches-new-milestone.
73 D. Trier, PlanEnergi, Skørping, Denmark, personal communication with REN21 in March 2021.
74 Ibid.
75 Ibid.
76 Ibid.
77 Ibid.
78 B. Epp, "NewHeat secures EUR 13 million loan to finance 5 solar heat plants", Solarthermalworld.org, 14 September 2020, https://www.solarthermalworld.org/news/newheat-secures-eur-13-million-loan-finance-5-solar-heat-plants.
79 H. Defréville, NewHeat, Bordeaux, France, personal communication with solrico in March 2021.
80 G. Wörther, Klima- und Energiefonds, Vienna, Austria, personal communication with REN21, April 2021.
81 Spörk-Dür, op. cit. note 1.
82 R. Hackstock, Austria Solar, Vienna, Austria, personal communication with REN21, April 2021.
83 B. Epp, "Construction of largest Swedish SDH plant with parabolics", Solarthermalworld.org, 23 December 2020, https://www.solarthermalworld.org/news/construction-largest-swedish-sdh-plant-parabolics.
84 B. Epp, "Reducing the level of harmful air pollutants is vital", Solarthermalworld.org, 5 March 2021, https://www.solarthermalworld.org/news/reducing-level-harmful-air-pollutants-vital.
85 F. Stier, "Three SDH plants under development in Croatia", Solarthermalworld.org, 22 October 2020, https://www.solarthermalworld.org/news/three-sdh-plants-under-development-croatia.
86 F. Stier, "Serbia's first big online conference on solar energy draws 2,000 attendees", Solarthermalworld.org, 23 April 2021, https://www.solarthermalworld.org/news/serbias-first-big-online-conference-solar-energy-draws-2000-attendees.
87 Ibid.
88 Ibid.
89 Spörk-Dür, op. cit. note 1.
90 **Figure 33** based on data from Spörk-Dür, op. cit. note 1, and from W. Weiss and M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2020, Detailed Market Figures 2019* (Gleisdorf, Austria: IEA SHC, 2020). http://www.iea-shc.org/solar-heat-worldwide. Year-end total installations of concentrating collector technologies (linear Fresnel, parabolic trough and dish) were reported by aperture area and converted into solar thermal capacity using the internationally accepted convention for stationary collectors, 1 million m^2 = 0.7 GW_{th}.
91 Spörk-Dür, op. cit. note 1.
92 Ibid.
93 International Renewable Energy Agency (IRENA) Coalition for Action, *Companies in Transition Towards 100% Renewables: Focus on Heating and Cooling* (Abu Dhabi: 2021).
94 B. Epp, "China keeps top spot for industrial solar heat", Solarthermalworld.org, 10 May 2021, https://www.solarthermalworld.org/news/china-keeps-top-spot-industrial-solar-heat.
95 Malaviya, op. cit. note 30.
96 B. Epp, "Industrial sector sees record-breaking capacity additions in 2019", Solarthermalworld.org, 26 April 2020, https://www.solarthermalworld.org/news/industrial-sector-sees-record-breaking-capacity-additions-2019.

97 Epp, op. cit. note 94.
98 Ibid.
99 Ibid.
100 M. Oropeza, solrico, Berlin, Germany, personal communication with REN21, April 2021.
101 Epp, op. cit. note 94.
102 Ibid.
103 Ibid.
104 Ibid.
105 Ibid.
106 Ibid.
107 Ibid.
108 Ramschak, op. cit. note 7.
109 Ibid.
110 Ibid.
111 B. Epp, "Hybrid solutions maximise solar yield per area", Solarthermalworld.org, 29 April 2020, https://www.solarthermalworld.org/news/hybrid-solutions-maximise-solar-yield-area.
112 Ramschak, op. cit. note 7.
113 B. Epp, "Mixed performance of world's largest flat plate producers in COVID year 2020", Solarthermalworld.org, 7 April 2021, https://www.solarthermalworld.org/news/mixed-performance-worlds-largest-flat-plate-producers-covid-year-2020.
114 Ibid.
115 Epp, op. cit. note 14.
116 News about ranking of the largest flat plate collector manufacturers yet to be published.
117 Epp, op. cit. note 113.
118 Epp, op. cit. note 14.
119 Epp, op. cit. note 113.
120 B. Epp, "Acquisition of strategic importance", Solarthermalworld.org, 3 April 2020, https://www.solarthermalworld.org/news/acquisition-strategic-importance.
121 Ibid.
122 Ibid.
123 C. Stadler, Viessmann, Allendorf, Germany, personal communication with REN21, March 2021; Epp, op. cit. note 120.
124 B. Epp, "Shareholders force Glasspoint into liquidation", Solarthermalworld.org, 27 May 2020, https://www.solarthermalworld.org/news/shareholders-force-glasspoint-liquidation.
125 Ibid.
126 Ibid.
127 B. Epp, "NewHeat secures EUR 13 million loan to finance 5 solar heat plants", Solarthermalworld.org, 14 September 2020, https://www.solarthermalworld.org/news/newheat-secures-eur-13-million-loan-finance-5-solar-heat-plants.
128 Ibid.
129 B. Epp, "Kyotherm wins 2019 SHC Solar Award", Solarthermalworld.org, 14 November 2019, https://www.solarthermalworld.org/news/kyotherm-wins-2019-shc-solar-award.
130 R. Cuer, Kyotherm, Paris, France, personal communication with REN21, December 2020.
131 J. Byström, Absolicon Solar Collector, Härnösand, Sweden, personal communication with solrico, March 2021.
132 Ibid.
133 Ibid.
134 Dias, op. cit. note 50.
135 Solar Payback, "Suppliers of Turnkey Solar Process Heat Systems", http://www.solar-payback.com/suppliers, viewed 28 February 2021.
136 The aperture area of the parabolic trough collector plant in Handan is planned to be 117,000 m^2, or 83 MW_{th} when using a conversion factor of 0.7 kW/m2, from Y. Wang, Inner Mongolia XuChen Energy, Baotou, Inner Mongolia, China, personal communication with solrico, April 2021; B. Epp, "World´s largest solar district heating plant with concentrating collectors", Solarthermalworld.org, 25 September 2020, https://www.solarthermalworld.org/news/worlds-largest-solar-district-heating-plant-concentrating-collectors.
137 N. Irwin, Solaflux, Reading, Pennsylvania, United States, personal communication with solrico, March 2021.
138 A. Gupta, Skyven Technologies, Fresno, California, United States, personal communication with solrico, March 2021; J. Ruiz Morales, True Solar Power, Madrid, Spain, personal communication with solrico, March 2021; E. Almaraz, Umbral Energia, Monterrey, Nuevo León, Mexico, personal communication with solrico, March 2021.
139 M. Berrada, Alto Solution, Aix-en-Provence, France, personal communication with solrico, March 2021; C. Graf von Moy, Heliovis, Wiener Neudorf, Austria, personal communication with solrico, March 2021.
140 E. Gerden, "Collector factory starts up in Saint Petersburg", Solarthermalworld.org, 11 August 2020, https://www.solarthermalworld.org/news/collector-factory-starts-saint-petersburg; E. Gerden, "Air collectors from Saint Petersburg", Solarthermalworld.org, 17 March 2021, https://www.solarthermalworld.org/news/air-collectors-saint-petersburg.
141 Epp, op. cit. note 94.
142 Survey among SHIP system suppliers listed in Solar Payback, op. cit. note 135, carried out in March/April 2021, from B. Epp, Bielefeld, Germany, personal communication with REN21, March 2021.
143 Ibid.
144 Ibid.
145 Epp, op. cit. note 94.
146 Ibid.
147 Ibid.
148 Survey among SHIP system suppliers, Epp, op. cit. note 142.
149 R. Cuer, Kyotherm, Paris, France, personal communication with REN21, March 2021.
150 Ibid.
151 Survey among SHIP system suppliers, Epp, op. cit. note 142.

BACK

WIND POWER

1 Figure of 93 gigawatts (GW) based on data from Global Wind Energy Council (GWEC), *Global Wind Report 2021* (Brussels: March 2021), p. 53, https://gwec.net/global-wind-report-2021, and from World Wind Energy Association (WWEA), "Worldwide wind capacity reaches 744 gigawatts – an unprecedented 93 gigawatts added in 2020", press release (Bonn: 24 March 2021), https://wwindea.org/worldwide-wind-capacity-reaches-744-gigawatts. Capacity added onshore (a record high) and offshore (second highest ever) from GWEC, op. cit. this note, p. 44. Additions are gross, but year-end totals account for decommissioned capacity. Note that GWEC reports installations with turbines larger than 200 kilowatts (kW); projects with smaller turbines are not included. Global net additions were 111,027 megawatts (MW), based on 733,276 MW at end-2020 and 622,249 MW at end-2019, from International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics* (Abu Dhabi: March 2021), https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021. Of this, 105,015 MW was added onshore and the remainder was offshore, based on data from IRENA, op. cit. this note. Global additions were 96.3 GW in 2020, compared with 60.7 GW in 2019, with 94% of additions onshore and the rest offshore (down 19% to 6.1 GW), from BloombergNEF, "Global wind industry had a record, near 100GW, year as GE, Goldwind took lead from Vestas", 10 March 2021, https://about.bnef.com/blog/global-wind-industry-had-a-record-near-100gw-year-as-ge-goldwind-took-lead-from-vestas. Note that additional capacity was in operation via small-scale turbines. See Box 7 in this section for details on turbines up to 100 kW in size.

2 Figure of 45% based on installations in 2015 of 63.8 GW, from GWEC, op. cit. note 1, p. 51, and 53% increase based on additions of 60,877 MW in 2019, from idem, p. 53.

3 GWEC, *Global Offshore Wind Report 2020* (Brussels: 5 August 2020), p. 24, http://gwec.net/global-offshore-wind-report-2020; WWEA, "World wind power deployment: Some delays in 2020 due to Covid-19, but bright future prospects", 6 November 2020, https://wwindea.org/world-wind-power-deployment-some-delays-in-2020-due-to-covid-19-but-bright-future-prospects; various impacts of pandemic from, for example, GWEC, op. cit. note 1, p. 53; B. Backwell and S. Mullin, GWEC, "2020 In review: End of year special", The Offshore Wind Podcast, December 2020, https://gwec.net.

4 Based on year-end 2020 capacity of 742,689 MW and year-end 2019 capacity of 650,199 MW, from GWEC, op. cit. note 1, p. 53, and double total capacity at end-2014 (370 GW), from idem, p. 52. Year-end global capacity was 733,276 MW, from IRENA, op. cit. note 1. China accounts for most of the difference between data from GWEC and IRENA. See endnote 26. Note that annual additions reported in this section are gross additions unless otherwise noted, but most countries did not decommission capacity during the year. **Figure 34** based on historical data from GWEC, op. cit. note 1, pp. 51-52; data for 2021 based on sources provided in endnote 1.

5 China's market was driven by the cut-off to the national feed-in tariff at year's end, and the US market was driven by a scheduled step-down in the production tax credit as of 1 January 2021 (the step-down was postponed in December), from GWEC, op. cit. note 1, p. 6. Rest of world based on data from idem, p. 53.

6 See, for example, infrastructure, policy and regulatory challenges in India, from GWEC, "China blows past global wind power records, doubling annual installations in 2020", 18 March 2021, https://gwec.net/china-blows-past-global-wind-power-records-doubling-annual-installations-in-2020; slow permitting or lack thereof was an issue in Germany and Italy, from WindEurope, *Wind Energy in Europe: 2020 Statistics and the Outlook for 2021-2025*, p. 23, https://windeurope.org/data-and-analysis/product/wind-energy-in-europe-in-2020-trends-and-statistics; lack of interconnections in Chile, Vietnam and other countries, and permitting processes in the Philippines, and financing in Ethiopia from GWEC, op. cit. note 1. Record installations based on the following: Argentina (added 1,014 MW), Australia (1,097 MW), Chile (684 MW), Japan (551 MW), Kazakhstan (300 MW) and Sri Lanka (88 MW), from GWEC, op. cit. note 1, p. 53, and from GWEC, "Global Wind Statistics 2020: Status as end of 2020" (Brussels: March 2020); Norway (1,532 MW) from WindEurope, op. cit. this note, pp. 11, 13; and the Russian Federation (715 MW), from WWEA, op. cit. note 1.

7 At least 49 countries and Tanzania, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from F. Zhao, GWEC, Copenhagen, personal communication with REN21, 26 April 2021. At least 55 countries in 2019 based on data from GWEC, "Global Wind Statistics 2019: Status as End of 2019" (Brussels: March 2020), and from Zhao, op. cit. this note, 13 April 2020. In 2018, at least 47 countries based on data from GWEC, *Global Wind Report 2018* (Brussels: April 2019), https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf. Tanzania added its first commercial wind farm, from Future Power Technology, "A look at Tanzania's first wind farm", https://power.nridigital.com/future_power_technology_jul20/tanzania_wind_farm, viewed 27 April 2021, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

8 Based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Zhao, op. cit. note 7, 26 April 2021.

9 GWEC, op. cit. note 1, p. 17; B. Eckhouse, "Solar and wind cheapest source of power in most of the world", Bloomberg, 28 April 2020, https://www.bloomberg.com/news/articles/2020-04-28/solar-and-wind-cheapest-sources-of-power-in-most-of-the-world; IRENA, *Renewable Power Generation Costs in 2018* (Abu Dhabi: 2019), pp. 9-11, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf; GWEC and MEC Intelligence, *India Wind Outlook Towards 2022: Looking Beyond Headwinds* (Brussels and Gurugram, India: May 2020), pp. 9, 13, https://gwec.net/india-wind-outlook-towards-2022-looking-beyond-headwinds; Frankfurt School-UNEP Collaborating Centre on Climate & Energy Finance (FS-UNEP) and BloombergNEF, *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), pp. 27-29, https://www.fs-unep-centre.org. See also, for example: Clean Energy Council, *Clean Energy Australia Report 2019* (Melbourne: 2019), p. 72, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2019.pdf; American Wind Energy Association (AWEA), "US wind power grew 8 percent amid record demand", press release (Washington, DC: 9 April 2019), https://www.awea.org/2018-market-report_us-wind-power-grew-8-percent-in-2018; B. Chapman, "Offshore wind energy price plunges 30 per cent to a new record low", *Independent* (UK), 20 September 2019, https://www.independent.co.uk/news/business/news/offshore-wind-power-energy-price-falls-record-low-renewables-a9113876.html.

10 S. Sawyer, GWEC, Brussels, personal communication with REN21, 13 March 2019. See also C. Bogmans, "Falling costs make wind, solar more affordable", International Monetary Fund, 26 April 2019, https://blogs.imf.org/2019/04/26/falling-costs-make-wind-solar-more-affordable; FS-UNEP and BloombergNEF, op. cit. note 9, p. 29.

11 GWEC, op. cit. note 1, p. 46; GWEC, *Global Wind Market Outlook Update Q3 2019* (Brussels: September 2019), p. 2; GWEC, *Global Wind Report 2019* (Brussels: March 2020), p. 37, https://gwec.net/global-wind-report-2019; Latin American Energy Organization (OLADE) and GWEC, cited in GWEC, "Public tenders and auctions have driven 80% of current renewable energy capacity in Latin America and the Caribbean", press release (Brussels: 4 March 2020), https://gwec.net/public-tenders-and-auctions-have-driven-80-of-current-renewable-energy-capacity-in-latin-america-and-the-caribbean. In 2020, about 56% of the market was driven by feed-in tariffs (FITs) (China), 19% was driven by the US Production Tax Credit, followed by auctions and tenders (19.7%), and green certificates and other mechanisms (totalling a combined 4.6%), from GWEC, op. cit. note 1.

12 BloombergNEF, cited in GWEC, op. cit. note 1, p. 7.

13 EU share and five Member States (Denmark, Ireland, Germany, Portugal and Spain), from WindEurope, op. cit. note 6, p. 19, and from I. Komusanac, WindEurope, personal communication with REN21, 12 April 2021. If the United Kingdom were still an EU member, the total share from wind would be 16% and the country would be on this list as well, from idem, both sources.

14 Denmark's share of consumption based on total of 16,353 gigawatt-hours (GWh) of wind energy generation and total electricity supply (including imports) of 34,104 GWh, for a share of 48%; share of net generation from wind based on total of 16,353 GWh from wind energy in 2020 and 27,907 GWh of total net generation, for a share of 58.6%, all from Danish Energy Agency, "Monthly energy statistics, electricity supply", https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics, viewed 1 March 2021. Denmark's share of consumption was 46.1%, from Wind Denmark, "2020 bød på rekordhøj produktion fra landets vindmøller", 2 January 2021, https://winddenmark.dk/nyheder/2020-boed-paa-rekordhoej-produktion-fra-landets-vindmoeller (using Google Translate), and it would have been closer to 51%, if not for curtailment during the year, from idem.

15 List of countries based on data from WindEurope, op. cit. note 6, p. 19. Data for **Ireland** based on EIRGRID GROUP, "System and Renewable Summary Report", http://www.eirgridgroup.com/how-the-grid-works/renewables, viewed 28 February 2021; **United Kingdom** (24.18%), based on 34,948 GWh generation onshore plus 40,662 GWh generated offshore, and total UK generation of 312,759 GWh in 2020, from UK Department for Business, Energy & Industrial Strategy (BEIS), "Energy Trends: Renewables",Table 6.1. Renewable electricity capacity and generation, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, updated 25 March 2021; **Portugal** from Associação Portuguesa de Energias Renováveis (APREN), *Portuguese Renewable Electricity Report* (Lisbon: December 2020), p. 1, https://www.apren.pt/contents/publicationsreportcarditems/portuguese-renewable-electricity-report-december2020.pdf; **Germany** share of gross generation in 2020 was 23.2%, based on wind energy gross generation of 130,965 GWh (including 103,662 GWh onshore and 27,303 GWh offshore), from Federal Ministry for Economic Affairs and Energy (BMWi) and Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), *Time Series for the Development of Renewable Energy Sources in Germany – based on statistical data from the Working Group on Renewable Energy-Statistics* (AGEE-Stat) (Status: February 2021) (Dessa-Roßlau: February 2021), p. 46, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, and on 565.3 terawatt-hours (TWh) of total gross generation (not including pumped storage) in 2020, from AG Energiebilanzen e.V., "Bruttostromerzeugung", Strommix – Stromerzeugung nach Energieträgern 1990-2020 (Stand Februar 2021)", https://ag-energiebilanzen.de/4-0-Arbeitsgemeinschaft.html, viewed 5 May 2021. Note that the share of national production in 2020 was 27.1%, from Fraunhofer ISE, "Annual wind share of electricity production in Germany", Energy-Charts, https://energy-charts.info/charts/renewable_share/chart.htm?l=en&c=DE&share=wind_share, updated 19 April 2021, and wind energy's share of national gross consumption in Germany was 23.6%, from BMWi and AGEE-Stat, op. cit. this note, p. 46. **Spain** from Red Eléctrica de España (REE), "2020, the year with the 'greenest' energy thanks to record wind and solar photovoltaic generation", press release (Madrid: 12 March 2021), https://www.ree.es/en/press-office/news/press-release/2021/03/2020-the-year-with-the-greenest-energy-thanks-to-record-wind-and-solar-photovoltaic-generation. Other European countries with shares of 10% or higher included **Belgium** (14%), **Lithuania** (13%), **Netherlands, Romania** and **Austria** (all 12%), **Estonia** (11%) and **Croatia** (10%), all based on data from ENTSO-E and corrected with data from national transmission service operators and governments and cited in WindEurope, op. cit. note 6, p. 19. Shares were 27% in the United Kingdom, 25% in Portugal, 22% in Spain and 20% in Sweden, from Komusanac, op. cit. note 13.

16 **Uruguay** generated 40.4% of its electricity with wind energy in 2020, based on production of 5,437.7 GWh from wind energy and 13,470.5 GWh total, from Ministerio de Industria, Energía y Minería (MIEM), Balance Energético Nacional Uruguay, "Balance preliminar 2020", https://ben.miem.gub.uy/preliminar.php, viewed 16 April 2021. **Nicaragua** generated 27.62% of total net electricity output with wind energy, from Instituto Nicaragüense de Energía (INE), Ente Regulador, "Generación neta de energía eléctrica sistema eléctrico nacional año 2020", https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion_Neta_2020_actagost20.pdf, viewed 1 March 2021; and wind energy accounted for 23.58% of total electricity generation, from INE, Ente Regulador, "Generación bruta de energía eléctrica sistema eléctrico nacional año 2020", https://www.ine.gob.ni/DGE/estadisticas/2020/Generacion_Bruta_2020_actagost20.pdf, viewed 1 March 2021.

17 Share of generation in 2020 based on estimated total global electricity generation of 25,849.92 TWh and total wind generation of 1,590.19 TWh, from Ember, *Global Electricity Review 2021* (London: 2021), https://ember-climate.org/project/global-electricity-review-2021. Global totals for 2020 were estimated by summing total electricity generation and electricity generation per energy source in 36 countries where 2020 national sources (including official government data and utility data) were available, comprising 90% of global generation. See Ember, "Methodology", https://ember-climate.org/global-electricity-review-2021/methodology, viewed 7 April 2021. Note that by the end of 2020, there was enough wind power capacity in operation to provide an estimated 6.38% of global electricity generation, based on GWEC, "Global Wind Energy Statistics 2020 Database", provided by Zhao, op. cit. note 7, 26 April 2021.

18 Share of market in 2019 (including Turkey), and total year-end capacity (including Turkey), based on data from GWEC, op. cit. note 1, p. 53; Asia (including Turkey) and China shares of market in 2020, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and revised data for Spain (1,720 MW added), from Komusanac, op. cit. note 13. Asia's share in 2018 was 51.9% (also including Turkey), based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 7; and the share in 2017 was 48%, based on data from GWEC, *Global Wind Report – Annual Market Update 2017* (Brussels: April 2018), p. 17, http://files.gwec.net/files/GWR2017.pdf.

19 Regional shares based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Komusanac, op. cit. note 13. Numbers in text are based on regional groupings that include Turkey as part of Asia, rather than Europe, and Mexico as part of Latin America, rather than North America. Other regional shares include Oceania (Australia and New Zealand added capacity) with 1.3% of the total added in 2020, Africa with almost 0.8%, and the Middle East with 0.1%, all from idem.

20 GWEC, op. cit. note 1, pp. 48, 53; Europe projects delayed to 2021 from Komusanac, op. cit. note 13.

21 GWEC, "Global Wind Statistics 2020", op. cit. note 6; Komusanac, op. cit. note 13.

22 Based on data from GWEC, op. cit. note 1, p. 53, from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13. **Figure 35** based on country-specific data and sources provided throughout this section, and largely drawn from the following: GWEC, op. cit. note 1; GWEC, "Global Wind Statistics 2020", op. cit. note 6; WindEurope, op. cit. note 6; WWEA, op. cit. note 1.

23 Based on data from GWEC, op. cit. note 1, p. 53; WindEurope, op. cit. note 6, p. 11; WWEA, op. cit. note 1; GWEC, "Global Wind Statistics 2019", op. cit. note 7; WindEurope, *Wind Energy in Europe in 2019: Trends and Statistics* (Brussels: 2020), p. 10, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf.

24 Grid connections from G. Baiyu, "Despite coronavirus, China aims for renewables grid parity", China Dialogue, 2 June 2020, https://chinadialogue.net/en/energy/despite-coronavirus-china-aims-for-renewables-grid-parity. China recovered quickly from the economic impacts of the pandemic, and the rapid recovery enabled project installations and manufacturing to bounce back as early as March; also, grid companies undertook measures to address bottlenecks and connect as much capacity as possible during the year, from GWEC, "A gust of growth in China makes 2020 a record year for wind energy", 21 January 2021, https://gwec.net/a-gust-of-growth-in-china-makes-2020-a-record-year-for-wind-energy.

25 China added an estimated 52,000 MW in 2020, including 48,940 MW onshore and 3,060 MW offshore, for a year-end total of 288,320 MW (278.3 GW onshore and nearly 10 GW offshore), and added 26,785 MW in 2019, all preliminary data from Chinese Wind Energy Association (CWEA), provided by GWEC, op. cit. note 1, p. 53, and GWEC, "Global Wind Statistics 2020", op. cit. note 6; and added 52 GW (48.9 GW onshore and 3.1 GW offshore) for a year-end total of 288.32 GW (278.19 GW onshore and 10.13 GW offshore), all preliminary data from H. Yu, CWEA, Beijing, personal communication with REN21, 12 May 2021; and China added 52,000 MW in 2020 for a total of 290,000 MW, from WWEA, op. cit. note 1. In 2018, global capacity additions totalled 50.7 GW, from GWEC, op. cit. note 1, p. 51.

26 Net additions of 72,380 MW, for a total of 281,530 MW, are official data based on 209,150 MW in operation at end of 2019 and 281,530 MW in operation at end of 2020, from China Electricity Council (CEC), cited in China Energy Portal, "2020 electricity & other energy statistics (preliminary)", 22 January 2021, https://chinaenergyportal.org/en/2020-electricity-other-energy-statistics-preliminary; and additions of 71.67 GW of grid-connected wind power capacity (68.61 GW onshore and 3.06 GW offshore) for a total of 281 GW (271 GW onshore and 9 GW offshore), from National Energy Board, cited in National Energy Administration (NEA), "Transcript of the online press conference of the National Energy Administration in the first quarter of 2021", 30 January 2021, http://www.nea.gov.cn/2021-01/30/c_139708580.htm (using Google Translate). Note that these data are based on grid-connected capacity; in addition, "Due to differences in statistical standards, confirmation of moment of grid connection, and other reasons, there are certain discrepancies in data on total and newly installed generation capacity", from CEC cited in idem. China added a total of 71.7 GW, from C. Richard, "China reports 72GW wind connected to grid in record-breaking 2020", Windpower Monthly, 22 January

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2021, https://www.windpowermonthly.com/article/1705268/china-reports-72gw-wind-connected-grid-record-breaking-2020. China added 68.6 GW of onshore wind capacity to the grid in 2020, from China's NEA, cited in GWEC, op. cit. note 1, p. 45, and GWEC, op. cit. note 24. However, CWEA estimates that 26 GW of this total was installed by the end of 2019 and only connected to the grid in 2020. Not including the 26 GW, new onshore installations in 2020 totalled 48.9 GW, and the amount of capacity installed and grid-connected in 2020 was about 45.4 GW, from GWEC, op. cit. note 1, p. 45, and GWEC, op. cit. note 24. In addition, some experts believed that the official Chinese numbers did not match observations on the ground, and that massive installations at year's end would have created supply constraints, for which there was little evidence in early 2021, from J. Deign, "What is going on with China's crazy clean energy installation figures?" Greentech Media, 2 February 2021, https://www.greentechmedia.com/articles/read/what-is-going-on-with-chinas-crazy-clean-energy-installation-figures. Note that the GSR uses GWEC/CWEA data for China rather than official data, which vary depending on government agency; GWEC/CWEA use these numbers because of the delay of grid connection in China, from GWEC, op. cit. note 1, p. 74. The difference in statistics among Chinese organisations and agencies results from the fact that they count different things. There are no Chinese statistics that provide actual grid-connected capacity, and discrepancies among available statistics can be large. In general, installed capacity refers to capacity that is constructed and usually has wires carrying electricity from the turbines to a sub-station (i.e., CWEA annual statistics); capacity qualifies as officially grid-connected (i.e., included in CEC statistics) once certification is granted and operators begin receiving the FIT premium payment, which at times has required weeks or even months. In recent years, due to transmission constraints in China, there often were lags of several months from when turbines were wire-connected to the sub-station until the process of certification and payment of the FIT premium was complete. In 2020, there was a great rush to ensure that projects were officially deemed to be grid-connected before the end of the year in order to guarantee receipt of the expiring onshore FIT; the higher, official statistics include capacity that was connected to the grid during the year at wind projects that were installed in 2020, as well as those from previous years. Data cited by CWEA are based on information collected from the industry during 2020 and early 2021, and are believed to most closely reflect the status of the market in China. All based on information provided in past years by GWEC and CWEA, as well as updates for 2020 and confirmation of accuracy provided by Yu, op. cit. note 25.

27 GWEC, op. cit. note 1, pp. 45, 49, 71; GWEC, "China blows past global wind power records", op. cit. note 6; GWEC, op. cit. note 24; Richard, op. cit. note 26. These were all projects that were approved through 2018.

28 GWEC, op. cit. note 1, p. 49. See also Everchem, "Chinese wind subsidies to end in December. China's renewable power price and subsidy: 'new' design in 2020?" 28 October 2020 / 29 January 2020, https://everchem.com/chinese-wind-subsidies-to-end-in-december.

29 See, for example, Reuters, "China to stop subsidy for offshore renewables, eyes 2021 start for green quota trading", Nasdaq, 23 January 2020, https://www.nasdaq.com/articles/china-to-stop-subsidy-for-offshore-renewables-eyes-2021-start-for-green-quota-trading-2020; Everchem, op. cit. note 28; Bloomberg News, "China boosts renewable power subsidies 7.5% to $13 billion", MSN, 18 June 2020, https://www.msn.com/en-us/money/markets/china-boosts-renewable-power-subsidies-7-5-to-13-billion/ar-BB15E9sk; I. Shumkov, "China to reduce subsidies for renewables by 30% in 2020", Renewables Now, 22 November 2019, https://renewablesnow.com/news/china-to-reduce-subsidies-for-renewables-by-30-in-2020-677495. China introduced the feed-in tariff for onshore wind power in 2009 and for offshore wind in 2014, from Everchem, op. cit. note 28.

30 Deficit and backlog from Everchem, op. cit. note 28; EurObserv'ER, *Wind Energy Barometer* (Paris: March 2020), p. 3, https://www.eurobserv-er.org/wind-energy-barometer-2020. The deficit situation was worsened by pandemic, from Baiyu, op. cit. note 24; competing subsidy-free from Reuters, op. cit. note 29. The cumulative deficit for all renewables amounted to the equivalent of USD 50 billion at the end of 2020, from Credit Suisse, cited in J. Wong, "China's green-power funding is blowing in the wind", *Wall Street Journal*, 21 April 2021, https://www.wsj.com/articles/chinas-green-power-funding-is-blowing-in-the-wind-11619003815. One source notes that wind and solar power projects benefit from lower technology costs, but other costs – such as curtailment, taxes on land, financing and initial development – remain high (accounting for 20% or more of wind and solar power project costs) and are barriers to grid parity, from Baiyu, op. cit. note 24.

31 GWEC, op. cit. note 1, p. 46.

32 360doc.com, "Multi-pictures: overview of the details of photovoltaic and wind power installed capacity and power generation in various provinces across the country in 2020", 17 February 2021, http://www.360doc.com/content/21/0217/07/73752269_962367138.shtml (using Google Translate). Wind power accounted for more than 20% of power capacity in Inner Mongolia (25.5%), Gansu (24.4%), Ningxia (23.2%), Hebei (22.8%), Xinjiang (21.7%) and Qinghai (20.9%), from idem.

33 Continued to shift from Ibid.; 40% from National Energy Board, op. cit. note 26.

34 Top provinces for total from 360doc.com, op. cit. note 32. Top provinces for additions in 2020 were Inner Mongolia (5.9 GW), Henan (5.5 GW) and Shanxi (4.7 GW), from Yu, op. cit. note 25, 10 May 2021.

35 M. Lifang, China Renewable Energy Industries Association, cited in G. Baiyu, "Offshore wind takes off in China", China Dialogue, 9 October 2020, https://chinadialogue.net/en/energy/china-offshore-wind-power-growth.

36 Figure of 16.6 TWh of potential curtailed, and 3% curtailment rate, from National Energy Board, op. cit. note 26; down from 4% (16.9 TWh) in 2019, based on data from NEA, "Wind power grid-connected operation in 2019", 28 February 2020, http://www.nea.gov.cn/2020-02/28/c_138827910.htm (using Google Translate); targeted cap of 5% for 2020 was set in China's Clean Energy Consumption Action Plan (2018-20), from Z. Tong, "Greening of renewable sector", *China Daily*, 20 January 2021, http://www.chinadaily.com.cn/a/202101/20/WS60077241a31024ad0baa3b71.html. Note that the rate of average curtailment was 2% in 2020, per NEA, 30 January 2021, provided by F. Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), personal communication with REN21, 26 March 2021. National curtailment was 7% (27.7 TWh) in 2018, based on data from NEA, "Wind power grid-connected operation in 2019", op. cit. this note; national curtailment in 2017 was 12% (41.9 TWh), from China National Energy Board, cited in NEA, "Wind grid operation in 2017", 1 February 2018, http://www.nea.gov.cn/2018-02/01/c_136942234.htm (using Google Translate); national curtailment in 2016 was 17% (49.7 TWh), from NEA and CEC, provided by S. Pengfei, CWEA, personal communication with REN21, 21 March 2017, and from NEA, "Wind power grid operation in 2016", 26 January 2017, http://www.nea.gov.cn/2017-01/26/c_136014615.htm (using Google Translate).

37 In Xinjiang, the curtailment rate fell 3.7 percentage points in 2020, to 10.3%; Gansu's declined 1.3 percentage points, to 6.4%, and Western Inner Mongolia's fell 1.9 percentage points, to 7.0%, from National Energy Board, op. cit. note 26. In Xinjiang, the curtailment rate fell more than 9 percentage points in 2019 relative to 2018, to 14%; Gansu's declined 11.4 percentage points in 2019, to 7.6%; Inner Mongolia's fell nearly 3 percentage points in 2019, to 7.1%, based on 2019 data from NEA, "Wind power grid-connected operation in 2019", op. cit. note 36, and on 2018 data from NEA, "2018 added solar PV capacities", Finance World, 28 January 2019, https://baijiahao.baidu.com/s?id=1623876437525496663&wfr=spider&for=pc (using Google Translate).

38 Based on total power production in 2020 of 7,623,600 GWh and total wind energy production of 466,500 GWh (based on grid-connected capacity), for a share of 6.1%, from CEC, op. cit. note 26. This was up from a share of 5.5% in 2019, based on total annual generation of 7,326,900 GWh and wind energy generation of 405,300 GWh, from idem. Wind energy produced 5.2% of total in 2018 based on generation of 365.8 TWh that year, from China Energy Portal, "2018 wind power installations and production by province", 28 January 2019, https://chinaenergyportal.org/en/2018-wind-power-installations-and-production-by-province, and based on data from China Electricity Council Express, cited in NEA, "National Energy Administration released statistics on national power industry in 2018", 18 January 2019, http://www.nea.gov.cn/2019-01/18/c_137754977.htm (using Google Translate). In 2017, wind energy generation was 305.7 TWh and its share of total generation was 4.8%, from China National Energy Board, cited in NEA, "Wind grid operation in 2017", op. cit. note 36.

39 Turkey installed a net of 1,224.8 MW in 2020, up from 671.5 MW in 2019, for a year-end total of 9,305 MW, from Turkish Wind Energy

Association (TWEA), "With 1.224 MWm new capacity in 2020, Turkey's cumulative installed wind power capacity reached 9.305 MWm", https://tureb.com.tr/eng/lib/uploads/6371c2b9854591cf.pdf, viewed 26 March 2021. Turkey added 1,224 MW for a total of 9,305 MW, from WindEurope, op. cit. note 6, p. 11; added 1,249 MW for a total of 9,305 MW, from WWEA, op. cit. note 1; and added 1,224 MW for a total of 9,279.5 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

40 Based on data from TWEA, op. cit. note 39; WindEurope, op. cit. note 6, p. 11; GWEC, "Global Wind Statistics 2020", op. cit. note 6.

41 T. Sidki Uyar, Eurosolar Turkey, presentation for WWEA webinar "Wind power around the world", 7 April 2021, https://wwindea.org/wweawebinar-wind-power-around-the-world.

42 "Turkey aims to double its solar energy capacity in 2021, compared to 2020", TRT World, 21 January 2021, https://www.trtworld.com/turkey/turkey-aims-to-double-its-solar-energy-capacity-in-2021-compared-to-2020-43452.

43 TWEA, op. cit. note 39.

44 Based on data from GWEC, op. cit. note 1, p. 53, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

45 Net additions of 1,119 MW for total of 38,624 MW based on 37,505.18 MW at end-2019 from Government of India, Ministry of New and Renewable Energy (MNRE), "Physical progress – programme/scheme wise physical progress in 2019-20 & cumulative upto Dec, 2019", https://mnre.gov.in/physical-progress-achievements, viewed 9 January 2020, and 38,624.15 MW at end-2020 from Government of India, MNRE, "Physical progress – programme/scheme wise physical progress in 2020-21 & cumulative upto Dec, 2020", https://mnre.gov.in/physical-progress-achievements, viewed 3 February 2021.

46 Data from GWEC, op. cit. note 1, p. 53, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6; decline from N. T. Prasad, "Solar is the new king as installed capacity surpasses wind", Mercom India, 4 February 2021, https://mercomindia.com/solar-is-the-new-king.

47 S. Gsänger, "A dangerous trend is challenging the success of wind power around the globe: Concentration and monopolization", WindTech International, 4 February 2020, https://www.windtech-international.com/view-from-inside/a-dangerous-trend-is-challenging-the-success-of-wind-power-around-the-globe-concentration-and-monopolisation; geographically concentrated from J. Hossain, WWEA, "Experience with auctions in India", from WWEA, "Webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 14 May 2020, https://wwindea.org/blog/2020/05/07/wweawebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may.

48 Government of India, MNRE, "State-wise installed capacity of grid interactive renewable power as on 31.12.2020", https://mnre.gov.in/img/documents/uploads/file_s-1612163907504.xlsx, viewed 3 February 2021.

49 Figure of 5% based on wind generation of 60.428 BU, from Central Electricity Authority, Centre for Energy Finance, India Renewables Dashboard, Monthly generation for 1 January 2020 through 31 December 2020, https://www.renewablesindia.in, viewed 6 May 2021,and total generation of 1,197.29 BU, from Government of India, Ministry of Power, Central Electricity Authority, "Dashboard – all India power generation from Jan-2020 to Dec-2020", https://cea.nic.in/dashboard/?lang=en, viewed 6 May 2021; down 24% during peak season, from D. Agarwal and G. Sidhu, "How did India's renewable energy sector perform during the year of COVID-19 lockdown?" 7 April 2021, https://www.ceew.in/blogs/how-did-india%E2%80%99s-renewable-energy-sector-perform-during-year-covid-19-lockdown; down 5% for the year from BloombergNEF, "Wind and solar supply one-tenth of India's power in 2020", New Energy Finance, 18 January 2021, https://about.newenergyfinance.com/blog/wind-and-solar-supply-one-tenth-of-indias-power-in-2020.

50 GWEC, op. cit. note 1, p. 48.

51 V. Petrova, "Only 2 GW of SECI wind projects for 2017-18 come to commissioning – report", Renewables Now, 15 May 2020, https://renewablesnow.com/news/only-2-gw-of-seci-wind-projects-for-2017-18-come-to-commissioning-report-699123. About two-thirds of the 6 GW in awarded by the Solar Energy Corporation of India in 2017, and 2018 tenders were not yet online by mid-year, from idem.

52 Caps have often been too low to attract investors and have resulted in undersubscribed tenders, leading to delayed deadlines and retenders, from A. Parikh, "No more tariff caps for solar and wind tenders", Mercom India, 6 March 2020, https://mercomindia.com/no-more-tariff-caps-solar-wind-tenders; the companies that announced they would not participate were Acciona (Spain) and Nordex (Germany), from K. Chandrasekaran, "Spain's Acciona and Germany's Nordex bearish on India's wind energy prospects", *Economic Times*, 7 September 2020, https://economictimes.indiatimes.com/industry/energy/power/spanish-firm-acciona-may-keep-away-from-new-renewables-projects-in-india/articleshow/77979193.cms.

53 Japan added 551 MW onshore for a total of 4,432 MW (4,373 MW onshore and 58.6 MW offshore), installations in 2019 and ranking, all based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

54 IEA, "Wind", in *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020/wind.

55 GWEC, "Global Wind Statistics 2020", op. cit. note 6. See also: A. Satubaldina, "Nine renewable energy projects to be launched in Kazakhstan by December", Astana Times, 27 April 2021, https://astanatimes.com/2020/05/nine-renewable-energy-projects-to-be-launched-in-kazakhstan-by-december; A. Cohen, "Oil-rich Kazakhstan begins the long march towards renewables", *Forbes*, 18 October 2019, https://www.forbes.com/sites/arielcohen/2019/10/18/oil-rich-kazakhstan-begins-the-long-march-towards-renewables.

56 GWEC, "Global Wind Statistics 2020", op. cit. note 6. Pakistan added 48.3 MW, the Republic of Korea added 160 MW (including 60 MW offshore), Sri Lanka added 88 MW, Chinese Taipei 74 MW and Vietnam 125 MW, from idem. Vietnam's FIT expiration from S. Lim, "Market to watch: Vietnam", GWEC, 23 April 2020, https://gwec.net/market-to-watch-vietnam-2, and from L. Qiao, "Vietnam needs to act now to mitigate wind development disruptions", GWEC, 23 April 2020, https://gwec.net/vietnam-needs-to-act-now-to-mitigate-wind-development-disruptions; and capital costs (down 30% in recent years) and electricity demand (average annual growth of 10%), from McKinsey, cited in GWEC, op. cit. note 1, p. 60. Vietnam ended the year short of a wind power target (800 MW) set in 2018, due largely to permitting delays and lack of interconnection availability (due to a surge of solar PV installations), from GWEC, op. cit. note 1, pp. 60-61. Vietnam added 125 MW for a year-end total of 612.3 MW, including 513.3 MW onshore and 99 MW offshore, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

57 The Americas added 21,763 MW in 2020 for a total of 170 GW, and US share, based on data from GWEC, "GWEC: North and Latin America increased wind power installations by 62% in 2020", 11 March 2021, https://gwec.net/north-and-latin-america-increased-wind-power-installations-by-62-in-2020. Figure of 62% based on data from GWEC, op. cit. note 1, p. 53. The region's estimated share (for all Americas and Caribbean) was 23%, based on total global additions of 93 GW, from idem, p. 53.

58 The United States added 16,913 MW for a total of 122,468 MW, from American Clean Power Association (ACPA), *ACP Market Report – Fourth Quarter 2020* (Washington, DC: 2021), p. 4, https://cleanpower.org/resources/american-clean-power-market-report-q4-2020. Utility-scale capacity added in 2020 was 14.2 GW, for a year-end total of 118 GW, from US Department of Energy (DOE), US Energy Information Administration (EIA), *Electric Power Monthly*, cited in R. Bowers and O. Comstock, "The United States installed more wind turbine capacity in 2020 than in any other year", US EIA, Today in Energy, 3 March 2021, https://www.eia.gov/todayinenergy/detail.php?id=46976. More than 60,000 turbines were operating across 41 US states and two territories at end-2020, from ACPA, op. cit. this note, p. 4.

59 ACPA, op. cit. note 58, p. 6. In the fourth quarter 10,593 MW was added, from idem.

60 Ibid., p. 9.

61 Ibid., p. 4; 38 million from ACPA, "Wind industry closes record 2020 with strongest quarter ever", 4 February 2021, https://cleanpower.org/news/wind-industry-closes-record-2020-with-strongest-quarter-ever. A further 17.3 GW was under construction with 17.5 GW in the advanced development stage (more than one quarter of this for offshore projects in US federal waters), from idem.

62 Texas lead, share and total capacity (33,133 MW), from ACPA, op. cit. note 58, p. 11. Fifth globally based on idem and data from GWEC, op. cit. note 1, p. 53. Other top states for total capacity at the end of 2020 were Iowa (11,660 MW), Oklahoma (9,048 MW) and Kansas (7,016 MW), and more than 20 US states had over 1 GW of

installed capacity, from ACPA, op. cit. this note. Texas leads for total utility-scale capacity (30.2 GW), from US EIA, cited in Bowers and Comstock, op. cit. note 58.

63 US EIA, cited in Bowers and Comstock, op. cit. note 58. The 100% PTC was scheduled to phase out at year's end for wind power projects that began construction in 2016, from GWEC, op. cit. note 57. In December, Congress passed a one-year extension of the PTC and investment tax credit (ITC) for land-based wind power, and a 30% ITC for offshore projects that start construction from the beginning of 2017 through 2025, from D. Wagman, "US to extend Investment Tax Credit for solar to 2024", pv magazine, 22 December 2020, https://www.pv-magazine.com/2020/12/22/us-to-extend-investment-tax-credit-for-solar-to-2024.

64 Demand from utilities from ACPA, op. cit. note 58, p. 18. Utilities commissioned 4,918 MW of new wind power capacity in 2020, from idem.

65 A total of 5,444 MW was contracted through PPAs, and announcements down, from ACPA, op. cit. note 58, pp. 4, 19. New wind power PPAs reached a record 8.7 GW in 2019, from AWEA, *U.S. Wind Industry Quarterly Market Report, Fourth Quarter 2019* (Washington, DC: January 2020), pp. 3, 4, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/4q2019_marketreport. Utilities signed 5,085 MW, their second highest amount, out of a record total of 8,726 MW of PPAs, from AWEA, *Wind Powers America – Annual Report 2019, Executive Summary* (Washington, DC: 2020), p. 5, https://www.awea.org/resources/publications-and-reports/market-reports/2019-u-s-wind-industry-market-reports/amr2019_executivesummary. Most of the projects under construction were expected to come online in 2020 to receive the full PTC value, from AWEA, *U.S. Wind Industry Quarterly Market Report*, op. cit. this note, pp. 3, 4. At year's end, more than 16 GW of projects was in the pipeline (just over half of the capacity) had a PPA in place; utilities accounted for 70% of the capacity under construction or in advanced development, from ACPA, op. cit. note 58, p. 18.

66 US EIA, cited in Bowers and Comstock, op. cit. note 58. Wind's share was 7.3% in 2019 and 6.5% of US total generation in 2018 based on data for utility-scale facilities net generation during 2018, from US EIA, *Electric Power Monthly with Data for December 2020* (Washington, DC: February 2021), Table ES1.B. Share from a decade earlier, from GWEC, op. cit. note 57. Daily highs were far higher in 2020; for example, on 23 December, wind energy accounted for 17% of total US electricity generation, from US EIA, "U.S. wind generation sets new daily and hourly records at end of 2020", Today in Energy, 2 February 2021, https://www.eia.gov/todayinenergy/detail.php?id=46617.

67 Texas the largest consumer and figure of nearly 20% of state generation from US EIA, cited in Bowers and Comstock, op. cit. note 58. Wind passed coal based on data from the Electric Reliability Council of Texas (the state's main grid operator), cited in K. Lowder, "Texas wind power dominates coal In crossover year", CleanTechnica, 17 January 2021, https://cleantechnica.com/2021/01/17/texas-wind-power-dominates-coal-in-crossover-year. Wind energy was second only to natural gas for Texas generation, accounting for 22% (compared with 18% from coal) in 2020, up from 8% in 2010, from idem. Wind power has seen billions of dollars in capital investment in the state since 2010; the investment and jobs created have helped wind power gain strong political support, from The Finance Info, "Wind power overtakes coal in Texas electricity generation", 12 January 2021, https://thefinanceinfo.com/2021/01/12/wind-power-overtakes-coal-in-texas-electricity-generation.

68 US EIA, cited in Bowers and Comstock, op. cit. note 58. Other states with higher shares than Texas include Nebraska (24%), Colorado (23%), Minnesota (22%), as well as Maine, New Mexico and South Dakota; also, in-state wind capacity accounted for at least 10% of 2020 generation in Idaho, Illinois, Montana, Oregon, Wyoming and Vermont, and accounted for 7% in California, all from idem.

69 Southwest Power Pool, "SPP becomes first regional grid operator with wind as No. 1 annual fuel source, considers electric storage participation in markets, approves 2021 transmission plan", 26 January 2021, https://spp.org/newsroom/press-releases/spp-becomes-first-regional-grid-operator-with-wind-as-no-1-annual-fuel-source-considers-electric-storage-participation-in-markets-approves-2021-transmission-plan; M. Bates, "Wind energy tops coal, natural gas in Southwest Power Pool", North American Wind Power, 26 January 2021, https://nawindpower.com/spp-in-2020-wind-energy-tops-coal-natural-gas. SPP meets electricity needs of 19 million people, from Southwest Power Pool, "About us – reliability through relationships", https://spp.org/about-us, viewed 26 March 2021. Wind energy's share is 31.3%, compared with coal's share of 30.9%, from Institute for Energy Economics and Financial Analysis, "Wind surpassed coal as No. 1 fuel source in 2020 for Southwest Power Pool", Energy Central News, 12 February 2021, https://energycentral.com/news/energy-ieefa-us-wind-surpassed-coal-no-1-fuel-source-2020-southwest-power-pool.

70 Bates, op. cit. note 69; windiest states from J. Broehl, ACPA, personal communication with REN21, 27 April 2021.

71 ACPA, op. cit. note 61.

72 Siting and resource availability from J. Gerdes, "California's wind market has all but died out. Could grid services revenue help?" Greentech Media, 30 March 2020, https://www.greentechmedia.com/articles/read/justin-california; grid congestion from K. Lydersen, "Grid congestion a growing barrier for wind, solar developers in MISO territory", Energy News Network, 29 September 2020, https://energynews.us/2020/09/29/midwest/grid-congestion-a-growing-barrier-for-wind-solar-developers-in-miso-territory.

73 Ibid, both sources. See also: E. Pearcey and R. Sayles, "As Texas probes power grid, national failings bite", Reuters Events, 17 March 2021, https://www.reutersevents.com/renewables/wind/texas-probes-power-grid-national-failings-bite; J. St. John, "Report: Renewables are suffering from broken US transmission policy", Greentech Media, 12 January 2021, https://www.greentechmedia.com/articles/read/report-renewables-are-suffering-from-broken-u.s-transmission-policy.

74 Canada added 185 MW, based on 13,413 MW at end-2019 and 13,588 MW at end-2020, from Canadian Renewable Energy Association, "By the numbers", https://renewablesassociation.ca/by-the-numbers, viewed 4 March 2021. The leading provinces for cumulative capacity continued to be Ontario, which ended the year with 5,436 MW (same as 2019), followed by Quebec (3,896 MW) and Alberta (1,822 MW), where most new installations took place, from idem.

75 Hardest hit from R. Fiestas, quoted in GWEC, op. cit. note 57; the region added 4,672.8 MW including in Argentina, Brazil, Chile, Mexico, Panama and Peru, and Brazil ranked third and eighth, all based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

76 Fastest growing from R. Fiestas, quoted in GWEC, op. cit. note 57; 33.9 GW from idem; number of countries based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

77 Brazil added 2,297 MW in 2020, up from 745 MW in 2019, for a total of 17,749.7 MW at end-2020, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

78 GWEC, op. cit. note 1, p. 49.

79 I. Atxalandabaso, "Renewable energy in Latin America: 5 renewable energy trends emerging from south of Rio Grande", Rated Power, 16 April 2021, https://ratedpower.com/blog/renewable-energy-latin-america; B. Bungane, "GWEC: Nearly 30GW of new wind energy capacity was auctioned in 2020", ESI Africa, 22 February 2021, https://www.esi-africa.com/industry-sectors/renewable-energy/gwec-nearly-30gw-of-new-wind-energy-capacity-was-auctioned-in-2020.

80 Brazil's wind capacity generated 56,623 GWh in 2020, amounting to 9.7%, based on data from Operador Nacional do Sistema Elétrico, "Geração de Energia Tipo de Usina" accessed at "Geração de Energia", for period 1 January 2020 through 31 December 2020, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed 4 March 2021. Wind power accounted for 9.4% of Brazil's electricity generation in 2019, up from 8.3% in 2018, based on total annual generation of 593,591 GWh and annual wind energy generation of 55,932 GWh in 2019, and on total annual generation of 581,923 GWh and annual wind energy generation of 48,443 GWh in 2018, all from Operador Nacional do Sistema Elétrico (ONS), "Geração de energia – composição", for period 1 January 2019 to 31 December 2019, http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/geracao_energia.aspx, viewed 24 April 2020.

81 Argentina added 1,014 MW for a total of 2,618 MW, and Chile added 683.5 MW for a total of 2,828.5 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Argentina ended the year

with 2,623 MW and wind energy accounted for 7% of generation during the year, from Compañía Administradora del Mercado Mayorista Eléctrico S.A. (CAMMESA), *Informe Mensual Principales Variables del Mes* (Buenos Ares: December 2020), pp. 12, 17, 23, https://portalweb.cammesa.com/memnet1/Pages/descargas.aspx. Share of generation based on 9,406 GWh of electricity generated with wind energy and total generation of 134,173 GWh, from idem. Chile's year-end capacity was 2,657 MW and wind energy accounted for 7.1% of annual generation, from Asociación Chilena de Energías Renovables y Almacenamiento AG. (ACERA), *Estadísticas Sector de Generación de Energía Eléctrica Renovable* (December 2020), pp. 1, 3, https://acera.cl/wp-content/uploads/2021/01/2020-12-Bolet%C3%ADn-Estad%C3%ADsticas-ACERA.pdf. Chile ended the year with another 1.5 GW under construction – completion was pushed into 2021 due to pandemic-related delays, from GWEC, op. cit. note 1, pp. 53, 56. Another 1,823 MW was under construction at end-2020 and 4,426 MW had been approved, from ACERA, op. cit. this note, pp. 3, 5.

82 Mexico added 574 MW for a total of 6,789 MW, Panama added 66 MW for a total of 336 MW, and Peru added 38 MW for a total of 411 MW, from GWEC, op. cit. note 57, and GWEC, "Global Wind Statistics 2020", op. cit. note 6.

83 Among top 10 and declined 45%, based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Policy and regulatory changes from R. Lozano, Emerging Leaders in Environmental and Energy Policy Network, Mexico, personal communication with REN21, 11 April 2021. Political challenges and rule changes in 2020 also from J. Villamil, "Why Mexico is pushing to slow down clean energy", Bloomberg, 16 July 2020, https://www.bloomberg.com/news/articles/2020-07-16/why-mexico-is-pushing-to-slow-down-clean-energy-quicktake; cancellation of auctions in 2019 from GWEC, *Global Wind Market Outlook Update Q3 2019*, op. cit. note 11, p. 4; GWEC, "Americas wind installations rise 12% in 2019 to 13.4GW", 4 February 2020, https://gwec.net/americas-wind-installations-rise-12-in-2019-to-13-4gw. Mexico ended the year far off track from its generation targets for 2021 (30% renewable electricity) and 2024 (35%), from Villamil, op. cit. this note. See also A. Stillman, "Mexico judge suspends controversial power law indefinitely", Bloomberg, 19 March 2021, https://www.bloomberg.com/news/articles/2021-03-19/mexico-judge-suspends-nationalistic-electricity-law-indefinitely, and "Mexico faces potential 'tsunami' of arbitration cases over electricity reform", BNAmericas, 9 April 2021, https://www.bnamericas.com/en/interviews/mexico-faces-potential-tsunami-of-arbitration-cases-over-electricity-reform.

84 Lozano, op. cit. note 83. See also Stillman, op. cit. note 83, and "Mexico faces potential 'tsunami' of arbitration cases over electricity reform", op. cit. note 83.

85 IEA, op. cit. note 54.

86 "Global corporate clean energy purchasing up 18% in 2020", Renewable Energy World, 27 January 2021, https://www.renewableenergyworld.com/solar/global-corporate-clean-energy-purchasing-up-18-in-2020. Brazil signed a record 1,057 MW of corporate PPAs for renewables (not only wind power), accounting for most of the 1.5 GW signed in Latin America during 2020, from BloombergNEF, cited in idem. That said, at least one PPA was signed in Mexico for a 105 MW wind farm, from A. Danigelis, "Bayer signs PPA for wind power in Mexico", 27 August 2020, https://www.environmentalleader.com/2020/08/bayer-wind-power-mexico.

87 All Europe data (not including Turkey) and down 6.6%, based on data from WindEurope, op. cit. note 6, pp. 7, 11, and from Komusanac, op. cit. note 13. Note that GWEC has lower numbers for Europe (not including Turkey), with 13.5 GW gross additions for a year-end total of 209.6 GW, from GWEC, op. cit. note 1, p. 53.

88 WindEurope, op. cit. note 6, p. 12; permitting delays in Germany from R. Hinrichs-Rahlwes, European Renewable Energy Federation, personal communication with REN21, 6 April 2021.

89 Many markets across the EU collapsed as a consequence of the shift away from FITs, with the diversity and number of investors declining, from S. Gsänger, WWEA, Bonn, personal communication with REN21, 20 April 2021.

90 WindEurope, op. cit. note 6, p. 12.

91 Norway added 1,532 MW for a total of 3,980 MW, from WindEurope, op. cit. note 6, pp. 11, 12, 13.

92 J. Agyepong-Parsons, "Europe's largest wind farm finished despite reindeer protests", Windpower Monthly, 21 August 2020, https://www.windpowermonthly.com/article/1692420/europes-largest-wind-farm-finished-despite-reindeer-protests. Due to its size and the geography of the chosen area, Fosen Vind is partitioned into a group of six individually named wind farms for a total of 1 GW, from Komusanac, op. cit. note 13.

93 The Russian Federation added 713 MW for a total of 905 MW, and 2018 auction, from WindEurope, op. cit. note 6, pp. 11, 14; added 0.7 GW for a total of more than 1 GW as of early 2021, from T. Lanshina, *Russia's Wind Energy Market: Potential for New Economy Development* (Bonn: Friedrich Ebert Stiftung, March 2021), pp. 5, 6, https://wwindea.org/wp-content/uploads/2021/03/210319-FESMOS-windenergy-en.pdf. See also E. Gerden, "Russia more than triples capacity in 2020 but now faces delays", Windpower Monthly, 26 November 2020, https://www.windpowermonthly.com/article/1701020/russia-triples-capacity-2020-faces-delays. The Russian Federation's largest wind farm (210 MW) was commissioned in December 2020, from Novawind Rosatom, "Electricity and power from the Rosatom's Kochubeyevskaya Wind Farm have entered the wholesale market", press release (Moscow: 11 January 2021), http://novawind.ru/eng/press/news/news_item.php?page=375.

94 Only major economy from Lanshina, op. cit. note 93, p. 6, and from S. Gsänger, P. Teschendorf and L. Gürth, preface in idem, p. 5. Wind power accounted for 0.4% of the Russian Federation's generating capacity (0.13% of generation) as of early 2021, from idem. Awarded capacity from E. Nikolaev, Russianwind, presentation for WWEA webinar "Wind power around the world", 7 April 2021, https://wwindea.org/wweawebinar-wind-power-around-the-world. Total installed capacity rose from 136 MW in 2018 to 191 in 2019 and 905 MW in 2020; a total of 3,351 MW is expected until 2024 due to tenders in past years, from idem.

95 Based on data from WindEurope, op. cit. note 6, p. 11, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6. The United Kingdom added 598 MW (115 MW onshore and 483 MW offshore) for a total of 24,167 MW, from WindEurope, op. cit. note 6. The country's end-2020 capacity totalled 24,665 MW (14,282 MW onshore and 10,383 MW offshore) (preliminary data), up from a total of 24,095 MW (14,125 MW onshore and 9,971 MW offshore), from UK BEIS, "Renewable electricity capacity and generation", Main Table, https://www.gov.uk/government/statistics/energy-trends-section-6-renewables, viewed 16 April 2021. The UK added 598 MW (115 MW onshore and 483 MW offshore) for a total of 23,937 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

96 J. Parnell, "UK lifts block on new onshore wind and solar", Greentech Media, 2 March 2020, https://www.greentechmedia.com/articles/read/uk-lifts-block-on-new-onshore-wind-and-solar.

97 UK BEIS, "Energy Trends UK, October to December 2020 and 2020", 25 March 2021, pp. 14, 17, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972790/Energy_Trends_March_2021.pdf.

98 J. Parnell, "Renewable generators are the UK's latest tool to smooth out renewable generation", Greentech Media, 23 June 2020, https://www.greentechmedia.com/articles/read/renewable-generators-are-uks-latest-tool-to-smooth-out-renewable-generation; National Grid ESO, "Power Available phase 2 further unlocks the potential for variable generation to provide balancing services", 30 March 2021, https://www.nationalgrideso.com/news/power-available-phase-2-further-unlocks-potential-variable-generation-provide-balancing; National Grid ESO, "Power Available: Unlocking renewables' potential to help balance the electricity system", 18 May 2020, https://www.nationalgrideso.com/news/power-available-unlocking-renewables-potential-help-balance-electricity-system. See also L. Stroker, "World's 'largest, most ambitious' energy flexibility market trials to launch in the UK", Current+, 26 February 2020, https://www.current-news.co.uk/news/worlds-largest-most-ambitious-energy-flexibility-market-trials-to-launch-in-the-uk.

99 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13.

100 Based on data from WindEurope, op. cit. note 6, p. 11; WindEurope, op. cit. note 23, p. 10.

101 Gross additions were down 1.5% and net additions were down 8%, based on data from WindEurope, op. cit. note 6, p. 11; WindEurope, op. cit. note 23, p. 10; and Komusanac, op. cit. note 13. The countries that installed more in 2020 than in 2019 were Belgium, Croatia, Finland, Luxembourg, the Netherlands and Poland, based on data from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13.

102 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13.

103 Based on data from WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13. France added 1,104.8 MW added in 2020 for year-end total of 17,616 MW, from Le Réseau de Transport d'Électricité (RTE), *Bilan Electrique 2020* (Paris: 2020), p. 54, https://assets.rte-france.com/prod/public/2021-03/Bilan%20electrique%202020_0.pdf, and added 1,105 MW for total of 17,616 MW, from RTE, *Panorama de l'Électricité Renouvelable* (Paris: 31 December 2020), p. 17, https://assets.rte-france.com/prod/public/2021-02/Panorama%20EnR_T4_2020_.pdf.

104 Poland added 731 MW in 2020 (up from 53 MW in 2019) for a year-end total of 6,614 MW, all onshore, from WindEurope, op. cit. note 6, p. 11, and WindEurope, op. cit. note 23, p. 10.

105 Based on data from WindEurope, op. cit. note 6, p. 11. France added 1,318 MW (net 1,303 MW) for a total of 17,949 MW, Italy added 137 MW for a total of 10,852 MW, and Sweden added 1,007 MW for a total of 9,992 MW, from WindEurope, op. cit. note 6, and from Komusanac, op. cit. note 13.

106 The Netherlands added 486 MW onshore and 1,493 MW offshore (total additions 1,979 MW) for a year-end total of 6,784 MW (4,174 MW onshore and 2,611 MW offshore), from WindEurope, op. cit. note 6, pp. 7, 11. In 2019, the country added 0.3 GW, from Komusanac, op. cit. note 13. The Netherlands added nearly 2 GW for a total of almost 6.6 GW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

107 WindEurope, op. cit. note 6, pp. 7, 11; P. Shreshtha, "Ørsted fully commissions 'largest' Dutch offshore wind farm", Energy Live News, 1 December 2020, https://www.energylivenews.com/2020/12/01/orsted-fully-commissions-largest-dutch-offshore-wind-farm.

108 K. Chamberlain and R. Sayles, "Community wind set to combat Europe's permit crisis", Reuters Events, 26 August 2020, https://www.reutersevents.com/renewables/wind/community-wind-set-combat-europes-permit-crisis.

109 Ibid. The Zeewolde project will have 322 MW of capacity, from idem.

110 Ibid.

111 Ibid. Community-owned projects accounted for only a small fraction of the country's wind (and solar) power capacity in 2020, but the Dutch government plans to require that all projects coming online from 2030 be at least 50% locally owned, from idem.

112 Ranking in region and capacity data from WindEurope, op. cit. note 6, p. 11, and from Komusanac, op. cit. note 13; global ranking also based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Spain added 1,720 MW in 2020 for a total of 27,446 MW, from Asociación Empresarial Eólica (AEE), cited in "Spain increases wind capacity by 1.7GW in 2020", reNEWS Biz, 24 February 2021, https://renews.biz/66696/spain-increases-wind-capacity-by-172gw-in-2020.

113 Figure of 2.2 GW added in 2019, based on 2,243 MW from Komusanac, op. cit. note 13, and from AEE, cited in "Spain increases wind capacity by 1.7GW in 2020", op. cit. note 112; other data from GWEC, "Global Wind Statistics 2020", op. cit. note 6; target is from the country's 2030 National Energy & Climate Plan, submitted to the EU, which called for annual installations of 2.2 GW of wind power capacity up to 2030, from WindEurope, "Spain submits ambitious 2030 National Plan – example for other countries to follow", 3 April 2020, https://windeurope.org/newsroom/press-releases/spain-submits-ambitious-2030-national-plan-example-for-other-countries-to-follow.

114 Watson Farley & Williams, "What you need to know about the Spanish renewable sector's first auction mechanism introduced in 2021", 17 December 2020, https://www.wfw.com/articles/what-you-need-to-know-about-the-spanish-renewable-sectors-first-auction-mechanism-introduced-in-2021.

115 REE, op. cit. note 15.

116 WindEurope, op. cit. note 6, p. 11; Komusanac, op. cit. note 13, 28 April 2021.

117 Germany added 1,650 MW gross (1,431 MW onshore and 219 MW offshore) and decommissioned 222 MW for a total of 62,627 MW (54,938 MW onshore and 7,689 MW offshore), from WindEurope, op. cit. note 6, pp. 7, 11, 17. Germany's additions in 2020 round up to 1.7 GW, from Komusanac, op. cit. note 13. Germany's net increase in capacity was 1,446 MW in 2020 (1,227 MW onshore and 219 MW offshore), for a year-end total of 62,167 MW (with 54,420 MW onshore and 7,847 MW onshore), from BMWi and AGEE-Stat, op. cit. note 15, p. 7. Germany added a gross of 1,668 MW (net 1,446 MW) for a total of 62,850 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6. WindEurope data are used in text to ensure consistent methodology across all countries in Europe.

118 Additions in 2020 from WindEurope, op. cit. note 6, p. 11; additions in 2019 from WindEurope, op. cit. note 23, p. 10; second lowest based on data from S. Hermann, German Environment Agency, personal communication with REN21, 13 April 2021; since 2010 from GWEC, "Global Wind Statistics 2020", op. cit. note 6; shift to tenders from Global Data, "Despite 46% growth in annual installed onshore wind capacity in 2020, Germany still off-target, says GlobalData", 5 February 2021, https://www.globaldata.com/despite-46-growth-annual-installed-onshore-wind-capacity-2020-germany-still-off-target-says-globaldata.

119 Wind energy generated 103,662 GWh onshore and 27,303 GWh offshore for a total of 130,965 GWh, and shares of national gross electricity consumption were 18.7% for onshore wind and 4.9% for offshore wind for a total of 23.6%, all from BMWI and AGEE-Stat, op. cit. note 15, p. 46; increase of 4% based on these data as well as numbers for 2019, from idem, p. 45. Surpassed lignite (92 TWh) for second consecutive year, from Hermann, op. cit. note 118. Nearly passed output of lignite and hard coal (43 TWh) combined, from idem. Note that wind accounted for 24.6% of output; its share increased due in part to a decline in overall electricity demand (and production), based on data from Germany's Federal Statistical Office (Destatis), cited in "Renewables deliver 47% of Germany power in 2020", reNEWS Biz, 5 March 2021, https://renews.biz/66943/renewables-deliver-47-of-germany-power-in-2020. Wind surpassed coal for generation in Germany for first time in 2020, generating 25.6% of electricity fed into the grid, from N. Weekes, "Wind beats coal to top spot in Germany's electricity supply", Windpower Monthly, https://www.windpowermonthly.com/article/1709227/wind-beats-coal-top-spot-germanys-electricity-supply. Wind passed lignite and hard coal (118 TWh combined), from D. Loy, Loy Energy Consulting, Germany, personal communication with REN21, 12 April 2021.

120 Undersubscribed, including in 2020, from WindEurope, op. cit. note 6, p. 23. In Germany, only 2.7 GW of 3.9 GW on offer were awarded because there were not enough projects permitted, from idem. See also C. Richard, "Looking back on 2020 – Part 5: Politicians pledge green post-Covid recovery", Windpower Monthly, 19 January 2021, https://www.windpowermonthly.com/article/1704283/looking-back-2020-%E2%80%93-part-5-politicians-pledge-green-post-covid-recovery; C. Richard, "German onshore wind reverses trend with successful tender", Windpower Monthly, 21 December 2020, https://www.windpowermonthly.com/article/1703315/german-onshore-wind-reverses-trend-successful-tender. Complex planning and local opposition from H. Schmitz, "New distance rules for wind turbines", Noerr, 26 August 2020, https://www.noerr.com/en/newsroom/news/new-distance-rules-for-wind-turbines; undersubscribed and lack of permitted projects from C. Richard, "Government plans to speed up wind lawsuits", Windpower Monthly, September 2020, p. 19, https://www.windpowermonthly.com/article/1692957/read-windpower-monthly-online. The lack of permitted projects is due to lack of investors, with many small- to medium-scale enterprises and community energy investors unable to assume the risks of preparing for and participating in tenders; in addition, well-connected opposition to wind power projects has risen as Germany has transitioned away from the FIT, and the number of local investors (and thus local proponents has declined) as only relatively large-scale developers have been able to participate, from Gsänger, op. cit. note 89, April and May 2021. See also S. Gsänger, WWEA, presentation for "WWEA webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 7 May 2020, https://wwindea.org/wweawebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may. The decline in onshore wind energy installations in Germany is due to switch from FITs to tenders, which brought about dramatic decline in investment, from H-J. Fell, Energy Watch Group, presentation for "WWEA webinar: Wind power and renewable energy policies: What is best to reach 100% RE", 7 May 2020, https://wwindea.org/wweawebinar-wind-power-and-renewable-energy-policies-what-is-best-to-reach-100-re-14-may. The volume of tenders for onshore wind power in 2020 was 3,860 MW in seven rounds; only about 68% of the tender volume awarded (2,672 MW). But participation was up from 2019, when only about half was awarded, from Deutsche WindGuard, *Status of Onshore Wind Energy Development in Germany – Year 2020* (Varel: 2021), p. 8, https://www.windguard.com/publications-wind-energy-statistics.html. The December tender saw bidding for onshore wind exceed

offered capacity for first time in 2020, from A. Lee, "End of year cheer for German onshore wind as tender bids overshoot for first time in 2020", Recharge, 21 December 2021, https://www.rechargenews.com/wind/end-of-year-cheer-for-german-onshore-wind-as-tender-bids-overshoot-for-first-time-in-2020/2-1-935048.

121 According to data from Germany's wind industry association Bundesverband WindEnergie e.V. (BWE), cited in Chamberlain and Sayles, op. cit. note 108.

122 Richard, "German onshore wind reverses trend with successful tender", op. cit. note 120; new rules also from Schmitz, op. cit. note 120; WDR, "Neue Windrad-Abstandsregelung: Was macht NRW?" 19 May 2020, https://www1.wdr.de/nachrichten/landespolitik/einigung-abstandregelung-windkraft-windrad-100.html.

123 Deutsche WindGuard, op. cit. note 120, p. 3; Global Data, op. cit. note 118. The offshore target for 2030 was increased from 15 GW to 20 GW, with an additional target of 40 GW by 2040, from Deutsche WindGuard, *Status of Offshore Wind Energy Development in Germany – Year 2020* (Varel: 2021), p. 4, https://www.windguard.com/publications-wind-energy-statistics.html.

124 WindEurope, op. cit. note 6, p. 18. Wind energy generated an estimated 417 TWh in the EU during the year, from WindEurope, op. cit. note 23, p. 8.

125 Figure of 1.9 percentage points from Komusanac, op. cit. note 13; causes from WindEurope, op. cit. note 6, p. 18. See also "Renewables achieve clean energy record as COVID-19 hits demand", Renewable Energy World, 6 April 2020, https://www.renewableenergyworld.com/2020/04/06/renewables-achieve-clean-energy-record-as-covid-19-hits-demand. Denmark, Germany and Ireland each covered almost 50% of their electricity demand with wind energy in February, due in part to volatile weather and to the large COVID-related demand drop from early February through March, which had the biggest impact on fossil and nuclear generation, but also a general trend of increasing share of wind capacity and generation, all from idem.

126 New Zealand added 103 MW of new capacity for a total of 793 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

127 Australia added 1,097 MW for a total of 7,376 MW, from Clean Energy Council, *Clean Energy Australia Report 2021* (Melbourne: 2021), pp. 84, 88, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf. This was up from a record 837 MW installed in 2019 for a total of 6,279 MW, from idem, p. 88. By year's end, more than 21 projects were under construction or financially committed, representing additional capacity totalling over 4 GW, from idem, p. 84. Australia added 1,097 MW for a total of 7,296 MW, from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

128 Clean Energy Council, op. cit. note 127, pp. 45, 46, 49; figure of 41% from Business Renewables Centre Australia, cited in idem, p. 49.

129 Clean Energy Council, op. cit. note 127, p. 89.

130 Wind power generated 22,605 TWh, accounting for 9.9% of Australia's total generation, from Ibid., p. 9. Increase over 2019 output based on generation of 19.487 TWh in 2019, accounting for 8.5% of Australia's total generation, from Clean Energy Council, *Clean Energy Australia Report 2020* (Melbourne: 8 April 2020), pp. 6, 9, 79, 81, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2020.pdf.

131 Based on data from Green Energy Markets, cited in Clean Energy Council, op. cit. note 127, p. 86. In 2019, the top three states/territories for share of generation from wind energy were South Australia (29.2%), Victoria (27.8%) and New South Wales (22.9%), from Green Energy Markets, cited in Clean Energy Council, op. cit. note 130, p. 80; shares in 2018 were South Australia (35%), Victoria (28%) and New South Wales (19%), from Clean Energy Council, op. cit. note 9, pp. 72-76. For more information, and different statistics, for Victoria, see E. Ingram, "Australia's Victoria doubles share of wind in generation mix in four years", 22 March 2021, https://www.renewableenergyworld.com/wind-power/australias-victoria-doubles-share-of-wind-in-generation-mix-in-four-years.

132 Clean Energy Council, op. cit. note 127, pp. 4-5, 8. Clean Energy Council, op. cit. note 130, pp. 4, 7. See also Solar PV section in this chapter for more on challenges in Australia. Australia is seeing an increasing number of large-scale projects (both wind and solar) that need connection to a 5,000-kilometre transmission line that was built to carry electricity from coal plants near three large mining areas, and not designed to carry electricity from variable and remote wind and solar projects. Delays in project approvals and grid connections are causing project delays and unanticipated costs for developers who fail to account for grid-related issues (e.g., congestion, curtailment), all from S. Paul, "Australia's solar, wind boom to power past grid woes in 2019", *Reuters*, 20 January 2019, https://www.reuters.com/article/us-australia-renewables-idUSKCN1PE0V8.

133 GWEC, "Africa is only tapping into 0.01% of its wind power potential", 4 March 2021, https://gwec.net/africa-is-only-tapping-into-0-01-of-its-wind-power-potential.

134 South Africa installed 515 MW for a year-end total of 2,495 MW, Senegal added 103.5 MW for a total of 158.7 MW and Morocco added 92 MW for a total of 1,315 MW, all from GWEC, op. cit. note 133, and from GWEC, "Global Wind Statistics 2020", op. cit. note 6. Senegal's wind farm began providing electricity to the grid in 2019 and was fully commissioned in 2020, from C. Richard, "First power from first West African wind farm", Windpower Monthly, 12 December 2019, https://www.windpowermonthly.com/article/1668654/first-power-first-west-african-wind-farm; A. Frangoul, "West Africa's first large-scale wind farm starts generating power", CNBC Sustainable Energy, 13 December 2019, https://www.cnbc.com/2019/12/13/west-africas-first-large-scale-wind-farm-starts-generating-power.html. Additional projects in Morocco included a 210 MW wind farm in Midelt that began operations in 2020, and construction starts for a 300 MW project in Boujdour and an 87 MW project in Taza, from L. El Bouazzati, Energy Policy Consultant, Morocco, personal communication with REN21, 4 April 2021. There were several new wind farms in South Africa; see, for example: B. Bungane, "Excelsior wind farm connects to South Africa's power grid", ESI Africa, 17 September 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/excelsior-wind-farm-connects-to-south-africas-power-grid; B. Bungane, "SA's Perdekraal East Wind Farm celebrates commercial operations", ESI Africa, 8 October 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/sas-perdekraal-east-wind-farm-celebrates-commercial-operations; B. Bungane, "South Africa: Kangnas Wind Farm kicks off operations", ESI Africa, 16 November 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/south-africa-kangnas-wind-farm-kicks-off-operations. The 140 MW Nxuba wind farm began commercial operations in late December 2020 or the beginning of January 2021, from T. Smith, "Enel Green Power: Nxuba wind farm now operational in Eastern Cape", ESI Africa, 6 January 2021, https://www.esi-africa.com/industry-sectors/generation/enel-green-power-nxuba-wind-farm-now-operational-in-eastern-cape.

135 Jordan installed 52 MW (including 7 MW reported by GE and the 45 MW Shoubak project) for a total of 527 MW, Iran added 45 MW for a total of 247 MW, Egypt added 13 MW for a total of 1,465 MW, and Tanzania added its first wind project, from GWEC, op. cit. note 133, from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Zhao, op. cit. note 7, 27 April 2021. Tanzania's first wind farm, a 2.4 MW project, was connected to a regional grid to compensate for low water levels during the dry season that reduce output of the local hydropower plant, from Future Power Technology, op. cit. note 7.

136 Numbers of countries by region based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6; cumulative combined capacities in the regions, and in South Africa, Egypt and Morocco, all from idem, from GWEC, op. cit. note 133, and from GWEC, op. cit. note 1, p. 53.

137 Diversify energy mix from, for example: Future Power Technology, op. cit. note 7; T. Smith, "How Egypt banks on renewables to meet likely energy demand surge", ESI Africa, 16 July 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/how-egypt-banks-on-renewables-to-meet-likely-energy-demand-surge; T. Smith, "Wind plans for Ghana gaining momentum", ESI Africa, 21 July 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/wind-plans-for-ghana-gaining-momentum; and (in Mozambique) GWEC, op. cit. note 1, p. 65. Lower costs and meet rising demand from, for example: Smith, "How Egypt banks on renewables to meet likely energy demand surge", op. cit. this note. Reduce reliance on imports from, for example: B. Bungane, "MIGA supports Djibouti's first utility-scale wind project", ESI Africa, 6 May 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/miga-supports-djiboutis-first-utility-scale-wind-project; B. Bungane, "Siemens Gamesa lands contract to build Djibouti's first wind farm", ESI Africa, 26 February 2020, https://www.esi-africa.com/industry-sectors/generation/siemens-gamesa-lands-contract-to-build-djiboutis-first-wind-farm; Smith, "Wind plans for Ghana gaining momentum", op. cit. this note. Free up oil and gas for export from, for example, Smith, "How Egypt banks on renewables to meet likely energy demand surge", op. cit. this note.

138 Bungane, "MIGA supports Djibouti's first utility-scale wind project", op. cit. note 137; Bungane, "Siemens Gamesa lands contract to build Djibouti's first wind farm", op. cit. note 137; Smith, "Wind plans for Ghana gaining momentum", op. cit. note 137.

139 GWEC, op. cit. note 133; "Barriers to foreign Investment", in Future Power Technology, op. cit. note 7; GWEC, "Africa and Middle East add 894MW of wind energy capacity in 2019, market expected to grow by over 10GW by 2024", 12 February 2020, https://gwec.net/africa-and-middle-east-add-894mw-of-wind-energy-capacity-in-2019-market-expected-to-grow-by-over-10gw-by-2024. See also IEA, op. cit. note 54.

140 Based on data from GWEC, "China installed half of new global offshore wind capacity during 2020 in record year", 25 February 2021, https://gwec.net/china-installed-half-of-new-global-offshore-wind-capacity-during-2020-in-record-year, from WindEurope, op. cit. note 6, p. 11, from GWEC, "Global Wind Statistics 2020", op. cit. note 6, and from Yu, op. cit. note 25. Note that GWEC has a figure of 24,837 MW for all of Europe, from idem, whereas Europe had a total 25,013 MW of offshore wind power capacity in operation at end-2020, from WindEurope, op. cit. note 6, pp. 11, 17. An estimated 5.2 GW (including only those projects with entire capacity in operation) was added to grids around the world in 2020, from World Forum Offshore Wind, *Global Offshore Wind Report 2020*, cited in A. McCorkell, "WFO: Record growth for offshore wind in 2020 despite Covid-19", Windpower Monthly, 9 February 2021, https://www.windpowermonthly.com/article/1706847/wfo-record-growth-offshore-wind-2020-despite-covid-19.

141 Figures for 2020 based on data from GWEC, op. cit. note 1, p. 53; less than 5% of capacity in 2019 based on data from GWEC, "Global Wind Statistics 2019", op. cit. note 7; 10% of global installations in 2019 from GWEC, "Record 6.1 GW of new offshore wind capacity installed globally in 2019", 19 March 2019, https://gwec.net/record-6-1-gw-of-new-offshore-wind-capacity-installed-globally-in-2019. Offshore accounted for 12% of commissioned wind power capacity in 2019, up from 8% in 2018, from C. Richard, "Vestas leads the pack with squeezed market share", Windpower Monthly, 18 February 2020, https://www.windpowermonthly.com/article/1674420/vestas-leads-pack-squeezed-market-share.

142 GWEC, op. cit. note 140.

143 China added 3.1 GW for a total of 10.13 GW (preliminary estimates), from Yu, op. cit. note 25, and added 3,060 MW for a total of 9,996 MW, from GWEC, op. cit. note 1, p. 53.

144 GWEC, op. cit. note 1, p. 49; "China's offshore wind energy industry post-2021", reve, 22 October 2020, https://www.evwind.es/2020/10/22/chinas-offshore-wind-energy-industry-post-2021/77839.

145 GWEC, op. cit. note 140; GWEC, op. cit. note 1, p. 49. China's offshore projects must be grid-connected before end of 2021 to qualify for the RMB 0.85 per kWh FIT, from GWEC, op. cit. note 1, p. 49.

146 The three provinces were home to nearly 85% of China's offshore capacity at the end of 2020, based on data from CWEA, "The potential of China offshore wind market and Sino-Norwegian Cooperation", presentation, April 2021, slide 4; 81% from GWEC, "Global Offshore Wind Project Database CY2020" (forthcoming), provided by Zhao, op. cit. note 7, 27 April 2021.

147 Provincial level targets include: Guangdong 30 GW by 2030, Jiangsu 15 GW, Zhejiang 6.5 GW, Fujian 5 GW, Shandong 3 GW; there are also development plans in other coastal provinces, from GWEC, op. cit. note 3, pp. 52-53. In addition, Guangdong is targeting cumulative offshore wind capacity of 15 GW by the end of 2025, from GWEC, op. cit. note 1, pp. 23-24, and from Polaris Wind Power Network News, "Guangdong Province will issue relevant policies to support the development of offshore wind power", 29 September 2020, https://news.bjx.com.cn/html/20200929/1107950.shtml (using Google Translate). Shandong set increased targets to install nearly 20 GW of offshore capacity by 2035, from Y. Yu, "Shandong eyes 20GW to join China's offshore wind top-table", Recharge, 17 July 2020, https://www.rechargenews.com/wind/shandong-eyes-20gw-to-join-chinas-offshore-wind-top-table/2-1-844813.

148 Republic of Korea from GWEC, op. cit. note 140. Japan's first offshore wind auction was launched in June 2020, and the country launched its first auction in July for a floating wind farm that must be at least 16.8 MW, from GWEC, op. cit. note 3, pp. 58, 59. Chinese Taipei from B. Chuang and A. Hwang, "Taiwan becoming Asian hub of offshore wind farms", Digitimes, 15 January 2021, https://www.digitimes.com/news/a20210113PD210.html. Chinese Taipei's capacity includes the 109 MW Changhua Domo and the 640 MW Yulin offshore projects, which began construction offshore in 2020; including offshore projects that began work but only onshore, the total recorded was 2,634 MW under construction at end-2020, from Zhao, op. cit. note 7, 27 April 2021.

149 The Republic of Korea targets 9.2 GW by 2025 and 16 GW by 2030, with 12 GW of this from offshore wind, from GWEC, op. cit. note 1, p. 26. Complex terrain, turbulent winds and strong incumbents (both coal in the energy sector and the fishing industry in the marine sector) make the Republic of Korea a challenging market, from GWEC, op. cit. note 3, p. 66. Japan targets are based on approved projects under the current feed-in tariff and will require that at least 60% of project equipment be sourced from domestic suppliers, from I-Ching Tseng, "Japan plans 45GW offshore wind power by 2040", Pinsent Mason, 23 December 2020, https://www.pinsentmasons.com/out-law/news/japan-plans-45gw-offshore-wind-power-by-2040, and from Public-Private Council on Enhancement of Industrial Competitiveness for Offshore Wind Power Generation, *Vision for Offshore Wind Power Industry (1st)* (Tokyo: 15 December 2020), pp. 6, 10, https://www.meti.go.jp/shingikai/energy_environment/yojo_furyoku/pdf/002_02_e02_01.pdf.

150 J. S. Hill, "Ørsted signs world's largest corporate renewable PPA in Taiwan", RenewEconomy, 9 July 2020, https://reneweconomy.com.au/orsted-signs-worlds-largest-corporate-renewable-ppa-in-taiwan-38136; J. Parnell, "Microchip giant TSMC signs 'world's largest' corporate renewables deal — for offshore wind", Greentech Media, 8 July 2020, https://www.greentechmedia.com/articles/read/orsted-signs-worlds-largest-corporate-ppa. TSMC (Chinese Taipei), the world's largest semiconductor manufacturer and supplier to Apple, signed the PPA with developer Ørsted, from Hill, op. cit. this note.

151 Parnell, op. cit. note 150; J. Parnell, "What offshore wind can bring to the corporate PPA party", Greentech Media, 1 June 2020, https://www.greentechmedia.com/articles/read/what-offshore-wind-can-bring-to-the-corporate-ppa-party.

152 WindEurope, *Offshore Wind in Europe – Key Trends and Statistics 2020* (Brussels: February 2021), p. 7, https://windeurope.org/data-and-analysis/product/offshore-wind-in-europe-key-trends-and-statistics-2020. See also Parnell, op. cit. note 150; Parnell, op. cit. note 151.

153 WindEurope, op. cit. note 152, p. 34.

154 Europe added 2,918 MW for a total of 25,013 MW, and no offshore capacity was decommissioned during the year, fromWindEurope, op. cit. note 6, pp. 11, 17; down 20% from WindEurope, op. cit. note 152, p. 9. At the end of 2020, Europe had a total of 5,402 grid-connected turbines in 116 offshore wind farms, including some with partial grid connection) across 12 countries, from WindEurope, op. cit. note 152, pp. 7, 9.

155 The Netherlands added 1,493 MW for a total of 2,611 MW, Belgium added 706 MW for a total of 2,261 MW, the United Kingdom added 483 MW for a total of 10,428 MW, Germany added 219 MW for a total of 7,689 MW and Portugal added 17 MW for a total of 25 MW, all from WindEurope, op. cit. note 6, p. 11. See also WindEurope, op. cit. note 152, p. 10. Data from GWEC are similar with the exceptions of the United Kingdom (483 MW added for total of 10,206 MW) and Germany (237 MW added for total of 7,728 MW), from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

156 The UK pipeline totalled more than 41 GW by early 2021, from GWEC, op. cit. note 1, p. 30. The UK slowdown was a result of time between the Contracts for Difference rounds 1 and 2, from GWEC, op. cit. note 140.

157 Lowest in nearly a decade from WindEurope, op. cit. note 152, p. 11; no projects under construction from Deutsche WindGuard, op. cit. note 123, p. 3; all planned projects had been installed from Hermann, op. cit. note 118. Germany's offshore wind tenders in 2017 and 2018 had a long period of time before commissioning deadlines, which caused a gap in projects due to the shift from administrative tariffs to auctions, from Komusanac, op. cit. note 13. New law and offshore tender volumes from Die Bundesregierung, "Mehr Rückenwind für den Strom – auch seitens der EU", 22 January 2021, https://www.bundesregierung.de/breg-de/themen/klimaschutz/fuer-mehr-windenergie-auf-see-1757176, viewed 27 April 2021. See also BMWi, "Altmaier: 'Deutschland baut seine Vorreiterrolle im Bereich Windenergie auf See weiter aus'", 9 December 2020, https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/12/20201209-altmaier-deutschland-baut-seine-vorreiterrolle-im-bereich-windenergie-auf-see-weiter-aus.html.

158 WindEurope, op. cit. note 152, p. 11.

159 Figure of 62 MW (83% of the global total) and pipeline, from WindEurope, op. cit. note 152, pp. 20, 21. The Windfloat Atlantic project has a total of 25 MW; in Scotland, the 50 MW Kincardine project, which will use five 9.5 MW floating turbines, was under construction in 2020, from idem.

160 WindEurope, op. cit. note 152, pp. 7, 14. The other countries with offshore capacity are Sweden, Finland, Ireland, Portugal, Spain, Norway and France, from idem.

161 Ibid., pp. 6-7, 32-33. The total includes EUR 2.1 billion (USD 2.58 billion) in offshore transmission infrastructure, from Komusanac, op. cit. note 13.

162 United Kingdom from Government of the UK, "New plans to make UK world leader in green energy", 6 October 2020, https://www.gov.uk/government/news/new-plans-to-make-uk-world-leader-in-green-energy; C. Richard, "UK's 40GW offshore wind target under pressure after leasing round delay", Windpower Monthly, 15 October 2020, https://www.windpowermonthly.com/article/1697347/uks-40gw-offshore-wind-target-pressure-leasing-round-delay. Germany from Deutsche WindGuard, op. cit. note 123, p. 4, from D. Foxwell, "Germany agrees big boost to offshore wind capacity", Riviera, 12 May 2020, https://www.rivieramm.com/news-content-hub/news-content-hub/germany-agrees-big-boost-to-offshore-wind-and-green-hydrogen-plan-59322, and from V. Petrova, "German Cabinet okays 40 GW offshore wind target", Renewables Now, 4 June 2020, https://renewablesnow.com/news/german-cabinet-okays-40-gw-offshore-wind-target-701416. Germany also set a target of 40 GW by 2040, from Deutsche WindGuard, op. cit. note 123. Other target-related developments in 2020 include: France increased its offshore wind tender goal for 2028 from 4.7-5.2 GW up to 8.75 GW, and aims for 2.4 GW with targeted commissioning by 2023, and for 5.2-6.2 GW to be operational by 2028, from "France to become Europe's fourth-largest offshore wind producer in 2030", Offshore Source, 6 May 2020, https://www.offshoresource.com/news/renewables/france-to-become-europe-s-fourth-largest-offshore-wind-producer-in-2030.

163 WindEurope, op. cit. note 152, p. 35. As of late 2020, the EU planned to aim for at least 60 GW of offshore capacity by 2030 and 300 GW by 2050, from A. Frangoul, "Europe is planning a 25-fold increase in offshore wind capacity by 2050", CNBC, 19 November 2020, https://www.cnbc.com/2020/11/19/europe-plans-25-fold-increase-in-offshore-wind-capacity-by-2050.html. Note that this target could include Turkey; Turkey's Energy and Natural Resources Ministry has a strategic plan that envisages 10 GW of offshore wind projects over the coming years, from Daily Sabah, "Turkey holds 75 gigawatts of offshore wind energy potential", 19 April 2021, https://www.dailysabah.com/business/energy/turkey-holds-75-gigawatts-of-offshore-wind-energy-potential.

164 US states with targets as of late 2020 included: Maryland (1.2 GW by 2030), Connecticut (2 GW by 2030), Virginia (5.2 GW by 2034), Massachusetts (3.2 GW by 2035), New Jersey (7.5 GW by 2035) and New York (2.4 GW by 2030 and 9 GW by 2035), from GWEC, op. cit. note 3, p. 21. See also T. Casey, "Empire State blows past offshore wind limit with 1,000 (more) MW", CleanTechnica, 24 April 2020, https://cleantechnica.com/2020/04/24/empire-state-blows-past-offshore-wind-limit-with-1000-more-mw, and K. Stromsta, "Second US offshore wind project finishes construction off Virginia", Greentech Media, 29 June 2020, https://www.greentechmedia.com/articles/read/second-us-offshore-wind-farm-finishes-construction-off-virginia.

165 W. Musial et al., *2019 Offshore Wind Technology Data Update* (Golden, CO: National Renewable Energy Laboratory (NREL), October 2020), pp. 18, 22, https://www.nrel.gov/docs/fy21osti/77411.pdf.

166 ACPA, *U.S. Offshore Wind Industry: Status Update 2021* (Washington, DC: 2021), p. 1, https://cleanpower.org/wp-content/uploads/2021/02/ACP_FactSheet-Offshore_Final.pdf; GWEC, op. cit. note 3, pp. 21, 53; Musial et al., op. cit. note 165, p. 23. Another project (2.6 GW) was planned for the adjacent site, with construction scheduled to start in 2024, from Stromsta, op. cit. note 164, and from Broehl, op. cit. note 70.

167 New York from Musial et al., op. cit. note 165, p. 19, and from "New York launches renewable energy solicitations for 4GW capacity", NS Energy Business, 22 July 2020, https://www.nsenergybusiness.com/news/new-york-state-renewable-energy-solicitations. The winner of two additional contracts (Equinor) for this 2.5 GW was announced in January 2021, from N. Greene, "In 2021 it's off to the races for offshore wind", Natural Resources Defense Council, 22 January 2021, https://www.nrdc.org/experts/nathanael-greene/2021-its-races-offshore-wind. Rhode Island and Massachusetts from ACPA, op. cit. note 58, p. 16. Icebreaker on Lake Erie from K. M. Kowalski, "Ohio regulators OK Lake Erie wind farm with 'poison pill' that may kill project", Energy News Network, 21 May 2020, https://energynews.us/2020/05/21/midwest/ohio-regulators-ok-lake-erie-wind-farm-with-poison-pill-that-may-kill-project; K. Stromsta, "'This could be final nail in coffin' for Icebreaker offshore wind project", Greentech Media, 22 May 2020, https://www.greentechmedia.com/articles/read/final-nail-in-coffin-for-icebreaker-first-offshore-wind-project-in-great-lakes; J. Pelzer, "Plans for Lake Erie wind farm clear a major hurdle, as 'poison pill' restriction is lifted", MSN, 17 September 2020, https://www.msn.com/en-us/news/us/plans-for-lake-erie-wind-farm-clear-a-major-hurdle-as-poison-pill-restriction-is-lifted/ar-BB199xys. Louisiana from Office of the Governor, "Gov. Edwards announces renewable energy initiative for Gulf of Mexico", 9 November 2020, https://gov.louisiana.gov/index.cfm/newsroom/detail/2790.

168 J. Partlow, "Interior Department approves first large-scale offshore wind farm in the U.S.", *Washington Post*, 11 May 2021, https://www.washingtonpost.com/nation/2021/05/11/interior-department-approves-first-large-scale-offshore-wind-farm-us.

169 Total of 18 includes Germany, Spain, the United Kingdom, France, Sweden, Denmark, the Netherlands, Ireland, Belgium, Norway, Finland and Portugal in Europe, from WindEurope, op. cit. note 6, and same countries in 2019, from WindEurope, *Offshore Wind in Europe: Key Trends and Statistics 2019* (Brussels: February 2020), p. 7, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2019.pdf; China, Japan, Chinese Taipei, the Republic of Korea and Vietnam in Asia; and the United States, all based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

170 WindEurope, op. cit. note 6, p. 11; GWEC, op. cit. note 1, p. 53; GWEC, "Global Wind Statistics 2020", op. cit. note 6; Yu, op. cit. note 25. Note that data for Europe from GWEC and WindEurope are similar with the exceptions of the United Kingdom, for which GWEC has 10,206 MW and WindEurope has 10,428 MW, and Germany, for which GWEC has 7,728 MW and WindEurope has 7,689 MW, from GWEC, op. cit. this note.

171 Europe share in 2020 based on data from GWEC, op. cit. note 1, p. 53, from WindEurope, op. cit. note 6, p. 11, and from Yu, op. cit. note 25. Europe home to 75% in 2019, based on data from GWEC, "Webcast on wind: Market update and outlook for global offshore wind", 19 March 2020; figures of 79% in 2018, down from 84% in 2017 and 88% in 2016, based on data from GWEC, *Global Wind Report 2018*, op. cit. note 7. **Figure 36** based on data from the following: GWEC, "Global Wind Statistics 2020", op. cit. note 6; GWEC, op. cit. note 1, p. 52; WindEurope, op. cit. note 6, p. 11; WindEurope, op. cit. note 169, pp. 7, 8; WindEurope, *Offshore Wind in Europe – Key Trends and Statistics 2017* (Brussels: February 2018), p. 6, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf; WindEurope, *The European Offshore Wind Industry – Key Trends and Statistics 2016* (Brussels: January 2017), p. 17, https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf; Yu, op. cit. note 25; ACPA, op. cit. note 166, p. 1; AWEA, "First US offshore wind farm unlocks vast new ocean energy resource", press release (Block Island, RI: 12 December 2016), http://www.awea.org/MediaCenter/pressreleasev2.aspx?ItemNumber=9627.

172 Musial et al., op. cit. note 165, p. 30. As of late 2020, the global offshore pipeline was 230,174 MW, including 27,064 MW in operation and 81,872 MW approved through regulatory processes, reached financial close, or under construction, and 203,110 MW announced, from idem.

173 G. Dixon, "$51bn in wind farm capital spending outstrips oil and gas for first time", TradeWinds, 2 February 2021, https://www.tradewindsnews.com/offshore/-51bn-in-wind-farm-capital-spending-outstrips-oil-and-gas-for-first-time/2-1-955552, cited in GWEC, op. cit. note 1, p. 9.

174 Total and number of countries based on data from GWEC, "Global Wind Statistics 2020", op. cit. note 6.

175 WindEurope, op. cit. note 6, p. 17. For Belgium, France, Luxembourg and the United Kingdom, decommissioned capacity amounted to 25 MW, 15 MW, 2 MW and 0.3 MW respectively, from idem. A total of 388 MW was fully decommissioned across Europe in 2020, from WindEurope, "WindEurope Bulletin CEO

Foreword on release of 2020 Statistics", press release (Brussels: 3 March 2021), https://windeurope.org/newsroom/news/windeurope-bulletin-ceo-foreword-on-release-of-2020-statistics.

176 GWEC, "Global Wind Statistics 2020", op. cit. note 6. Japan decommissioned 35 MW onshore and 7 MW offshore, and the Republic of Korea decommissioned 4.7 MW onshore, from idem.

177 WindEurope, op. cit. note 152, p. 35; IEA, "Renewable energy market update – report extract: Technology summaries", https://www.iea.org/reports/renewable-energy-market-update/technology-summaries#abstract, viewed 5 May 2021; IEA, op. cit. note 54.

178 IEA, op. cit. note 177; IEA, op. cit. note 54.

179 Richard, "Looking back on 2020", op. cit. note 120; IEA, op. cit. note 177; IEA, op. cit. note 54.

180 WindEurope, op. cit. note 152, p. 35; BloombergNEF, "Covid-19 wreaks havoc on the wind industry", 1 April 2020, https://about.bnef.com/blog/covid-19-wreaks-havoc-on-the-wind-industry; N. Ford, "Solar, wind investors adapt PPAs for post-COVID pickup", Reuters Events, 6 May 2020, https://analysis.newenergyupdate.com/pv-insider/solar-wind-investors-adapt-ppas-post-covid-pickup; C. Bussewitz, J. Flesher and P. Whittle, "Solar, wind energy struggle as coronavirus takes toll", *Associated Press*, 2 May 2020, https://apnews.com/e3ea11613c2ad83f05bc85f75a26181a; B. Radowitz, "Stricter Covid-19 shutdown forces wind OEMs to close all 'non-essential' plants in Spain", Recharge, 30 March 2020, https://www.rechargenews.com/wind/stricter-covid-19-shutdown-forces-wind-oems-to-close-all-non-essential-plants-in-spain/2-1-783868; E. Crouse and D. Conner, "Opinion: Distressed supply chains uniquely impact renewable energy", *Puget Sound Business Journal*, 20 April 2020, https://www.bizjournals.com/seattle/news/2020/04/20/distressed-supply-chains-uniquely-impacts-energy.html; C. Richard, "O&M budgets 'slashed' during Covid-19 pandemic", Windpower Monthly, 21 July 2021, https://www.windpowermonthly.com/article/1689926/o-m-budgets-slashed-during-covid-19-pandemic; IEA, op. cit. note 177; IEA, op. cit. note 54.

181 C. Richard, "Looking back on 2020 – how wind defied global pandemic", Windpower Monthly, 13 January 2021, https://www.windpowermonthly.com/article/1704181/looking-back-2020-%E2%80%93-part-1-wind-industry-defied-global-pandemic; Richard, op. cit. note 180. Wind turbine manufacturers margins have been eroded by several factors, including the introduction of auctions, global trade tensions and pandemic-induced disruptions, from Siemens Gamesa, *Annual Report 2020* (Vizcaya: 2021), p. 16, https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/investors-and-shareholders/annual-reports/2020/siemens-gamesa-renewable-energy-annual-report-2020-en.pdf.

182 See text and sources throughout this Wind Power section. Grid challenges from, for example, St. John, op. cit. note 73; GWEC, op. cit. note 1; E. Holbrook, "New report shows power purchase agreement prices rising across North America", Environment + Energy Leader, 21 October 2020, https://www.environmentalleader.com/2020/10/new-report-shows-power-purchase-agreement-prices-rising-across-north-america. Grid congestion from L. Gorroño, Aalborg University, Denmark, presentation for "Why community power matters in times of crisis – industrialised countries", WWEA, 30 April 2020, https://wwindea.org/wwea-presents-why-community-power-matters-in-times-of-crisis-industrialised-countries-on-30-april. Land and resources from, for example, Gerdes, op. cit. note 72; grid congestion from Lydersen, op. cit. note 72; China's main wind power regions are approaching saturation, with fewer available sites, from Baiyu, op. cit. note 35; India is a predominantly low-wind market, from "Vestas launches low-wind turbine in India",enews Biz, 6 October 2020, https://renews.biz/63578/vestas-launches-low-wind-turbine-in-india. Lack of available land with good resources is a driver for manufacturers' development of turbines for low-wind sites, as well as for development offshore.

183 See text and sources throughout this Wind Power section. Permitting delays and public opposition from, for example, Chamberlain and Sayles, op. cit. note 108; Schmitz, op. cit. note 120; C. Richard, "WindEurope: Permitting key hurdle to EU wind investments", Windpower Monthly, 13 April 2021, https://www.windpowermonthly.com/article/1712657/windeurope-permitting-key-hurdle-eu-wind-investments. The diversity of investors is increasing with the shift from FITs to auctions, which is having an indirect negative impact on social support for wind farms, with local citizens often not identifying themselves with local wind energy projects, from Gsänger, op. cit. note 89, 14 April and 20 April 2021. Social acceptance has been a major challenge in many countries and reduced social interaction (such as during the pandemic) further increased the risk of project delays, from IEA, op. cit. note 177; in Denmark, projects are facing increasing local opposition, from Gorroño, op. cit. note 182. Price pressures from, for example, Gsänger, op. cit. note 89, 14 April and 20 April 2021; GWEC, *Global Wind Report 2019*, op. cit. note 11, p. 11; A. Hübner and M. Martin, "German wind turbine maker Senvion files for insolvency", *Reuters*, 9 April 2019, https://uk.reuters.com/article/us-germany-senvion/german-wind-turbine-maker-senvion-files-for-insolvency-idUKKCN1RL271; "Wind margin pressures shift from turbines to service market", New Energy Update, 7 March 2019, https://analysis.newenergyupdate.com/wind-energy-update/wind-margin-pressures-shift-turbines-service-market. Wind turbine manufacturers margins have been eroded by several factors, including the introduction of auctions, global trade tensions and pandemic-induced disruptions, from Siemens Gamesa, op. cit. note 181, p. 16. Delays due to reassigned staff from Komusanac, op. cit. note 13.

184 See text and sources throughout this Wind Power section. Lack of investment and participants driving prices up in some markets, from Gsänger, op. cit. note 89, 14 April and 20 April 2021. In the Russian Federation, for example, the average price of onshore wind energy is substantially higher than in the rest of Europe due to the small size of the market and lack of competition and of local equipment production, from Lanshina, op. cit. note 93, p. 34.

185 For example: In the United States, projects under construction but delayed by COVID were permitted an additional year to be placed into service and still qualify for tax credits, from Musial et al., op. cit. note 165, p. 25; R. Frazin, "Trump administration gives renewables more time to take advantage of tax credits", The Hill, 27 May 2020, https://thehill.com/policy/energy-environment/499837-trump-administration-gives-renewables-more-time-to-take-advantage. At the same time, however, the US government ended a two-year rent holiday for renewable energy (wind, solar and geothermal) projects on federal lands, and many plant owners received large retroactive bills, from N. Groom, "Trump admin slaps solar, wind operators with retroactive rent bills", *Reuters*, 18 May 2020, https://www.reuters.com/article/us-usa-interior-renewables/trump-admin-slaps-solar-wind-operators-with-retroactive-rent-bills-idUSKBN22U0FW. In France, onshore wind (and solar PV) developers were granted extensions for installation schedules and auction timetables were adjusted, from C. Richard, "Prices hit new low in French onshore", 2 April 2020, https://www.windpowermonthly.com/article/1679192/prices-hit-new-low-french-onshore. In Greece, the government extended licencing and construction deadlines, from C. Richard, "Greece momentum continues with record onshore prices", Windpower Monthly, 9 April 2020, https://www.windpowermonthly.com/article/1679862/greece-momentum-continues-record-onshore-prices. Germany's parliament enacted several measures to address the backlog in onshore permitting, from J. Parnell, "Onshore wind compromise averts German solar market crisis", 18 May 2020, https://www.greentechmedia.com/articles/read/onshore-wind-policy-dispute-could-decimate-germanys-distributed-solar-industry, and enacted a six-month extension to commissioning deadlines, from IEA, op. cit. note 54. In Turkey, the main support scheme for onshore wind power (a feed-in tariff in place since 2011) was extended by six months, to mid-2021, to account for project delays due to the pandemic, from WindEurope, "Turkey offers more visibility on wind energy pipeline with new support scheme", press release (Brussels: 11 February 2021), https://windeurope.org/newsroom/news/turkey-offers-more-visibility-on-wind-energy-pipeline-with-new-support-scheme; N. Erkul, "Tariff scheme key for investors in Turkey's renewables", Anadolu Agency, 1 March 2020, https://www.aa.com.tr/en/energy/finance/tariff-scheme-key-for-investors-in-turkey-s-renewables/28511; A. Richter, "Turkey extends feed-in-tariff scheme for geothermal to mid-2021", Think GeoEnergy, 18 September 2020, https://www.thinkgeoenergy.com/turkey-extends-feed-in-tariff-scheme-for-geothermal-to-mid-2021.

186 B. Backwell, "The three 'Rs' took the wind industry through a tough year – and I can't help feeling optimistic", GWEC, 31 December 2020, https://gwec.net/the-three-rs-took-the-wind-industry-through-a-tough-year; Richard, "Looking back on 2020", op. cit. note 181, C. Richard, "Global turbine orders rise in 2020 despite early Covid-19 slump", Windpower Monthly, 22 January 2021, https://www.windpowermonthly.com/article/1705192/global-turbine-orders-rise-2020-despite-early-covid-19-slump.

187 See examples and sources below in this section.

188 Backwell, op. cit. note 186; GWEC, op. cit. note 1; and from information and sources throughout this section.

189 Based on the LCOE of onshore wind energy falling from USD 48 per MWh in the second half of 2019 to USD 41 per MWh in the second half of 2020, and the LCOE of offshore wind energy falling from USD 80 per MWh to USD 79 per MWh during the same period, from BloombergNEF, provided by Zhao, op. cit. note 7, 27 April 2021. LCOE continued to decline significantly in 2020 for onshore and offshore wind in China, from Q. Haiyan, CWEA, presentation for "WWEA webinar: Wind power around the world", 7 April 2021, https://wwindea.org/wweawebinar-wind-power-around-the-world. In the previous year, onshore LCOE declined 10% from 2018 to 2019, to average of USD 48.5 per MWh, and fell 28% offshore to USD 83.50 per MWh, from FS-UNEP and BloombergNEF, op. cit. note 9, p. 28. In the United States, cost reductions have accelerated in recent years, from Lawrence Berkeley National Laboratory (LBNL), "Experts anticipate sustained wind energy cost reductions and technology advancements", fact sheet (Berkeley, CA: 2021), https://eta-publications.lbl.gov/sites/default/files/expert_survey_factsheet.pdf. LCOE estimates vary widely from place to place and are influenced by several factors, including resources and local regulatory, finance and labour cost characteristics, upfront capital costs, project design life, capacity factor and operating costs, from idem, and from J. Broehl, "Beating the projections: Future wind costs 50 percent lower than predicted five years ago", 21 April 2021, https://cleanpower.org/blog/beating-the-projections-future-wind-costs-50-percent-lower-than-predicted-five-years-ago.

190 See, for example, FS-UNEP and BloombergNEF, op. cit. note 9, p. 28; IEA, op. cit. note 54; BloombergNEF, cited in C. Richard, "Renewables 'cheapest option for most of the world'", Windpower Monthly, 29 April 2020, https://www.windpowermonthly.com/article/1681740/renewables-cheapest-option-world; S. Evans, "Wind and solar are 30-50% cheaper than thought, admits UK government", CarbonBrief, 27 August 2020, https://www.carbonbrief.org/wind-and-solar-are-30-50-cheaper-than-thought-admits-uk-government.

191 Figures of 26.5%, 35 GW and second highest on record, from GWEC, "Nearly 30 GW of new wind power capacity auctioned in H2 2020, a clear signal that growth is back on-track", 15 February 2021,https://gwec.net/nearly-30-gw-of-new-wind-power-capacity-auctioned-in-h2-2020-a-clear-signal-that-growth-is-back-on-track; 33.7 GW onshore from GWEC, op. cit. note 1, p. 46. Note that 3,770 MW of this is from the hybrid auction in India, from Zhao, op. cit. note 7, 27 April 2021.

192 Capacity reduced and postponements from GWEC, "GWEC Market Intelligence releases Q1 2020 Wind Auctions Database", 14 May 2020, https://gwec.net/gwec-market-intelligence-releases-q1-2020-wind-auctions-database. Auctioned capacity was down in the first four months of year (3.35 GW) relative to same period in 2019 (almost 5 GW); early auctions occurred in Europe (2.1 GW) and Asia (1.2 GW), with delays in several countries including Brazil, China and the United States, from idem. Second half of 2020 from GWEC, op. cit. note 191. Nearly 30 GW of new onshore capacity awarded through auction in second half of 2020, up from 28 GW during same period of 2019, from idem. Auctions postponed or cancelled for 2020 in Brazil, Chile and the United States were rescheduled for 2021, from idem.

193 China accounted for 67%, and "subsidy-free" onshore wind projects represented 96% of China's approved capacity, from GWEC, op. cit. note 191.

194 Figure of 13 countries or regions based on the following: GWEC database, provided by Zhao, op. cit. note 7, 27 April 2021; several countries in Europe, Ecuador and India from GWEC, op. cit. note 191; WindEurope, op. cit. note 6, p. 23; Windpower Monthly/Windpower Intelligence, "Tender Watch", https://www.windpowermonthly.com/tender-watch, viewed 7 March 2021. In order of awarded capacity, these countries were: India (2.2 GW), Germany (1.5 GW), Poland (900 MW), the Netherlands (759 MW) Ireland (479 MW), Greece (472 MW), France (258 MW) and Ecuador (110 MW), from GWEC, op. cit. note 191. Italy also held several (technology-neutral) auctions during the year, from WindEurope, op. cit. note 6, p. 23. An auction also was held in the US state of New Jersey, based on data from Windpower Monthly/Windpower Intelligence, op. cit. this note, and from New Jersey Board of Public Utilities, "New Jersey offshore wind solicitation #2", https://njoffshorewind.com.

195 See, for example, WindEurope, op. cit. note 23, pp. 8, 21; IRENA, *Renewable Energy Auctions: Status and Trends Beyond Price* (Abu Dhabi: 2019), p. 14, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Dec/IRENA_RE-Auctions_Status-and-trends_2019.pdf.

196 Figures for 2020 from Komusanac, op. cit. note 13; figures for 2019 from Komusanac, op. cit. note 13, 14 April 2020.

197 Richard, "Looking back on 2020", op. cit. note 120. See also Richard, "Greece momentum continues with record onshore prices", op. cit. note 185; H. O'Brian, "Wind corners Italy's first joint auction", Windpower Monthly, 29 January 2020, https://www.windpowermonthly.com/article/1672375/wind-corners-italys-first-joint-auction; C. Richard, "Shell advances hydrogen plan with Eneco deal", Windpower Monthly, 7 May 2020, https://www.windpowermonthly.com/article/1682629/shell-advances-hydrogen-plan-eneco-deal.

198 Bid prices rose in Italy from Komusanac, op. cit. note 13. Italy's 2020 auctions were undersubscribed due to the slow permitting process, from WindEurope, op. cit. note 6, p. 23. Note that a total of four auctions were held by end-2020, with the first in 2019, when the auction was oversubscribed for group A (solar PV and wind power), with bids for 595 MW, well above the 500 MW available capacity, from A. Di Pardo, Gestore dei Servizi Energetici (GSE), Italy, personal communication with REN21, 7 April 2021.

199 Gsänger, op. cit. note 89, 7 May 2020 and 14 April 2021. All wind-specific auctions in Germany had average winning bids above EUR 62 (USD 76.2) per MWh and around the ceiling price and above prices from previous years, from Komusanac, op. cit. note 13. See also BMWi, "Ausschreibungsergebnisse Windenergie an Land", https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/ausschreibungsrunden-windenergie-an-land-balkendiagramm.pdf, viewed 27 April 2021, and Bundesnetzagentur, "Completed tenders", https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Ausschreibungen/Wind_Onshore/BeendeteAusschreibungen/BeendeteAusschreibungen_node.html, viewed 27 August 2021. Awarded bid prices fell significantly in the first year of auctions in Germany, but increased in 2018 and 2019, to above the statutory tariffs of the old EEG, or Germany's FIT, from WWEA and Landesverband Erneuerbare Energien Nordrhein-Westfalen (LEE NRW), *Community Wind Under the Auctions Model: A Critical Appraisal* (Bonn/Düsseldorf: September 2019), WWEA Policy Paper Series, pp. 7, 11, https://wwindea.org/download/community-power-study-september-2019, and from Gsänger, op. cit. note 89, 7 May 2020. Note that the final onshore wind tender of 2020 was not undersubscribed, from Richard, "German onshore wind reverses trend with successful tender", op. cit. note 120; but the first of 2021 was undersubscribed, with the average winning bid price up slightly relative to the final tender in 2020, from C. Richard, "Developers stay away from German onshore wind tender", Windpower Monthly, 30 April 2021, https://www.windpowermonthly.com/article/1714500/developers-stay-away-german-onshore-wind-tender.

200 Council on Energy, Environment and Water, Centre for Energy Finance, *Clean Energy Investment Trends 2020* (New Delhi: 2020), https://cef.ceew.in/solutions-factory/CEEW-CEF-clean-energy-investment-trends-2020.pdf.

201 Rise in tariffs, regulatory environment and suitable sites, all from Prasad, op. cit. note 46; decline in participants and competition from Gsänger, op. cit. note 89, 20 April 2021. India had a very diverse wind power sector with dozens of small and medium enterprises investing, but only a handful of large companies has participated in auctions, representing a dramatic reduction in competition and diversity of actors, from idem.

202 Government of the Netherlands, "Shell and Eneco to build third unsubsidised Dutch offshore wind farm", 29 July 2020, https://www.government.nl/latest/news/2020/07/29/shell-and-eneco-to-build-third-unsubsidised-dutch-offshore-wind-farm; WindEurope, op. cit. note 6, p. 23; J. Parnell, "Dutch offshore wind tender deadline passes amid concerns of depressed interest", Greentech Media, 1 May 2020, https://www.greentechmedia.com/articles/read/dutch-offshore-wind-tender-closes-amid-fears-of-falling-interest. Seabed rights from Komusanac, op. cit. note 13. The second such tender was held in 2019, from GWEC, *Global Wind Report 2019*, op. cit. note 11, p. 38; A. Lee, "Vattenfall wins 760 MW of Dutch zero-subsidy offshore wind", Recharge, 10 July 2019, https://www.rechargenews.com/wind/vattenfall-wins-760mw-of-dutch-zero-subsidy-offshore-wind/2-1-636547. The first was

held in 2018, from WindEurope, "World's first offshore wind farm without subsidies to be built in the Netherlands", press release (Brussels: 20 March 2018), https://windeurope.org/newsroom/press-releases/worlds-first-offshore-wind-farm-without-subsidies-to-be-built-in-the-netherlands.

203 "Shell, Eneco win Dutch offshore wind tender", reNEWS, 29 July 2020, https://renews.biz/62089/shell-eneco-win-dutch-offshore-wind-tender.

204 New Jersey from Windpower Monthly / Windpower Intelligence, op. cit. note 194, and from New Jersey Board of Public Utilities, "New Jersey offshore wind solicitation #2", https://njoffshorewind.com; "France launches 1GW Normandy offshore tender", reNEWS Biz, 7 December 2020, https://renews.biz/64975/france-launches-1gw-normandy-offshore-tender.

205 WWEA, op. cit. note 3.

206 Ibid.

207 Trended up from Holbrook, op. cit. note 182; down in final quarter from H. Edwardes-Evans, "PPA prices dip in Q4 2020 as developers absorb COVID impacts: LevelTen", SP Global, 13 January 2021, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/011321-ppa-prices-dip-in-q4-2020-as-developers-absorb-covid-impacts-levelten.

208 Holbrook, op. cit. note 182; E. Holbrook, "Report: North American PPA prices rose throughout 2020", Environment + Energy Leader, 20 January 2021, https://www.environmentalleader.com/2021/01/report-north-american-ppa-prices-rose-throughout-2020; E. Penrod, "Renewable PPAs could see 'sellers market' in 2021 after year of price increases, LevelTen finds", Utility Dive, 21 January 2021, https://www.utilitydive.com/news/renewable-ppa-prices-are-rising-for-the-first-time-creating-potential-sel/593708. Windiest sites with easy grid access (so new sites often have either less strong winds and/or more development challenges) from Broehl, op. cit. note 70.

209 LBNL, "Wind Technologies Market Report", https://emp.lbl.gov/wind-technologies-market-report, viewed 15 February 2021.

210 C. Richard, "Mayflower lowers US offshore to $58/MWh", Windpower Monthly, 12 February 2020, https://www.windpowermonthly.com/article/1673776/mayflower-lowers-us-offshore-58-mwh; 13% from K. Stromsta, "Why 2020 has been a surprisingly good year for US offshore wind", Greentech Media, 25 September 2020, https://www.greentechmedia.com/articles/read/why-2020-has-been-a-surprisingly-good-year-for-us-offshore-wind.

211 More than 100 suppliers from GWEC, *Global Wind Report 2019*, op. cit. note 11, p. 18; down from 63 original equipment manufacturers that reported installations in 2013, and 51 in 2015, and 33 suppliers reported installations in 2019 (20 of these were from Asia Pacific), also from F. Zhao, J. Lee and A. Lathigara, *Global Wind Market Development – Supply Side Data 2019* (Brussels: GWEC, May 2020), p. 20. In 2019, 20 of the 33 turbine suppliers were from Asia Pacific, from idem. Data for 2020 were not available by date of publication. However, the number of turbine manufacturers installing machines in 2020 may have been higher than in 2019 (33 total) due to the rush of installations in China; in addition, Hyundai (Republic of Korea) reported installations during the year, from Zhao, op. cit. note 7, 27 April 2021.

212 Top six in 2020 from GWEC, op. cit. note 1, p. 17; 64% in 2017 based on data from FTI Consulting, *Global Wind Market Update – Demand & Supply 2017, Part One – Supply Side Analysis* (London: April 2018), pp. 6, 10, 11. In 2019 the top 10 companies captured 85.5% of the capacity installed, from share from Zhao, op. cit. note 7, 15 May 2020, and from Zhao, Lee and Lathigara, op. cit. note 211. This was up from 85% in 2018, from GWEC Market Intelligence, *Global Wind Market Development – Supply Side Data 2018* (Brussels: April 2019), p. 3; 80% for 2017 from FTI Consulting, op. cit. this note, pp. 6, 10, 11; 75% in 2016 based on data from FTI Consulting, *Global Wind Market Update – Demand & Supply 2016, Part One – Supply Side Analysis* (London: 2017), p. 10.

213 GWEC, "GWEC releases Global Wind Turbine Supplier Ranking for 2020", 23 March 2021, https://gwec.net/gwec-releases-global-wind-turbine-supplier-ranking-for-2020. The rankings were GE (US), Goldwind (China), Vestas (Denmark), Envision (China), Siemens Gamesa (Spain) and Mingyang, Shanghai Electric, Windey, CRRC and Sany (all China), and the top four accounted for 55% of the machines deployed in 2020, from BloombergNEF, op. cit. note 1. Rankings were Vestas, Goldwind (moved to second from fourth place in 2019), GE, Envision (up from fifth place in 2019), Siemens Gamesa (down from second), Mingyang, SEwind (China), Nordex (Germany), Windey and CRRC, with Chinese manufacturers taking 10 of the top 15 places, from S. Barla, "Global wind turbine market: State of play", Wood Mackenzie, 14 April 2021, https://www.woodmac.com/news/opinion/global-wind-turbine-market-state-of-play.

214 Top five from GWEC, op. cit. note 213. Mingyang was in sixth place with around 6 GW of new installations, from Zhao, op. cit. note 7, 13 May 2021. GE, *2020 Annual Report* (Boston: 2020), https://www.ge.com/sites/default/files/GE_AR20_AnnualReport.pdf.

215 Barla, op. cit. note 213.

216 Enercon, for example, saw its sales in Germany fall from 1,282 MW in 2018 to 378 MW in 2019, from S. Knight, "Enercon looks to exports for recovery – analysis", Windpower Monthly, 9 June 2020, https://www.windpowermonthly.com/article/1685675/enercon-looks-exports-recovery-%E2%80%94-analysis. After filing for insolvency in 2019, Senvion sold its Indian manufacturing operations, exiting the local market, and continued selling other assets (including a blade factory in Portugal) to Siemens Gamesa, from the following: Hübner and Martin, op. cit. note 183, E. de Vries, "The rise and fall of Senvion", Windpower Monthly, 18 September 2019, https://www.windpowermonthly.com/article/1654013/rise-fall-senvion. Indian operations and market, from V. Petrova, "Senvion agrees to shed Indian subsidiary", Renewables Now, 9 April 2020, https://renewablesnow.com/news/senvion-agrees-to-shed-indian-subsidiary-694422. Sale of assets to Siemens Gamesa from, for example, C. Richard, "SGRE completes Senvion purchase", Windpower Monthly, 9 January 2020, https://www.windpowermonthly.com/article/1670368/sgre-completes-senvion-purchase; D. Weston, "Factory sale finalizes SGRE-Senvion Deal", Windpower Monthly, 1 May 2020, https://www.windpowermonthly.com/article/1681997/factory-sale-finalises-sgre-senvion-deal. Enercon reached a EUR 1.15 billion (USD 1.41 billion) agreement with banks mid-year to extend loans and help secure projects overseas and, in September, announced plans to streamline its domestic manufacturing (including cutting about 3,000 jobs), and to shift production overseas to reduce costs; the company will target international markets while awaiting a rebound in the German market, from the following: Agreement with banks, from Knight, op. cit. this note. The agreement includes EUR 550 million loan extension and EUR 600 million new guarantee facility that will help secure projects overseas, from idem. Streamline, cut jobs and shift production overseas from C. Richard, "Energy restructures manufacturing setup", Windpower Monthly, September 2020, pp. 10-11, https://www.windpowermonthly.com/article/1692957/read-windpower-monthly-online. Suzlon was relying largely on long-term service agreements after struggling to compete at home with a growing number of foreign turbine manufacturers following India's shift to auctions, from Saurabh, "Financial lifeline for troubled indian wind company Suzlon Energy approved", CleanTechnica, 12 April 2020, https://cleantechnica.com/2020/04/12/financial-lifeline-for-troubled-indian-wind-company-suzlon-energy-approved; R. Ranjan, "Suzlon completes restructuring of debt with capital infusion of ₹3.92 billion", Mercom India, 3 July 2020, https://mercomindia.com/suzlon-completes-restructuring-debt. Suzlon's losses continued to mount early in 2020 due in part to the pandemic's impact on sales, but it completed debt restructuring mid-year, from idem; N. T. Prasad, "Suzlon's net losses rose to ₹26.92 billion in FY 2020 amid historically low installations", Mercom India, 8 July 2020, https://mercomindia.com/suzlons-losses-rose-historically-low-installations.

217 For example, Vestas cut jobs and discontinued a range of products due in part to uncertainty about impact of the pandemic, from J. Parnell, "Vestas cuts 400 jobs as coronavirus slams global renewables sector", Greentech Media, 20 April 2020, https://www.greentechmedia.com/articles/read/vestas-makes-400-job-cuts-as-coronavirus-impact-bites. Vestas produced and shipped 35% more turbines (based on capacity) than in 2019, meaning higher revenues, but profits were squeezed by higher costs associated with the pandemic and a highly competitive market, from C. Richard, "Vestas sees profits fall despite higher revenues in 2020", Windpower Monthly, 10 February 2021, https://www.windpowermonthly.com/article/1706953/vestas-sees-profits-fall-despite-higher-revenues-2020. GE's LM Glasfiber closed plants in Denmark to reduce costs, from B. Radowitz, "Cost cuts prompts GE's LM Wind Power to shut Danish blade plants", Recharge, 27 February 2020, https://www.rechargenews.com/wind/cost-cutting-prompts-ge-s-lm-wind-to-shut-danish-plants/2-1-763424; "Wind turbine manufacturing plant in Arkansas

to close", Associated Press, 14 April 2020, https://apnews.com/a0d44432268a249271ba25ff208005e4. GE restructured some of its debts to strengthen its financial condition, from "General Electric (GE) announces debt-restructuring actions", Nasdaq, 7 May 2020, https://www.nasdaq.com/articles/general-electric-ge-announces-debt-restructuring-actions-2020-05-07. GE ended the year with a record order backlog and full-year revenues were up 2% over 2019 (due mainly to improved pricing and project execution), but the company recorded a loss for the year (although less than the 2019 loss), from C. Richard, "GE Renewable Energy narrows losses in 2020", Windpower Monthly, 26 January 2021, https://www.windpowermonthly.com/article/1705583/ge-renewable-energy-narrows-losses-2020. Siemens Gamesa restructured operations in Spain in response to project delays due mainly to the pandemic, from M. McGovern, "SGRE temporarily cuts jobs at Spanish plant", Windpower Monthly, 17 September 2020, https://www.windpowermonthly.com/article/1694735/sgre-temporarily-cuts-jobs-spanish-plant; Parnell, op. cit. this note. The company doubled its orders for offshore turbines, but onshore orders declined in 2020, from C. Richard, "Coronavirus pandemic sends Siemens Gamesa to €900 million full-year loss", Windpower Monthly, 5 November 2020, https://www.windpowermonthly.com/article/1699242/coronavirus-pandemic-sends-siemens-gamesa-%E2%82%AC900-million-full-year-loss. Siemens Gamesa reported a net loss for its 2020 fiscal year, with revenues down because of pandemic-induced project delays and reduced commercial activity, from idem. Wind turbine manufacturers margins have been eroded by several factors, including the introduction of auctions, global trade tensions and pandemic-induced disruptions, from Siemens Gamesa, op. cit. note 181, p. 16.

218 Orders were down 3% for both companies, from Richard, "Vestas sees profits fall despite higher revenues in 2020", op. cit. note 217. Richard, "GE Renewable Energy narrows losses in 2020", op. cit. note 217. Order intakes for Vestas were 17,977 MW in 2019, from Vestas, "Wind turbine orders announced in 2019", https://www.vestas.com/en/investor/company%20announcements#!turbine-orders-2019, viewed 27 April 2021, and 17,249 MW in 2020, from Vestas, "Company announcements", https://www.vestas.com/en/investor/company%20announcements#!2020, viewed 27 April 2021. Orders were up to record levels for Siemens Gamesa, but 2020 was a challenging year financially, from Siemens Gamesa, op. cit. note 181, p. 18.

219 C. Richard, "How SGRE and GE's escalating legal battle could backfire", Windpower Monthly, 9 October 2020, https://www.windpowermonthly.com/article/1696818/sgre-ges-escalating-legal-battle-backfire; I. Shumkov, "GE files IP infringement complaint against Siemens Gamesa", Renewables Now, 4 August 2020, https://renewablesnow.com/news/ge-files-ip-infringement-complaint-against-siemens-gamesa-708760; T. Pieffers, "Siemens Gamesa challenges GE with new 14MW offshore turbine", 19 May 2020, https://www.projectcargojournal.com/equipment/2020/05/19/siemens-gamesa-challenges-ge-with-new-14mw-offshore-turbine; M. Spector, "GE alleges Siemens Energy used stolen trade secrets to rig contract bids", *Reuters*, 14 January 2021, https://www.reuters.com/article/us-ge-siemens-lawsuit-idUKKBN29J2N2.

220 E. F. Merchant, "5 wind energy giants embracing solar power", Greentech Media, 19 May 2020, https://www.greentechmedia.com/articles/read/five-large-scale-wind-developers-pivoting-to-solar; "Hybrid power plants are growing rapidly: are they a good idea?" Electricity Markets & Policy, 13 March 2020, https://emp.lbl.gov/news/hybrid-power-plants-are-growing-rapidly-are; "Vattenfall's largest hybrid energy park is taking shape in the Netherlands", NS Energy, 30 July 2020, https://www.nsenergybusiness.com/news/vattenfalls-largest-hybrid-energy-park-is-taking-shape-in-the-netherlands.

221 "Orsted to unleash 430MW solar project in Texas", reNEWS Biz, 2 December 2020, https://www.renews.biz/64876/orsted-to-proceed-with-430mwac-solar-project-in-texas. Note that the capacity (430 MW) of the project in Texas is in alternating current, but the source does not specify if the total capacity provided (1.1 GW) is in AC or DC.

222 J. Agyepong-Parsons, "Double hit for Chinese OEMs as market shrinks amid falling turbine prices", Windpower Monthly, 18 June 2020, https://www.windpowermonthly.com/article/1686943/double-hit-chinese-oems-market-shrinks-amid-falling-turbine-prices.

223 E. Vries, "Turbines of the Year 2020: Winners against all odds", Windpower Monthly, 11 January 2021, https://www.windpowermonthly.com/article/1704030/turbines-year-2020-winners-against-odds.

224 Jörg Scholle, Enercon, cited in E. de Vries, "Exclusive: Enercon fires-up first E-160 prototype", Windpower Monthly, 23 July 2020, https://www.windpowermonthly.com/article/1690157/exclusive-enercon-fires-up-first-e-160-prototype. See also GWEC, "Pressures to reduce costs are transforming the global wind blade supply chain", 16 December 2020, https://gwec.net/pressures-to-reduce-costs-are-transforming-the-global-wind-blade-supply-chain.

225 M. Bolinger et al., *Opportunities for and Challenges to Further Reductions in the "Specific Power" Rating of Wind Turbines Installed in the United States* (Berkeley, CA: LBNL, January 2020), https://eta-publications.lbl.gov/sites/default/files/wind_engineering_accepted_manuscript_w_disclaimer_copyright.pdf; R. Wiser et al., "The hidden value of large-rotor, tall-tower wind turbines in the United States", Wind Engineering, July 2020, pp. 1-15, cited in D. Milborrow, "How lower specific ratings translate into cheaper power", Windpower Monthly, September 2020, pp. 33-34, https://www.windpowermonthly.com/article/1692957/read-windpower-monthly-online; R. Wiser et al., "Interactive: Wind turbines are getting more powerful as 'specific power' declines", Utility Dive, 23 August 2018, https://www.utilitydive.com/news/a-big-wind-power-trend-you-may-have-never-heard-of-declining-specific-pow/530811.

226 E. Holbrook, "5 trends shaping the wind energy industry", Environmental Leader, 29 September 2020, https://www.environmentalleader.com/2020/09/5-trends-shaping-the-wind-energy-industry.

227 C. Richard, "Looking back on 2020 – Part 3: Turbine ratings and rotor sizes continue to go up", Windpower Monthly, 15 January 2021, https://www.windpowermonthly.com/article/1704255/looking-back-2020-%E2%80%93-part-3-turbine-ratings-rotor-sizes-continue-go; GE's 6 MW Cypress onshore turbine will be available by 2022, from C. Richard, "GE launches 6MW onshore wind turbine", Windpower Monthly, 30 November 2020, https://www.windpowermonthly.com/article/1701374/ge-launches-6mw-onshore-wind-turbine; A. McCorkell, "Nordex pushes N149/5.X prototype to 5.7MW", Windpower Monthly, 14 September 2020, https://www.windpowermonthly.com/article/1694291/nordex-pushes-n149-5x-prototype-57mw; Siemens Gamesa from E. de Vries, "SGRE uses offshore experience to take 5.X onshore platform past 6MW", Windpower Monthly, 1 June 2020, https://www.windpowermonthly.com/article/1684754/sgre-uses-offshore-experience-5x-onshore-platform-past-6mw, and from E. Pearcey, "Onshore turbine capacities smash 6 MW, pressuring logistics", Reuters Events, 6 May 2020, https://www.reutersevents.com/renewables/wind-energy-update/onshore-turbine-capacities-smash-6-mw-pressuring-logistics; C. Richard, "Vestas tests new V162-6.0MW prototype wind turbine", Windpower Monthly, 8 October 2020, https://www.windpowermonthly.com/article/1696691/vestas-tests-new-v162-60mw-prototype-wind-turbine; C. Richard, "MingYang unveils new 6.25MW onshore turbine", Windpower Monthly, 16 October 2020, https://www.windpowermonthly.com/article/1697454/mingyang-unveils-new-625mw-onshore-turbine; Mingyang also launched a new 5.2 MW onshore turbine, from "MingYang unveils 5.2MW onshore turbine", reNEWS Biz, 28 July 2020, https://renews.biz/62013/mingyang-unveils-52mw-onshore-turbine.

228 For example, D. Weston, "Enercon installs debut EP3 E2 prototype", Windpower Monthly, 30 March 2020, https://www.windpowermonthly.com/article/1678684/enercon-installs-debut-ep3-e2-prototype; Richard, "Looking back on 2020", op. cit. note 227; C. Richard, "Goldwind unveils onshore turbines at conference amid pandemic", Windpower Monthly, 19 October 2020, https://www.windpowermonthly.com/article/1697610/goldwind-unveils-onshore-turbines-conference-amid-pandemic. For specific markets, Siemens Gamesa launched a turbine that operates between 4 and 5 MW with low noise output to make it suitable for locations with strict noise restrictions, from C. Richard, "Siemens Gamesa unveils new low-wind turbine", Windpower Monthly, 12 November 2020, https://www.windpowermonthly.com/article/1699928/siemens-gamesa-unveils-new-low-wind-turbine; a new turbine by Vestas is specifically for low-wind sites in China, from C. Richard, "First orders for Vestas low-wind turbine", Windpower Monthly, 4 March 2020, https://www.windpowermonthly.com/article/1675887/first-orders-vestas-low-wind-turbine; Siemens Gamesa Renewable Energy launched a turbine for the Indian market, from "Indian prime minister inaugurates 750MW solar project", Power Technology, 10 July 2020, https://www.power-technology.com/news/narendra-modi-inaugurates-750mw-solar-project-india, and K. Chandrasekaran,

"Siemens Gamesa wary of cut-throat projects of wind energy", *Economic Times*, 10 July 2020, https://economictimes.indiatimes.com/industry/energy/power/siemens-gamesa-wary-of-cut-throat-projects-of-wind-energy/articleshow/76895363.cms.

229 E. de Vries, "Goldwind prioritises larger rotors over higher ratings to reduce LCoE", Windpower Monthly, 20 November 2020, https://www.windpowermonthly.com/article/1700741/goldwind-prioritises-larger-rotors-higher-ratings-reduce-lcoe.

230 See, for example, Pearcey, op. cit. note 227; P. Day, "Inflatable blades, airships could leapfrog transport barriers", Reuters Events, 4 December 2019, https://www.reutersevents.com/renewables/wind-energy-update/inflatable-blades-airships-could-leapfrog-transport-barriers.

231 "Nordex starts up Spanish tower factory", reNEWS Biz, 1 December 2020, https://www.renews.biz/64828/nordex-starts-up-spanish-concrete-wind-tower-factory.

232 J. Calma, "GE will make taller wind turbines using 3D-printing", The Verge, 17 June 2020, https://www.theverge.com/2020/6/17/21293456/ge-200-meter-onshore-taller-wind-turbines-3d-printing. Also in the United States, US-based Keystone Tower Systems is developing an on-site spiral welding process that should enable hub heights in excess of 180 metres, and Keystone has received funding from the US DOE to demonstrate the technology, from Pearcey, op. cit. note 227.

233 C. Richard, "World's longest wind turbine blade gets engineers' approval", Windpower Monthly, 10 November 2020, https://www.windpowermonthly.com/article/1699714/worlds-longest-wind-turbine-blade-gets-engineers-approval.

234 GWEC, op. cit. note 224.

235 Ibid. The same has been true with gearbox suppliers, from GWEC, op. cit. note 1, pp. 17-18.

236 "Wind turbine manufacturing plant in Arkansas to close", Associated Press, 14 April 2020, https://apnews.com/a0d444322 68a249271ba25ff208005e4; J. Parnell, "Siemens Gamesa cuts 266 jobs as onshore wind restructuring continues", 14 January 2021, https://www.greentechmedia.com/articles/read/siemens-gamesa-cuts-266-jobs-as-onshore-rejig-continues; C. Richard, "Siemens Gamesa slashes jobs at US blade factory", Windpower Monthly, 15 September 2020, https://www.windpowermonthly.com/article/1694512/siemens-gamesa-slashes-jobs-us-blade-factory. See also B. Radowitz, "Cost cuts prompts GE's LM Wind Power to shut Danish blade plants", Recharge, 27 February 2020, https://www.rechargenews.com/wind/cost-cutting-prompts-ge-s-lm-wind-to-shut-danish-plants/2-1-763424.

237 Average rated capacity of turbines delivered to market worldwide in 2019 was 2,755 kW (averages of 2,603 kW onshore and 5,653 kW offshore), from Zhao, Lee and Lathigara , op. cit. note 211, and 2020 averages from Zhao, op. cit. note 7, 27 April 2021; figure of 2% based on 2019 data from idem., both sources. Onshore, the largest country averages were seen in Finland (4.5 MW), Chile (4.26 MW) and Norway (4.2 MW), with averages exceeding 2.5 MW in all other established markets – including China; offshore, the highest average power ratings were in Belgium (8.71 MW), the Netherlands (8.68 MW) and Portugal (8.4 MW). Across Europe, the average per unit capacity of newly installed turbines in 2020 was 3.3 MW onshore (with the most powerful in Finland, at 4.5 MW), and rose to 8.2 MW offshore, up from 7.2 MW in 2019. The average offshore in China was 4.7 MW. All from Zhao, op. cit. note 7, 27 April 2021, and China data are preliminary.

238 MHI Vestas, "Final turbine installed at Borsselle III/IV in spite of COVID-19", 27 November 2020, https://mhivestasoffshore.com/final-turbine-installed-at-borssele-iii-iv-in-spite-of-covid-19. MHI Vestas was reacquired by Vestas and reintegrated in late 2020, from Vestas, "Vestas and Mitsubishi Heavy Industries close partnership agreement, and senior leaders from joint venture take on new roles in Vestas", 14 December 2020, https://www.vestas.com/en/media/company%20news?l=62&n=3850009#!NewsView.

239 GWEC, op. cit. note 3, p. 7. The wind farms were Vindeby (total of 4.95 MW) and Tunø Knob (5 MW).

240 C. Richard, "GE upgrades Haliade-X prototype to 13MW", Windpower Monthly, 22 October 2020, https://www.windpowermonthly.com/article/1698085/ge-upgrades-haliade-x-prototype-13mw; M. Bates, "GE Renewable Energy upgrades the Haliade-X wind turbine", North American Wind Power, 22 October 2020, https://nawindpower.com/ge-upgrades-the-haliade-x-wind-turbine; C. Richard, "GE boosts Haliade-X to 14MW for third Dogger Bank site", Windpower Monthly, 18 December 2020, https://www.windpowermonthly.com/article/1703196/ge-boosts-haliade-x-14mw-third-dogger-bank-site. GE Renewable Energy began building a factory in China to produce Haliade-X 12 MW turbines starting in the second half of 2021, from GWEC, op. cit. note 3, p. 53. The 13 MW machine will be 248 metres tall with 107 metre blades, from GE Renewable Energy, "Meet the Haliade-X 13 MW", https://www.ge.com/news/sites/default/files/2020-09/ge_haliade_x_horizontal_9_21_2020_0.pdf, viewed 27 April 2021. GE received full certification for both the 12- and 13-MW Haliade-X in 2020, from GE, op. cit. note 214.

241 GWEC, op. cit. note 3, p. 81; Musial et al., op. cit. note 165, p. 61; E. de Vries, "How SGRE upped the offshore stakes with 14MW+ turbine and 222m rotor", Windpower Monthly, 19 May 2020, https://www.windpowermonthly.com/article/1683570/sgre-upped-offshore-stakes-14mw+-turbine-222m-rotor; A. Frangoul, "Details released of a huge offshore wind turbine that can power 18,000 homes per year", CNBC, 19 May 2020, https://www.cnbc.com/2020/05/19/siemens-gamesa-releases-details-of-huge-offshore-wind-turbine.html.

242 As of mid-2020, six Chinese turbine manufacturers had introduced offshore models of 8 MW or larger, from GWEC, op. cit. note 3, p. 53; S. Campbell, "Dongfang due to install China's first 10MW turbine", Windpower Monthly, 25 June 2020, https://www.windpowermonthly.com/article/1687749/dongfang-due-install-chinas-first-10mw-turbine; C. Richard, "MingYang unveils 11MW turbine", Windpower Monthly, 7 July 2020, https://www.windpowermonthly.com/article/1688770/mingyang-unveils-11mw-turbine; E. de Vries, "MingYang scale-up hybrid-drive technology to supersize class", Windpower Monthly, 2 September 2020. https://www.windpowermonthly.com/article/1693241/mingyang-scales-up-hybrid-drive-technology-supersize-class. Mingyang also aims to develop a 10 MW floating model, from Y. Yu, "China's Ming Yang eyes 15MW offshore wind turbine after $850m fundraising", Recharge, 17 April 2020, https://www.rechargenews.com/wind/chinas-ming-yang-eyes-15mw-offshore-wind-turbine-after-850m-fundraising/2-1-793243.

243 E. De Vries, "Exclusive: How Vestas beat rivals to launch first 15MW offshore turbine", Windpower Monthly, 10 February 2021, https://www.windpowermonthly.com/article/1706924/exclusive-vestas-beat-rivals-launch-first-15mw-offshore-turbine. Vestas aims to install prototype by mid-2022, from idem. Upgradeable from Zhao, op. cit. note 7, 27 April 2021.

244 See, for example, K. Stromsta, "GE lands first orders for 12MW offshore wind turbine, and they're huge", Greentech Media, 19 September 2019, https://www.greentechmedia.com/articles/read/ge-wins-lands-first-big-deals-for-12mw-offshore-wind-turbine; "The largest offshore wind project In the United States will use Siemens Gamesa turbines", Maritime Herald, 27 May 2020, https://www.maritimeherald.com/2020/the-largest-offshore-wind-project-in-the-united-states-will-use-siemens-gamesa-turbines; GE, "GE Renewable Energy confirmed as preferred turbine supplier for 1.2 GW third phase of Dogger Bank Wind Farm in the UK", 18 December 2020, https://www.ge.com/news/press-releases/ge-renewable-energy-confirmed-preferred-turbine-supplier-for-third-phase-dogger-bank-wind-farm-uk; J. Murray, "More than $16bn of wind turbine capacity ordered in second quarter of 2020", NS Energy, 14 October 2020, https://www.nsenergybusiness.com/news/wind-turbine-capacity-2020.

245 B. Backwell, GWEC, "Take offshore wind global", presentation for Renewable Energy Institute, REvision – Webinar, 4 March 2020, slide 10, https://www.renewable-ei.org/pdfdownload/activities/11_BenBackwell.pdf; WindEurope, Brussels, personal communication with REN21, 29 March 2018; "Offshore wind operators use scale, analytics to cut vessel trips", New Energy Update, 7 March 2019, http://www.newenergyupdate.com/wind-energy-update/offshore-wind-operators-use-scale-analytics-cut-vessel-trips; Sawyer, op. cit. note 10, 30 March 2019; lower grid-connection costs from P. Pragkos, E3 Modelling, personal communication with REN21, 7 April 2019. For example, Vestas has said that using its new V236-15.0 (15 MW) unit for a 900 MW wind plant, instead of its previous V174-9.5 (9.5 MW) turbine, would increase annual energy production by 5% with 34 fewer wind turbines, and without the corresponding foundations and complicated offshore wind construction, from Broehl, op. cit. note 70.

246 J. Parnell, "Total and Macquarie invest in 2.3GW portfolio of floating wind projects in South Korea", Greentech Media,

1 September 2020, https://www.greentechmedia.com/articles/read/total-and-macquarie-partner-on-worlds-first-full-scale-floating-wind-projects; M. J. Coren, "Floating wind farms just became a serious business", Quartz, 22 June 2019, https://qz.com/1650433/hywind-scotland-makes-floating-wind-farms-a-serious-business; viable and economically attractive from WindEurope, "Floating offshore wind vision statement" (Brussels: June 2017), https://windeurope.org/wp-content/uploads/files/about-wind/reports/Floating-offshore-statement.pdf; stronger and more consistent from Statoil, "World class performance by world's first floating wind farm", press release (Stavanger, Norway: 15 February 2018), https://www.statoil.com/en/news/15feb2018-world-class-performance.html; best winds rather than suitable topography from Sawyer, op. cit. note 10, 20 April 2018.

247 GWEC, op. cit. note 3, pp. 22, 90.

248 A. McCorkell, "MHI Vestas installs 'most powerful' floating offshore wind turbine", Windpower Monthly, 11 November 2020, https://www.windpowermonthly.com/article/1699782/mhi-vestas-installs-most-powerful-floating-offshore-wind-turbine; MHI Vestas, "First ever V164-9.5 MW turbine installed on a floating wind project", 11 November 2020, https://mhivestasoffshore.com/first-ever-v164-9-5-mw-turbine-installed-on-a-floating-wind-project. It was the first of five at the 50 MW Kincardine Offshore Windfarm, from idem, both sources. There are three main types of bases, all derived from experience in the oil and gas industry, but efforts continued to develop a common platform that can host ocean energy, solar PV and power-to-x generation technologies as well as wind turbines, from GWEC, op. cit. note 3, p. 87.

249 For example, Ørsted was leading a group of Danish companies to develop a hydrogen production facility, from D. Weston, "Industry's hydrogen experiment steps up a gear", Windpower Monthly, 26 May 2020, https://www.windpowermonthly.com/article/1684230/industrys-hydrogen-experiment-steps-gear. Vattenfall, RWE, Equinor and Enel unveiled plans in 2020 for research or to develop projects to use electricity to produce other fuels (energy carriers), from Richard, "Looking back on 2020", op. cit. note 120; A. McCorkell, "RWE and Equinor back 'groundbreaking' NorthH2 green hydrogen project", Windpower Monthly, 7 December 2020, https://www.windpowermonthly.com/article/1702060/rwe-equinor-back-groundbreaking-north2-green-hydrogen-project; H. O'Brian, "Enel prepares to produce green hydrogen", Windpower Monthly, 15 June 2020, https://www.windpowermonthly.com/article/1686321/enel-prepares-produce-green-hydrogen. The NorthH2 project off the coast of the Netherlands aims to power electrolysis of seawater into hydrogen to be used in industry, from "Japan and EU race to develop 'green hydrogen'", Nikkei Asia, 11 January 2021, https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Japan-and-EU-race-to-develop-green-hydrogen2. In addition, as of early 2020, discussions were under way between countries in northern Africa and the European Commission about using wind energy for industrial purposes, including the production of ammonia in Morocco to manufacture fertiliser using local phosphates, from K. Benhamou, Sahara Wind, presentation for WWEA, "Webinar: Wind power markets around the world", 16 April 2020, https://wwindea.org/blog/2020/04/08/webinar-wind-power-markets-around-the-world.

250 Siemens Energy and Siemens Gamesa, "Joint press release from Siemens Gamesa and Siemens Energy", press release (Vizcaya, Spain: 13 January 2021), https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/newsroom/2021/01/siemens-gamesa-press-release-agreement-siemens-energy-green-hydrogen-en.pdf; C. Steitz, T. Käckenhoff and V. Eckert, "Exclusive: Siemens spin-offs tap hydrogen boom in wind alliance", *Reuters*, 13 January 2021, https://www.reuters.com/article/us-siemens-gamesa-r-siemens-energ-windpo/exclusive-siemens-gamesa-siemens-energy-tap-hydrogen-boom-in-wind-alliance-idUSKBN29I12Z.

251 See, for example, J. Parnell, "Shell's latest offshore wind bid would power a huge green hydrogen cluster", Greentech Media, 7 May 2020, https://www.greentechmedia.com/articles/read/latest-shell-offshore-wind-bid-would-power-green-hydrogen-cluster; B. Radowitz, "Dutch zero-subsidy offshore wind tender on despite coronavirus", Recharge, 17 March 2020, https://www.rechargenews.com/wind/dutch-zero-subsidy-offshore-wind-tender-on-despite-coronavirus/2-1-775751; Westwood Global Energy Group, "Scaling Rrnewables: The converging world of oil & gas and the clean energy supermajors", 15 February 2021, https://www.westwoodenergy.com/news/westwood-insight/scaling-renewables.

252 Significant investment in the sector from Backwell and Mullin, op. cit. note 3; knowledge and skills transfer from Westwood Global Energy Group, op. cit. note 251, and V. Kretzschmar, Wood Mackenzie, "Why are oil majors investing in offshore wind?" *Forbes*, 6 April 2021, https://www.forbes.com/sites/woodmackenzie/2021/04/06/why-are-oil-majors-investing-in-offshore-wind. See also GWEC, op. cit. note 3, pp. 88-89; J. Parnell, "Equinor: Floating wind farms a natural fit for oil and gas companies", Greentech Media, 6 February 2020, https://www.greentechmedia.com/articles/read/floating-wind-is-cutting-costs-faster-than-regular-offshore-wind; B. Magill, "Oil industry eyed as catalyst for floating offshore wind", Bloomberg Environment, 13 June 2019, https://news.bloombergenvironment.com/environment-and-energy/oil-industry-eyed-as-catalyst-for-floating-offshore-wind.

253 S. Lassen, N. Valentine and V. Kretzschmar, "How Big Oil is set to transform the offshore wind sector", Wood Mackenzie, 5 April 2021, https://www.woodmac.com/news/opinion/how-big-oil-is-set-to-transform-the-offshore-wind-sector.

254 Ibid.

255 Total from J. Parnell, "Germany and France, Europe's economic giants, bulk up offshore wind ambitions", Greentech Media, 4 June 2020, https://www.greentechmedia.com/articles/read/europes-heavy-hitters-bulk-up-their-offshore-wind-arsenals; M. Holder, "Total wades into UK floating wind sector with Simply Blue Energy partnership", Business Green, 19 March 2020, https://www.businessgreen.com/news/4012737/total-wades-uk-floating-wind-sector-simply-blue-energy-partnership; Total, "Renewables: Total enters floating offshore wind with a first project in the UK", 20 March 2020, https://www.total.uk/renewables-total-enters-floating-offshore-wind-first-project-uk, Parnell, op. cit. note 246; Eni, "Eni enters the UK offshore wind market", press release (Rome: 4 December 2020), https://www.eni.com/en-IT/media/press-release/2020/12/eni-enteres-uk-offshore-wind-market.html.

256 "Offshore wind energy potential in Brazil attracts Equinor and Neoenergia", Brazil Energy Insight, 25 November 2020, https://brazilenergyinsight.com/2020/11/25/offshore-wind-energy-potential-in-brazil-attracts-equinor-and-neoenergia; J. Parnell, "BP makes offshore wind debut, partnering with Equinor in US market", Greentech Media, 10 September 2020, https://www.greentechmedia.com/articles/read/bp-and-equinor-partner-up-for-us-offshore-wind; "BP and Equinor cement US offshore wind partnership", reNEWS Biz, 29 January 2021, https://renews.biz/66134/bp-and-equinor-cement-us-offshore-wind-partnership.

257 Shell partnering in projects from, for example, J. Parnell, "Super-Hybrid: Dutch offshore wind farm to include floating solar, batteries and hydrogen", Greentech Media, 29 July 2020, https://www.greentechmedia.com/articles/read/shell-jv-wins-dutch-offshore-wind-tender-with-continuous-power-hybrid-project; "Shell joins floating wind project offshore Ireland", Offshore Engineer, 29 January 2021, https://www.oedigital.com/news/484925-shell-joins-floating-wind-project-offshore-ireland. Shell and TetraSpar, from W. Mathis, "Inventor of wind turbine is trying to harness unlimited power", BNN Bloomberg, 5 June 2020, https://www.bnnbloomberg.ca/inventor-of-wind-turbine-is-trying-to-harness-unlimited-power-1.1446122. Benefits of TetraSpar foundation from Shell, "Wind power", https://www.shell.com/energy-and-innovation/new-energies/wind.html, viewed 14 March 2021.

258 M. Mazengarb, "Huge 1,100MW offshore wind farm proposed in W.A. by oil explorer", RenewEconomy, 4 September 2020, https://reneweconomy.com.au/huge-1100mw-offshore-wind-farm-proposed-in-w-a-by-oil-explorer-55055.

259 Some Chinese utility companies are moving into offshore wind, from GWEC, op. cit. note 3, pp. 88-89. Japan's TEPCO signed a memorandum of understanding with developer Ørsted to work jointly on offshore wind projects in Japan and elsewhere, from idem, p. 61. Partnerships also were launched between Kyushu Electric Power Company (Japan) and RWE, J Power (Japan) and Engie, and Tokyo Gas Company and Principle Power (US) to focus on offshore wind, from idem, p. 62. In Europe, examples include RWE Renewables (Germany), Iberdrola (Spain), EDF (France), EnBW (Germany), EDP (Portugal) and ENGIE (France), from idem, pp. 88-89. In the United States, RWE and Mitsubishi acquired a floating demonstration project off the coast of Maine, from K. Stromsta, "Maine's $100M floating offshore wind project finds major backers: RWE and Mitsubishi", Greentech Media, 5 August 2020, https://www.greentechmedia.com/articles/read/maines-floating-offshore-wind-project-scores-major-backers-rwe-and-mitsubishi.

260 India from C. Richard, "India energy giants to form renewables JV", Windpower Monthly, 22 May 2020, https://www.windpowermonthly.com/article/1684088/indian-energy-giants-form-renewables-jv. The companies are India's Oil and Natural Gas Corporation and utility National Thermal Power Corporation, from idem. For additional examples, see W. Mathis, "Inventor of wind turbine is trying to harness unlimited power", Bloomberg News, 5 June 2020, https://www.bnnbloomberg.ca/inventor-of-wind-turbine-is-trying-to-harness-unlimited-power-1.1446122; D. McPhee, "Balmoral plots move into floating offshore wind market", Energy Voice, 2 March 2020, https://www.energyvoice.com/otherenergy/225772/balmoral-plots-move-into-floating-offshore-wind-market.

261 A. Lee, "Five big problems for offshore wind: Angry birds, grumpy neighbours and more", Recharge, 7 September 2020, https://www.rechargenews.com/wind/five-big-problems-for-offshore-wind-angry-birds-grumpy-neighbours-and-more/2-1-870639; A. McCorkell, "Warning over heavy lift vessel 'bottleneck' for offshore wind", Windpower Monthly, 26 November 2020, https://www.windpowermonthly.com/article/1701220/warning-heavy-lift-vessel-bottleneck-offshore-wind; J. Calma, "The US offshore wind boom will depend on these ships", The Verge, 23 Feb 2021, https://www.theverge.com/22296979/us-offshore-ships-wind-boom-installation-vessels.

262 McCorkell, op. cit. note 261.

263 GWEC, op. cit. note 3, pp. 21, 27, 42, 73, 79; GWEC, *Global Wind Report 2019*, op. cit. note 11, p. 60; N. Ford, "Orsted deal with US utility sets up offshore growth surge", New Energy Update, 20 February 2019, http://www.newenergyupdate.com/wind-energy-update/orsted-deal-us-utility-sets-offshore-growth-surge.

264 Stromsta, op. cit. note 210; K. Stromsta, "New York issues second offshore wind solicitation, overcoming coronavirus delays", Greentech Media, 21 July 2020, https://www.greentechmedia.com/articles/read/new-york-fights-through-coronavirus-delays-to-issue-second-offshore-wind-solicitation; K. Stromsta, "New Jersey to build nation's largest offshore wind port", Greentech Media, 16 June 2020, https://www.greentechmedia.com/articles/read/new-jersey-announces-plans-for-nations-largest-offshore-wind-port; T. Bergeron, "N.J. announced $250M manufacturing facility for wind energy components at Paulsboro Marine Terminal", ROI-NJ, 22 December 2020, https://www.roi-nj.com/2020/12/22/industry/energy-utilities/n-j-announces-250m-manufacturing-facility-for-wind-energy-components-at-paulsboro-marine-terminal. States include Connecticut, Maryland, New York, New Jersey, Virginia, Massachusetts, from idem, all sources. Worker training from, for example, "NJ spending $6M for wind and other clean energy projects", Associated Press News, 9 September 2020, https://apnews.com/bd4d238a3e5ad681fea3bb5f59ee4efd. For more on challenges in the United States, also see "U.S. offshore wind vessel demand set to soar", Marine Link, 2 March 2021, https://www.marinelink.com/news/abs-us-offshore-wind-vessel-demand-set-485668; IEA, op. cit. note 54.

265 See other endnotes for this paragraph. Repowering explanation in footnote based on information from WindEurope, *Decommissioning of Onshore Wind Turbines: Industry Guidance Document* (Brussels: November 2020), p. 7, https://windeurope.org/data-and-analysis/product/decommissioning-of-onshore-wind-turbines, and from H. K. Trabish, "Zombie wind and solar? How repowering old facilities helps renewables keep cutting costs", Utility Dive, 26 October 2016, https://www.utilitydive.com/news/zombie-wind-and-solar-how-repowering-old-facilities-helps-renewables-keep/429047.

266 See, for example, CanWEA, "Decommissioning/Repowering a wind farm", https://canwea.ca/communities/decommissioningrepowering-wind-farm, viewed 9 May 2020; GE Renewable Energy, "Upgrades and refurbishment for your onshore wind assets: Repowering and life extension for older onshore wind turbines", https://www.ge.com/renewableenergy/wind-energy/onshore-wind/services/upgrades-refurbishment, viewed 9 May 2020; K. Centera, "Six factors to consider before repowering a wind site", Windpower Engineering & Development, 25 February 2019, https://www.windpowerengineering.com/business-news-projects/six-factors-to-consider-before-repowering-a-wind-site.

267 K. Blunt, "Utilities cash in on green energy subsidy for bigger wind farms", *Wall Street Journal*, 16 August 2020, https://www.wsj.com/articles/utilities-cash-in-on-green-energy-subsidy-for-bigger-wind-farms-11597579201; F. Jossi, "Wind developers are retrofitting newer projects with bigger, better blades", *Wall Street Journal*, 4 February 2021, https://energynews.us/2021/02/04/midwest/wind-developers-are-retrofitting-newer-projects-with-bigger-better-blades.

268 ACPA, op. cit. note 58, pp. 4, 8. Partial repowering totalled 2,899 MW in 2020, 3,008 MW in 2019, 1,269 MW in 2018 and 2,077 MW in 2017, from idem.

269 Blunt, op. cit. note 267; Jossi, op. cit. note 267.

270 Germany from Deutsche WindGuard, op. cit. note 120, p. 4; all Europe data also from WindEurope, op. cit. note 6, p. 17.

271 Komusanac, op. cit. note 13; Reve, "Wind energy in China, repowering with larger wind turbines", Evwind, 17 December 2019, https://www.evwind.es/2019/12/17/wind-energy-in-china-repowering-with-larger-wind-turbines/72555.

272 Most blades are made of resin and fibreglass, from C. Stella, "As wind energy thrives, so does its waste problem", NET News and Harvest Public Media, 31 August 2019, http://netnebraska.org/article/news/1188411/wind-energy-thrives-so-does-its-waste-problem; difficult and expensive from NREL, "Greening industry: Building recyclable, next-generation turbine blades", 21 April 2020, https://www.nrel.gov/news/program/2020/greening-industry.html; C. Richard, "Blade recycling remains challenges, says WindEurope", Windpower Monthly, 27 May 2020, https://www.windpowermonthly.com/article/1684326/blade-recycling-remains-challenge-says-windeurope. About 85-90% of dismantled turbines can be recycled – towers, foundations, generators and gearboxes can be broken down into concrete, steel, cast iron and recycled – but not blades, from J. Agyepong-Parsons, "GE signs deal to use old turbine blades in cement production", Windpower Monthly, 8 December 2020, https://www.windpowermonthly.com/article/1702248/ge-signs-deal-use-old-turbine-blades-cement-production.

273 Sound barriers from "Sharpening-up blade recycling", Windpower Monthly, 4 February 2020, https://www.windpowermonthly.com/article/1672913/sharpening-up-blade-recycling; Richard, op. cit. note 272; "GE and Veolia team up to provide wind turbine blade recycling", Renewable Energy World, 12 August 2020, https://www.renewableenergyworld.com/wind-power/ge-and-veolia-team-up-to-provide-wind-turbine-blade-recycling; Agyepong-Parsons, op. cit. note 272; different materials from C. Richard, "Cross-sector group developing '100% recyclable' blade", Windpower Monthly, 23 September 2020, https://www.windpowermonthly.com/article/1695250/cross-sector-group-developing-100-recyclable-blade. See also NREL, "NREL advanced manufacturing research moves wind turbine blades toward recyclability", press release (Golden, CO: 17 November 2020), https://www.nrel.gov/news/press/2020/nrel-advanced-manufacturing-research-moves-wind-turbine-blades-toward-recyclability.html.

274 "GE and Veolia team up to provide wind turbine blade recycling", Renewable Energy World, 12 August 2020, https://www.renewableenergyworld.com/wind-power/ge-and-veolia-team-up-to-provide-wind-turbine-blade-recycling; Agyepong-Parsons, op. cit. note 272. One turbine blade that weighs about 7 tonnes and is recycled through this process enables Veolia's cement kiln to avoid consuming almost 5 tonnes of coal, about 2.5 tonnes of silica, nearly 2 tonnes of limestone and almost 1 tonne of other mineral-based raw materials, from idem. Innovationsfonden, "DecomBlades consortium awarded funding for a large, cross-sector wind turbine blade recycling project", https://innovationsfonden.dk/da/nyheder-presse-og-job/decomblades-consortium-awarded-funding-large-cross-sector-wind-turbine-blade, viewed 4 May 2021; Vestas, "DecomBlades consortium awarded funding for a large, cross-sector wind turbine blade recycling project", press release (Aarhus: 25 January 2021), https://www.vestas.com/en/media/blog/sustainability/20210125_decomblades; IRT Jules Verne, "L'IRT Jules Verne et un consortium d'acteurs industriels lancent le projet ZEBRA dédiéaudéveloppementde paleséoliennesen matériauxcomposites 100% recyclables", press release (Nantes: 23 September 2020), https://www.irt-jules-verne.fr/wp-content/uploads/06_IRT-JULES-VERNE_CP-ZEBRA_FR_vfinale.pdf; Richard, op. cit. note 273; NREL, "Advanced thermoplastic resins for manufacturing wind turbine blades", https://www.nrel.gov/manufacturing/comet-wind-blade-resin.html, viewed 26 April 2021; J. S. Hill, "US research identifies new resin material to make wind turbine recycling easier", RenewEconomy, 25 November 2020, https://reneweconomy.com.au/us-research-identifies-new-resin-material-to-make-wind-turbine-recycling-easier-76316.

275 T. Gualtieri and L. M. Lombrana, "Making wind turbines greener could also make them more expensive", Bloomberg, 11 February 2021, https://www.bloomberg.com/news/articles/2021-02-11/making-wind-turbines-greener-could-also-make-them-more-expensive.

276 Siemens Gamesa Renewable Energy (SGRE), "Achieving a better future – committed to sustainable development", https://www.siemensgamesa.com/sustainability, viewed 4 May 2020; SGRE, "DecomBlades consortium awarded funding for a large, cross sector wind turbine blade recycling project", press release (Madrid: 25 January 2021), https://www.siemensgamesa.com/en-int/newsroom/2021/01/210125-siemens-gamsa-press-release-decomblades-launched; SGRE, *Consolidated Non-Financial Statement 2019 (former Sustainability Report)* (Vizcaya, Spain: 2019), p. 3, https://www.siemensgamesa.com/-/media/siemensgamesa/downloads/en/sustainability/siemens-gamesa-consolidated-non-financial-statement-2019-en.pdf. See also D. Snieckus, "Siemens Gamesa tackles wind supply chain emissions in net-zero strategy step-up", Recharge, 23 April 2020, https://www.rechargenews.com/transition/siemens-gamesa-tackles-wind-supply-chain-emissions-in-net-zero-strategy-step-up/2-1-796565.

277 RE100, "Vestas", http://there100.org/vestas, viewed 13 May 2020; A. Lee, "Wind power giant Vestas sets 2030 carbon-neutral goal", Recharge, 6 January 2020, https://www.rechargenews.com/wind/wind-power-giant-vestas-sets-2030-carbon-neutral-goal/2-1-732261; WindEurope, "Circular economy: Blade recycling is a top priority for the wind industry", 12 February 2020, https://windeurope.org/newsroom/news/blade-recycling-a-top-priority-for-the-wind-industry; C. Richard, "Vestas plans 'zero-waste turbines' by 2040", 20 January 2020, https://www.windpowermonthly.com/article/1671285/vestas-plans-zero-waste-turbines-2040.

278 Envision, "Envision promises to be operation-level carbon neutral by 2022, value chain carbon neutral by 2028: Envision's first carbon neutrality report", press release (Shanghai: 23 April 2021), https://markets.businessinsider.com/news/stocks/envision-promises-to-be-operation-level-carbon-neutral-by-2022-value-chain-carbon-neutral-by-2028-envision-s-first-carbon-neutrality-report-1030338427.

279 **Box 7** based on the following sources: uses of small-scale turbines from WWEA, *2017 Small Wind World Report Summary* (Bonn: June 2017), p. 5, from A. Orrell et al., *2016 Distributed Wind Market Report* (Richland, WA: Pacific Northwest National Laboratory (PNNL), August 2017), p. i, https://energy.gov/sites/prod/files/2017/08/f35/2016-Distributed-Wind-Market-Report.pdf, from US DOE, "Small wind electric systems", https://www.energy.gov/energysaver/save-electricity-and-fuel/buying-and-making-electricity/small-wind-electric-systems, viewed 19 April 2021, from G. McKay and W. Mathis, "In a world of big wind, there's still a place for tiny turbines", Bloomberg, 2 April 2021, https://www.bloomberg.com/news/articles/2021-04-02/in-a-world-of-big-wind-there-s-still-a-place-for-tiny-turbines, and from Australian Renewable Energy Agency (ARENA), "Small wind turbines solving big problems", 19 November 2020, https://arena.gov.au/blog/small-wind-turbines-solving-big-problems. Small-scale wind power descriptions and capacity limits in footnote from WWEA, op. cit. this note, and from US DOE, Office of Energy Efficiency & Renewable Energy (EERE), *2018 Offshore Wind Technologies Market Report* (Washington, DC: August 2019), p. 1, https://www.energy.gov/sites/prod/files/2019/09/f66/2018%20Offshore%20Wind%20Technologies%20Market%20Report.pdf. Market shrinkage from information and sources throughout this box; inconsistent policy support and local permitting laws (also perceived noise and aesthetic impacts) from A. Orrell, PNNL, cited in J. Gerdes, "Struggling distributed wind sector eyes role in microgrids market", Greentech Media, 28 April 2020, https://www.greentechmedia.com/articles/read/distributed-wind; planning laws also from P. Crossley, University of Sydney, Sydney, personal communication with REN21, 9 April 2021; competition from solar PV from McKay and Mathis, op. cit. this note, and from Gerdes, op. cit. this note; 42.5 MW added in six countries in 2019 from J-D. Pitteloud, WWEA, Bonn, personal communication with REN21, April 2021; 47 MW in 2018 from US DOE, EERE, *2018 Distributed Wind Market Report*, p. iv; the 114 MW in 2017 was installed in a documented 10 countries, from US DOE, EERE, *2017 Distributed Wind Market Report* (Washington, DC: 2018), p. 9, https://www.energy.gov/sites/prod/files/2018/09/f55/2017-DWMR-091918-final.pdf. Lack of data and no off-grid systems included from Pitteloud, op. cit. this note. The WWEA estimates that more than 1 million small-scale turbines were in operation at the end of 2019, totalling at least 3 GW of capacity, but data are difficult to estimate and official numbers from Italy, Japan, United Kingdom and the United States include only grid-connected capacity, from Pitteloud, op. cit. this note; total global small-scale wind power capacity was estimated to be at least 1.7 GW at end-2018, from US DOE, EERE, *2018 Distributed Wind Market Report* (Washington, DC: 2019), p. 12, https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf, and more recent data are not available from this source. Data for China, Denmark, Germany, Japan and the United Kingdom from Pitteloud, op. cit. this note. China saw a slight annual increase in 2018, but installations were down substantially relative to previous year, from CWEA, cited in US DOE, EERE, *2018 Distributed Wind Market Report*, op. cit. this note, p. 13. US capacity additions in 2019 and retrofits from A. Orrell et al., *2019 Distributed Wind Data Summary* (Richland, WA: PNNL, August 2020), pp. 3, 20, https://www.pnnl.gov/sites/default/files/media/file/2019%20Distributed%20Wind%20Data%20Summary-10Aug20.pdf. The United States added 2,167 units in 2019, from PNNL, "2019 Distributed Wind Data Summary", Excel Data Tables, 6 August 2020, Figure 14, https://www.pnnl.gov/distributed-wind, viewed 19 April 2021. US installations in 2019 were down from 1.5 MW (2,661 units) in 2018, 1.7 MW (3,269 units) in 2017, 2.4 MW in 2016, and 4.3 MW in 2015, from US DOE, EERE, *2017 Distributed Wind Market Report*, op. cit. this note, pp. iv, 8, 9. However, per unit sales of units <1 kW continued to increase in the United States during 2019, from idem, p. 21. Japan projects under FIT, from Japan Small Wind Turbines Association, https://www.meti.go.jp/shingikai/sankoshin/hoan_shohi/denryoku_anzen/newenergy_hatsuden_wg/pdf/018_01_03.pdf (in Japanese), with data provided by Pitteloud, op. cit. this note. Shrinking markets and sharp decline in number of producers in China and United States, from PNNL, "2019 Distributed Wind Data Summary", Excel Data Tables, op. cit. this note, and see past coverage of small-scale wind in previous editions of the GSR for longer-term trends. US exports in 2019 totalled 475 kW, down steadily from 2015, when exports totaled 21,446 kW; exports were 937 kW in 2018, 5,541 kW in 2017, and 10,322 kW in 2016, from PNNL, "2019 Distributed Wind Data Summary", Excel Data Tables, op. cit. this note. Key markets dried up, from A. Orrell et al., 2019 Distributed Wind Data Summary, op. cit. this note, p. 9. US domestic sales from PNNL, "2019 Distributed Wind Data Summary", Excel Data Tables, op. cit. this note. Sales early in the decade were, for example, 19.2 MW in 2010 and 15.2 MW in 2011, from idem. Looking up and role of tax credit and US R&D efforts from Gerdes, op. cit. this note, and from US DOE, EERE, "Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad", February 2020, https://www.energy.gov/sites/prod/files/2020/03/f72/miracl-fact-sheet-v2.pdf. See also US DOE, EERE, "Distributed wind competitiveness improvement project helps manufacturers develop, certify next-gen technologies", 19 November 2019, https://www.energy.gov/eere/articles/distributed-wind-competitiveness-improvement-project-helps-manufacturers-develop. US R&D on plug-and-play, from US DOE, EERE, "Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad", op. cit. this note. Italy FIT incentive and market data, from Pitteloud, op. cit. this note. The incentive offers a tariff of EUR 150 (USD 184.3) per MWh for 20 years and uses a registry and quota system. The main difference from previous policies is that small-scale wind and solar PV must compete for the 770 MW available, from idem. For further details, see GSE, "Accesso agli incentivi", https://www.gse.it/servizi-per-te/fonti-rinnovabili/fer-elettriche/incentivi-dm-04-07-2019, viewed 27 April 2021 (in Italian); and GSE, "Tariffe incentivanti di riferimento, vita utile e premi stabiliti dal DM 2019",https://www.gse.it/servizi-per-te_site/fonti-rinnovabili_site/fer-elettriche_site/Documents/TAB1_dmfer2019.pdf, viewed 27 April 2021 (in Italian). Start-up companies from, for example: McKay and Mathis, op. cit. this note; Diffuse Energy, "Smarter wind generation", https://www.diffuse-energy.com, viewed 27 April 2021; Alpha 311, "Local renewable energy for the world", https://alpha-311.com/, viewed 27 April 2021. New uses from ARENA, op. cit. this note.

280 **Sidebar 6** and **Figure 37** based on IRENA, *Renewable Electricity Generation Costs in 2020* (Abu Dhabi: 2021) and IRENA, personal communication with REN21, May 2021.

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1 **Figure 38** from International Energy Agency (IEA) et al., *Tracking SDG 7: The Energy Progress Report* (World Bank, Washington, DC: 2021), https://trackingsdg7.esmap.org/downloads, and from A. Whiteman, International Renewable Energy Agency (IRENA), personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 31 March 2021.

2 World Health Organization (WHO), "Household air pollution", 8 May 2018, https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health.

3 IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Abu Dhabi and Paris: 2020), https://www.ren21.net/wp-content/uploads/2019/05/IRENA_IEA_REN21-Policies_HC_2020_Full_Report.pdf.

4 Ibid.

5 Sustainable Energy for All (SEforALL), *Chilling Prospects: Tracking Sustainable Cooling for All 2020* (Vienna: 2020), https://www.seforall.org/system/files/2020-07/CP-2020-SEforALL.pdf.

6 Ibid.

7 A. Pozzer et al., "Regional and global contributions of air pollution to risk of death from COVID-19", *Cardiovascular Research*, vol. 116, no. 14 (2020), pp. 2247-53, https://doi.org/10.1093/cvr/cvaa288. While this study looked at urban air pollution, the findings should equally (if not more) apply to indoor air pollution as it is also caused by particulate matter.

8 **Box 8** from the following sources: 4 million deaths from WHO, op. cit. note 2, and from US Centers for Disease Control and Prevention, "Covid-19 – people with certain medical conditions", 1 December 2020, https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/people-with-medical-conditions.html; 60% of healthcare facilities from R. Cronk and J. Bartram, "Environmental conditions in health care facilities in low- and middle-income countries: Coverage and inequalities", *International Journal of Hygiene and Environmental Health*, vol. 221, no. 3 (2018), pp. 409-22, https://doi.org/10.1016/j.ijheh.2018.01.004; rural sub-Saharan Africa from IEA et al., *Tracking SDG 7: The Energy Progress Report* (Washington, DC: 2020), https://trackingsdg7.esmap.org/downloads; T. Peters and B. Hartley, "Sustainable cold chains needed for equitable COVID-19 distribution", SEforALL, 12 November 2020, https://www.seforall.org/news/sustainable-cold-chains-needed-for-equitable-covid-19-vaccine-distribution; WHO, "Direct-drive solar vaccine refrigerators – a new choice for vaccine storage" (Geneva: May 2013), https://www.who.int/immunization/programmes_systems/supply_chain/optimize/direct_drive_solar_vaccine_refrigerator.pdf; Efficiency for Access, "An interview with Dr. Karan Sagar from Gavi, the vaccine alliance", 30 June 2020, https://medium.com/efficiency-for-access/an-interview-with-dr-karan-sagar-from-gavi-the-vaccine-alliance-fe01b45d5a68; N. Lewis, "How solar tech could help distribute Covid-19 vaccines in Africa", CNN, 15 January 2021, https://edition.cnn.com/2021/01/14/africa/africa-covid-vaccine-cold-chain-spc-intl/index.html; US Agency for International Development (USAID), "Power Africa Covid-19 response", https://www.usaid.gov/powerafrica/coronavirus, viewed 4 March 2021.

9 V. Castán Broto and J. Kirshner, "Energy access is needed to maintain health during pandemics", *Nature Energy*, vol. 5 (2020), pp. 419-21, https://www.nature.com/articles/s41560-020-0625-6; B. Ieri and W. Mathai, "Energy access is key to sub-Saharan Africa's economic recovery", World Resources Institute, 3 February 2021, https://www.wri.org/insights/energy-access-key-sub-saharan-africas-economic-recovery.

10 IEA et al., op. cit. note 1.

11 IEA, "Access to electricity", https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity#abstract, viewed 6 December 2020.

12 IEA, "The Covid-19 crisis is reversing progress on energy access in Africa", 20 November 2020, https://www.iea.org/articles/the-covid-19-crisis-is-reversing-progress-on-energy-access-in-africa.

13 IEA, op. cit. note 11.

14 Ibid.

15 IEA et al., op. cit. note 8.

16 Ibid.

17 Ibid.

18 Ibid.

19 Ibid.

20 IEA, "Defining energy access: 2020 methodology", https://www.iea.org/articles/defining-energy-access-2020-methodology, viewed 4 December 2020.

21 Ibid.

22 Energy Sector Management Assistance Program (ESMAP), *The State of Access to Modern Cooking Energy Services* (Washington, DC: World Bank, 2020), http://documents.worldbank.org/curated/en/937141600195758792/The-State-of-Access-to-Modern-Energy-Cooking-Services. The report looked at six dimensions: availability, affordability, exposure, efficiency, convenience and safety, based on the World Bank's Multi-Tier Framework. Tier 4 (on a scale of 0 to 5) is considered as having reached access to modern energy cooking services.

23 Ibid.

24 **Figure 39** from Ibid.

25 IEA et al., op. cit. note 1.

26 Ibid.

27 Ibid.

28 IEA, "Electricity access database", https://iea.blob.core.windows.net/assets/93fd1a56-5c8f-4209-ba6e-7f6ff9fffb19/WEO2020-Electricityaccessdatabase.xlsx, viewed 6 December 2020.

29 Ibid.

30 Ibid.

31 Ibid.

32 Ibid.

33 Ibid.

34 Ibid.

35 Ibid.

36 Ibid.

37 IEA et al., op. cit. note 8.

38 IEA, "Data and statistics: Electricity generation by fuel Indonesia", https://www.iea.org/data-and-statistics?country=INDONESIA&fuel=Energy%20supply&indicator=ElecGenByFuel, viewed 8 November 2020.

39 IEA, "Data and statistics: Electricity generation by fuel India", https://www.iea.org/data-and-statistics?country=INDIA&fuel=Electricity%20and%20heat&indicator=ElecGenByFuel, viewed 5 April 2021.

40 IEA, "Data and statistics: Electricity generation by fuel Bangladesh", https://www.iea.org/data-and-statistics?country=BANGLADESH&fuel=Electricity%20and%20heat&indicator=ElecGenByFuel, viewed 28 April 2021.

41 IEA, "Data and statistics: Electricity generation by fuel Cambodia", https://www.iea.org/data-and-statistics?country=CAMBODIA&fuel=Energy%20supply&indicator=ElecGenByFuel, viewed 8 November 2020; IEA, "SDG7: Data and projections, access to electricity", https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity#abstract, viewed 28 April 2021.

42 IEA, "Data and statistics: Electricity generation by fuel Ethiopia", https://www.iea.org/data-and-statistics?country=ETHIOPIA&fuel=Energy%20supply&indicator=ElecGenByFuel, viewed 8 November 2020.

43 IEA, "Data and statistics: Electricity generation by fuel Kenya", https://www.iea.org/data-and-statistics?country=KENYA&fuel=Energy%20supply&indicator=ElecGenByFuel, viewed 8 November 2020.

44 Whiteman, op. cit. note 1.

45 Energy for Growth Hub, "Raising global energy ambitions: The 1000 kWh modern energy minimum", 26 January 2021, https://www.energyforgrowth.org/report/modern-energy-minimum.

46 Afrobarometer, "Progress toward 'reliable energy for all' stalls across Africa, Afrobarometer survey finds", press release (Accra: 5 December 2019),https://afrobarometer.org/sites/default/files/publications/Dispatches/ab_r6_dispatchno75_electricity_in_africa_eng1.pdf.

47 Populations at "high risk" are characterised by no access to electricity, low incomes and other factors, from the framework developed in SEforALL, op. cit. note 5.

48 Ibid.

49 Ibid.

50 SEforAll, op. cit. note 5.

51 Ibid.

52 Ibid.

53 Ibid.

54 IRENA, *Off-Grid Renewable Energy Solutions to Expand Electricity Access* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Off-grid_RE_Access_2019.pdf.

55 REN21, *Renewables Global Status Report 2020* (Paris: 2020), http://ren21.net/gsr-2020.

56 Energising Development (EnDev), "COVID-19 Energy Access Industry Barometer – presentation of results in a webinar hosted by EnDev", 7 August 2020, https://endev.info/covid-19-energy-access-industry-barometer-presentation-of-results-in-a-webinar-hosted-by-endev.

57 Ibid.

58 Ibid.

59 D. Corbyn and L. Fortes, "2020: Off-grid solar investment remains robust during Covid-19 pandemic", GOGLA, 21 March 2021, https://www.gogla.org/about-us/blogs/2020-off-grid-solar-investment-remains-robust-during-covid-19-pandemic.

60 ESMAP, op. cit. note 22.

61 Ibid.

62 Ibid.

63 Ibid.

64 Ibid.

65 World Bank, *Household Cookstoves, Environment, Health and Climate Change* (Washington, DC: 2011), https://openknowledge.worldbank.org/handle/10986/27589.

66 WHO, *Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children* (Geneva: 2016), https://apps.who.int/iris/bitstream/handle/10665/204717/9789241565233_eng.pdf.

67 Infrastructure Development Company Limited (IDCOL), "Improved cookstove program", https://idcol.org/home/ics, viewed 26 March 2021.

68 EnDev, *Accelerating Uptake of Pico PV Systems and High Tier Cookstoves in Kenya Through Results-Based Financing* (Eschborn, Germany: 2020), https://endev.info/wp-content/uploads/2021/01/pico-PV_systems_and_high_tier_cookstoves_in_Kenya_through_RBF_report.pdf.

69 EnDev, "SNV EnDev Cookstoves RBF facility", fact sheet (Eschborn, Germany: 2020), https://snv.org/cms/sites/default/files/explore/download/endev_kenya_stoves_rbf_factsheet_aug_2020.pdf.

70 IRENA, *Biogas for Domestic Cooking: Technology Brief* (Abu Dhabi: 2017), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Dec/IRENA_Biogas_for_domestic_cooking_2017.pdf.

71 Whiteman, op. cit. note 1.

72 **Figure 40** from Ibid; population data from World Bank, DataBank, "Population estimates and projections", https://databank.worldbank.org/source/population-estimates-and-projections/Type/TABLE/preview/on#, viewed 7 May 2021.

73 Ibid.

74 H. Clemens, Hivos, personal communication with REN21, 15 February 2021.

75 Fair and Sustainable Consulting, *African Biogas Partnership Programme Phase 2 Effect Evaluation, Final Report* (Louvain-La-Neuve, Belgium: 2019),https://www.government.nl/binaries/government/documents/reports/2019/05/13/africa-biogas-partnership-programme-abpp-phase-2---effect-evaluation/Africa+Biogas+Partnership+Programme.pdf.

76 Clemens, op. cit. note 74.

77 ESMAP, *Cooking with Electricity: A Cost Perspective*, Report Summary (Washington, DC: World Bank, 2020), http://documents1.worldbank.org/curated/en/121371601050459132/pdf/Report-Summary.pdf.

78 H. Blair, "Accelerating the uptake of electric pressure cookers on mini-grids in Tanzania", CLASP, 8 June 2020, https://clasp.ngo/updates/2020/accelerating-the-uptake-of-electric-pressure-cookers-on-mini-grids-in-tanzania; ESMAP, op. cit. note 77.

79 ESMAP, op. cit. note 77.

80 Efficiency for Access Coalition, *2021 Appliance Data Trends* (January 2021), https://storage.googleapis.com/e4a-website-assets/2021-ApplianceDataTrends.pdf.

81 Global Leap Awards, "Electric pressure cookers", https://globalleapawards.org/electric-pressure-cookers, viewed 7 March 2021.

82 Solar Cookers International, "Distribution of solar cookers", https://www.solarcookers.org/partners/distribution-solar-cookers, viewed 7 March 2021.

83 GOGLA, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January – June 2020* (Amsterdam: 2020), https://www.gogla.org/sites/default/files/resource_docs/global_off_grid_solar_market_report_h1_2020.pdf.

84 GOGLA, *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, July – December 2020* (Amsterdam: 2020), https://www.gogla.org/sites/default/files/resource_docs/global_off-grid_solar_market_report_h2_2020.pdf.

85 Ibid.

86 REN21, op. cit. note 55.

87 GOGLA, op. cit. note 84.

88 Ibid.

89 Ibid.

90 Ibid.

91 Ibid.

92 Ibid.

93 Ibid.

94 Ibid.

95 Ibid.

96 Ibid.

97 Ibid.

98 Ibid.

99 **Figure 41** from Ibid.

100 Ibid.

101 REN21, op. cit. note 55.

102 GOGLA, op. cit. note 84.

103 REN21, op. cit. note 55.

104 ESMAP, *Mini-Grids for Half a Billion People* (Washington, DC: World Bank, 2019), https://esmap.org/mini_grids_for_half_a_billion_people.

105 Mini-Grids Partnership, *State of the Global Mini-Grids Market 2020* (London: BloombergNEF and SEforALL, 2020), https://minigrids.org/market-report-2020.

106 **Figure 42** from Ibid.

107 Ibid.

108 Africa Minigrid Developers Association (AMDA), *Benchmarking Africa's Mini-Grids* (Nairobi: 2020), https://africamda.org/wp-content/uploads/2020/11/AMDA-Benchmarking-2020-.pdf.

109 Ibid.

110 Ibid.

111 Husk Power Systems, "Husk Power Systems – first minigrid company to cover 100 communities & 5,000 small business customers", press release (Fort Collins, CO: 10 December 2020), https://huskpowersystems.com/husk-power-systems-first-minigrid-company-to-power-100-communities-5000-small-business-customers.

112 Mini-Grids Partnership, op. cit. note 105.

113 Ibid.

114 Africa Solar Industry Association, *Africa Solar Outlook 2021* (Kigali: February 2021), http://afsiasolar.com/wp-content/uploads/2021/02/AFSIA-Africa-Solar-Outlook-2021-final-2.pdf.

115 Ibid.

116 Rural Electrification Agency (REA), "Nigeria electrification project (NEP) solar hybrid mini grids component", http://rea.gov.ng/minigrids, viewed 18 February 2021.

117 Ibid.

118 J. M. Takouleu, "Nigeria: Renewvia connects two solar mini-hybrid grids in Bayelsa State", Afrik21, 4 June 2020, https://www.afrik21.africa/en/nigeria-renewvia-connects-two-solar-mini-hybrid-grids-in-bayelsa-state; REA,

"Shimankar Community welcomes solar electricity", press release (Lagos: 3 December 2020), https://rea.gov.ng/press-release-shimankar-community-welcomes-solar-electricity.

119 REA, "Solar power Naija", e-news, December 2020, https://mailchi.mp/rea.gov.ng/enews-dec2020.

120 USAID, "Power Africa Covid-19 response", https://www.usaid.gov/powerafrica/coronavirus, viewed 24 March 2021.

121 Nextier Power, "SustainSolar to install 7 containerised mini-grids for OnePower in Lesotho", Nigeria Electricity, 4 November 2020, https://www.nigeriaelectricityhub.com/2020/11/04/sustainsolar-to-install-7-containerised-solar-mini-grids-for-onepower-in-lesotho.

122 J. M. Takouleu, "Benin: 11 companies selected for 8 mini solar grids projects in rural areas", Afrik21, 16 July 2020, https://www.afrik21.africa/en/benin-11-companies-selected-for-8-mini-solar-grids-projects-in-rural-areas.

123 I. Magoum, "Togo: 129 localities soon to be electrified via mini-grids", Afrik21, 5 February 2021, https://www.afrik21.africa/en/togo-129-localities-soon-to-be-electrified-via-mini-grids; "Senegal's ASER launches a call for tenders for 133 solar mini grids in rural areas", Energy Mix Report, 11 January 2021, https://www.energymixreport.com/senegals-aser-launches-a-call-for-tenders-for-133-solar-mini-grids-in-rural-areas.

124 AMDA, op. cit. note 108.

125 J. M. Takouleu, "Kenya: Renewvia commissions 3 mini-grids in Turkana and Marsabit countries", Afrik21, 11 June 2020, https://www.afrik21.africa/en/kenya-renewvia-commissions-3-mini-grids-in-turkana-and-marsabit-counties.

126 J. M. Takouleu, "Kenya: Kenya Power wants to hybridise 23 mini diesel grids with solar and wind power", Afrik21, 8 February 2021, https://www.afrik21.africa/en/kenya-kenya-power-wants-to-hybridise-23-mini-diesel-grids-with-solar-and-wind-power.

127 J. M. Takouleu, "DRC: Nuru connects 1.3 MW solar off-grid hybrid in Goma", Afrik21, 8 February 2020, https://www.afrik21.africa/en/drc-nuru-connects-1-3-mw-solar-off-grid-hybrid-in-goma.

128 Sustainable and Renewable Energy Development Authority (SREDA), "National database of renewable energy", https://ndre.sreda.gov.bd/index.php?id=1&i=5, viewed 18 February 2021.

129 Ibid.

130 S. Maradona, "La energía del sol llevará luz a dos parajes inhóspitos de la estepa", Rio Negro, 11 October 2020, https://www.rionegro.com.ar/la-energia-del-sol-llevara-luz-a-dos-parajes-inhospitos-de-la-estepa-1531673.

131 IRENA, *Innovation Landscape Brief: Pay-As-You-Go* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Pay-as-you-go_models_2020.pdf.

132 GOGLA, op. cit. note 84.

133 M-Kopa, "Products", https://m-kopa.com/products, viewed 14 November 2020.

134 J. M. Takouleu, "AFRICA: Bboxx and Canal+ sign agreement for solar-powered television", Afrik21, 28 July 2020, https://www.afrik21.africa/en/africa-bboxx-and-canal-sign-agreement-for-solar-powered-television.

135 Bboxx, "Bboxx launches the new bpower20 products", press release (London: 25 August 2020), https://www.bboxx.com/press-releases/bboxx-launches-the-new-bpower20-product.

136 Ibid.

137 GOGLA, op. cit. note 84.

138 J. M. Takouleu, "Rwanda: Engie and OffGridBox provide green energy, water and Wi-Fi in Kigali", Afrik21, 21 October 2020, https://www.afrik21.africa/en/rwanda-engie-and-offgridbox-provide-green-energy-water-and-wi-fi-in-kigali.

139 Ibid.

140 Ibid.

141 "Bboxx, EDF, and SunCulture to accelerate access to solar-powered farming in Togo", African Review, 18 December 2020, https://www.africanreview.com/energy-a-power/power-generation/togo-government-partners-bboxx-edf-and-sunculture-to-accelerate-access-to-sustainable-solar-powered-farming.

142 Ibid.

143 Dalberg, "Cleaning up cooking in urban Kenya with LPG and bio-ethanol", 28 June 2018, http://dalberg.com/our-ideas/cleaning-cooking-urban-kenya-lpg-and-bio-ethanol.

144 Ibid.

145 Ibid.

146 KOKO Networks, "50,000th Nairobi household switches to KOKO fuel", 25 August 2020, https://kokonetworks.com/news/50000th-nairobi-household-switches-to-koko-fuel.

147 RVO, "Access to energy: SDG 7 selects 12 new projects", https://english.rvo.nl/news/access-energy-sdg-7-selects-12-new-projects, viewed 29 November 2020.

148 My PR, "Engie Africa partners with PayGas to provide affordable clean cooking to 20000 beneficiaries in South Africa", 17 July 2020, https://mypr.co.za/engie-africa-partners-with-paygas-to-provide-affordable-clean-cooking-to-20000-beneficiaries-in-south-africa.

149 Ibid.

150 Clean Cooking Alliance (CCA), "Cooking industry catalysts", https://www.cleancookingalliance.org/cooking-industry-catalyst, viewed 14 November 2020.

151 Mini-Grids Partnership, op. cit. note 105.

152 Ibid.; ESI Africa, "Mini-grids can electrify thousands of health centres in sub-Saharan Africa", 2 June 2020, https://www.esi-africa.com/news/mini-grids-can-electrify-thousands-of-health-centres-in-sub-saharan-africa.

153 AMDA, op. cit. note 108.

154 Energy and Environment Partnership Trust Fund (EEP Africa), "East Africa Power (EAP): Bihonora Multi-Purpose Hydropower Project", https://eepafrica.org/Portfolio/east-african-power, viewed 29 April 2021.

155 EEP Africa, "Engie Equatorial: Rural Economic Agro Labs Through Mini-grids (REALM)", https://eepafrica.org/Portfolio/engie-equatorial, viewed 29 April 2021.

156 Ibid.

157 Sunkofa, "Sunkofa and PowerGen awarded 40 mini-grids on the Benin mini-grid call for proposals", press release (Paris: 25 June 2020), https://www.linkedin.com/posts/sunkofa-energy_press-release-activity-6683288136736481281-_blX.

158 Ibid.

159 SEforALL, *Energizing Finance: Understanding the Landscape 2020* (Washington, DC: 2020),https://www.seforall.org/publications/energizing-finance-understanding-the-landscape-2020.

160 Ibid.

161 Ibid.

162 Ibid.

163 Ibid.

164 Ibid.

165 Ibid.

166 Ibid.

167 Ibid.

168 IRENA and Climate Policy Initiative (CPI), *Global Landscape of Renewable Energy Finance 2020* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_CPI_Global_finance_2020.pdf.

169 Ibid.

170 **Figure 43** from Ibid.

171 B. Attia, "Session I – Status quo of the DRE sector in Sub-Saharan Africa (SSA) and Asia-Pacific (APAC): Global investment trends in the sector", presentation, Alliance for Rural Electrification (ARE) and Energy Catalyst Rural Electrification Masterclass, 8 March 2021.

172 Acumen, "Acumen and Green Climate Fund boost COVID-19 relief in off-grid energy access", 12 November 2020, https://acumen.org/blog/acumen-and-green-climate-fund-boost-covid-19-relief-in-off-grid-energy-access.

173 African Development Bank (AfDB), "The African Development Bank launches $50 million facility to support energy access companies through and beyond the COVID-19 pandemic", press release (Abidjan: 4 December 2020), https://www.afdb.org/en/news-and-events/press-releases/african-development-bank-launches-50-million-facility-support-energy-access-companies-through-and-beyond-covid-19-pandemic-39746.

174 Shine, "Covid-19 Recovery Fund Grant", https://www.shineinvest.org/covid-19, viewed 7 March 2021.

175 CCA, *2021 Clean Cooking Industry Snapshot* (Washington, DC: 2021), https://www.cleancookingalliance.org/binary-data/RESOURCE/file/000/000/620-1.pdf.

176 Ibid.

177 Burn, "BurninNews October 2020 Newsletter", 15 October 2020, https://burnstoves.com/media/newsletter/post?s=2020-burninnews-october-2020-newsletter.

178 Betterinvest, "Biomasse-Briketts für Kenia", https://www.bettervest.com/de/project/sanergy-2-projektprofil, viewed 7 March 2021.

179 FMO, "Buen Manejo del Campo S.A. De CV", https://www.fmo.nl/project-detail/59373, viewed 10 February 2020.

180 CCA, op. cit. note 175.

181 Ibid.

182 Ibid.

183 GOGLA, "Total capital raised", https://infogram.com/1p9yk05mkv773df7ze1d01m9yji3gjk2gm5?live-%20, viewed 22 March 2021.

184 SEforALL, op. cit. note 159.

185 GOGLA, "Type of debt investment per year", https://infogram.com/1p9yk05mkv773df7ze1d01m9yji3gjk2gm5?live-%20, viewed 23 March 2021.

186 **Figure 44** from GOGLA, "Financing blend", https://infogram.com/1p9yk05mkv773df7ze1d01m9yji3gjk2gm5?live-%20, viewed 22 March 2021.

187 I. Shumkov, "Lumos obtains USD 35m in financing for solar expansion in Nigeria", Renewables Now, 15 September 2020, https://renewablesnow.com/news/lumos-obtains-usd-35m-in-financing-for-solar-expansion-in-nigeria-713653.

188 J. M. Takouleu, "DRC EIF OGEF lends $4m to Bboxx for electrification via solar home systems", Afrik21, 24 November 2020, https://www.afrik21.africa/en/drc-eif-ogef-lends-4m-to-bboxx-for-electrification-via-solar-home-systems.

189 Oolu, "Oolu, a West Africa-based solar pay-as-you-go distributor, raises $8.5 million in Series B round with RP Global as lead investor", press release (Dakar: 2 December 2020), https://oolusolar.com/pressarticles/2020/12/14/mky7th4cd1xlizlaysdbtscbxh3e3f.

190 EDFI Electrify, "UpOwa raises €3m from EDFI ElectriFI to accelerate expansion in Cameroon", 7 September 2020, https://www.electrifi.eu/news/upowa-raises-e3m-from-edfi-electrifi-to-accelerate-expansion-in-cameroon.

191 Easy Solar, "Easy Solar raises $5M in Series A equity and debt funding to scale operations in West Africa", 29 September 2020, https://medium.com/@easysolar/easy-solar-raises-5m-in-series-a-equity-and-debt-funding-to-scale-operations-in-west-africa-99e6a86581f5.

192 European Investment Bank, "Uganda: 1.4 million Ugandans to access reliable and affordable energy under new EIB – ENGIE initiative", press release (Luxembourg: 28 July 2020), https://www.eib.org/en/press/all/2020-207-14-million-ugandans-to-access-reliable-and-affordable-energy-under-new-eib-engie-initiative.

193 Energy+, "ENERGY+ secures funding from Venturebuilder, CORDAID, and USADF", press release (Bamako: 12 August 2020), https://eplusmali.com/documentation/energy-secures-funding.

194 Angaza, "SIMA Angaza Distributor Finance Fund announces first three investments", press release (San Francisco, New York and Nairobi: 13 October 2020), https://www.angaza.com/2020/10/13/sima-angaza-distributor-finance-fund-announces-first-three-investments.

195 ARE, "ARE member Sunculture raises USD 14 million Series A funding", press release (Nairobi: 7 December 2020), http://www.ruralelec.org/news-from-are/are-member-sunculture-raises-usd-14-million-series-funding.

196 GOGLA, *Off-Grid Solar Investment Trends* (Amsterdam: 2020), https://www.gogla.org/sites/default/files/resource_docs/off-grid_solar_investment_trends_2019-2020.pdf.

197 Energise Africa, "Investments", https://www.energiseafrica.com/investments, viewed 28 February 2021; Energise Africa, "Energising off-grid solar access in Africa – back to business (almost) as usual", 12 October 2020, https://www.energiseafrica.com/news/energising-off-grid-solar-access-in-africa-back-to-business-almost-as-usual.

198 Energise Africa, "Investments", op. cit. note 197.

199 Attia, op. cit. note 171.

200 Husk Power Systems, "Dutch Development Bank FMO spotlights Husk Power as 'energy disruptors'; invested USD 5 million in minigrid developer", press release (Fort Collins, CO: 5 October 2020), https://huskpowersystems.com/dutch-development-bank-fmo-spotlights-husk-power-as-energy-disruptors-invested-us-5-million-in-minigrid-developer.

201 J. M. Takouleu, "Africa: Winch energy obtains $16 million to finance 49 mini-grids in two countries", Afrik21, 16 February 2021, https://www.afrik21.africa/en/africa-winch-energy-obtains-16-million-to-finance-49-mini-grids-in-two-countries.

202 Ibid.

203 J. M. Takouleu, "Nigeria: NDIF invests $4.6m in Havenhill for 22 solar mini-grids", Afrik21, 11 March 2021, https://www.afrik21.africa/en/nigeria-ndif-invests-4-6m-in-havenhill-for-22-solar-mini-grids.

204 Angaza, "Angaza raises $13.5 million in Series B financing", press release (San Francisco: 27 October 2020), https://www.angaza.com/2020/10/27/angaza-raises-13-5-million-in-series-b-financing.

205 ARE, "ARE member Sparkmeter completes USD 12 million Series A financing", press release (Washington, DC: 25 August 2020), https://www.ruralelec.org/news-from-are/are-member-sparkmeter-completes-12-million-series-financing.

206 Acumen, "Our latest investment: Solaris Off-grid", 17 April 2020, https://acumen.org/blog/new-investment-solaris.

207 T. McManan-Smith, "Platform to create a global market for distributed renewable energy", The Energyst, 21 January 2021, https://theenergyst.com/innovative-platform-creates-a-global-market-for-distributed-renewable-energy.

208 Ibid.

209 SEforALL, op. cit. note 159.

210 BloombergNEF, "4Q 2019 off-grid and mini-grid market outlook", Climatescope 2020, 10 January 2020, https://global-climatescope.org/library/off-grid/4q-2019.

211 SEforALL, op. cit. note 159.

212 World Bank, "World Bank project to boost household access to affordable energy", press release (Washington, DC: 17 September 2020), https://www.worldbank.org/en/news/press-release/2020/09/17/world-bank-project-to-boost-household-access-to-affordable-energy.

213 Ibid.

214 Ibid.

215 Ibid.

216 World Bank, "Burundi to improve access to services and opportunities for the poor in rural areas", press release (Washington, DC: 28 February 2020), https://www.worldbank.org/en/news/press-release/2020/02/28/burundi-to-improve-access-to-services-and-opportunities-for-the-poor-in-rural-areas.

217 World Bank, "New World Bank funding to boost Lesotho's efforts to improve electricity to thousands of Basotho", press release (Washington, DC: 30 January 2020), https://www.worldbank.org/en/news/press-release/2020/01/30/new-world-bank-funding-to-boost-lesothos-efforts-to-improve-electricity-access-to-thousands-of-basotho.

218 World Bank, "World Bank supports sustainable renewable energy for priority healthcare facilities responding to COVID-19 in Haiti", press release (Washington, DC: 30 September 2020), https://www.worldbank.org/en/news/press-release/2020/09/30/world-bank-supports-sustainable-renewable-energy-for-priority-healthcare-facilities-responding-to-covid-19.

219 AfDB, "African Development Bank invests in pioneering SPARK+ Africa Fund to deliver clean cooking solutions", press release (Abidjan: 30 November 2020), https://www.afdb.org/en/news-and-events/press-releases/african-development-bank-invests-pioneering-spark-africa-fund-deliver-clean-cooking-solutions-39574.

220 Ibid.

221 AfDB, "African Development Bank's Facility for Energy Inclusion attracts $160 million in commitments for small-scale renewable energy", 16 March 2020, https://www.afdb.org/en/news-and-events/african-development-banks-facility-energy-inclusion-attracts-160m-commitments-small-scale-renewable-energy-34792.

222 AfDB, "African Development Bank approves $7 million in SEFA technical assistance to transform mini-grid investment in Africa",

press release (Abidjan: 18 December 2020), https://www.afdb.org/en/news-and-events/press-releases/african-development-bank-approves-7-million-sefa-technical-assistance-transform-mini-grid-investment-africa-39965.

223 European Commission, "Team Europe: EU seals agreements to generate €10 billion in investment in Africa and the EU Neighbourhood and stimulate global recovery", press release (Brussels: 12 November 2020), https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2076.

224 Ibid.

225 Ibid.

226 Renewable Energy & Energy Efficiency Partnership (REEP), "Beyond the Grid Fund for Africa expands to Uganda", 6 May 2020, https://www.reeep.org/news/%E2%80%98beyond-grid-fund-africa%E2%80%99-expands-uganda.

227 Ibid.

228 Beyond the Grid Fund for Africa, "BGFA, Sweden and NEFCO kick-off new initiative on clean cooking financing solutions", 11 September 2020, https://beyondthegrid.africa/news/sweden-and-nefco-kick-off-new-initiative-on-clean-cooking-financing-solutions.

229 Green Climate Fund (GCF), "SAP013 Scaling smart, solar, energy access minigrids in Haiti", https://www.greenclimate.fund/project/sap013, viewed 29 November 2020; GCF, "FP138 ASER solar rural electrification project", https://www.greenclimate.fund/project/fp138, viewed 29 November 2020; GCF, "FP 129 Afghanistan rural energy market transformation initiative", https://www.greenclimate.fund/project/fp129, viewed 29 November 2020.

230 Ibid., all references.

231 GCF, "FP148 Participation in energy access relief facility", https://www.greenclimate.fund/project/fp148, viewed 29 November 2020.

232 Rockefeller Foundation, "The Rockefeller Foundation commits USD1 billion to catalyse a green recovery from pandemic", press release (New York: 26 October 2020), https://www.rockefellerfoundation.org/news/the-rockefeller-foundation-commits-usd1-billion-to-catalyze-a-green-recovery-from-pandemic.

233 Ibid.

234 Carbon Trust, "The Carbon Trust awarded €5 million IKEA foundation funding to realise the potential of energy access in sub-Saharan Africa", 24 June 2020, https://www.carbontrust.com/news-and-events/news/the-carbon-trust-awarded-eu5-million-ikea-foundation-funding-to-realise-the.

235 Ibid.

236 SEforALL, "Universal Energy Facility opens for mini-grid projects in Benin", 28 January 2021, https://www.seforall.org/news/universal-energy-facility-opens-for-mini-grid-projects-in-benin.

237 Ashden, "Fair Cooling fund pledges $580,000 to protect the most vulnerable", 11 November 2020, https://ashden.org/news/fair-cooling-fund-pledges-580000-to-protect-the-most-vulnerable.

238 Engineers Without Borders USA, "In the News: Awardees announced in Engineers Without Borders-USA's 'Chill Challenge'", 21 May 2020, https://www.ewb-usa.org/in-the-news-awardees-announced-in-engineers-without-borders-usas-chill-challenge.

239 MECS, "MECS Eco competition funds 14 projects to the value of £826,000 to facilitate greater uptake and understanding of opportunities for the use of efficient electric cooking appliances", 19 August 2020, https://mecs.org.uk/mecs-eco-competition-funds-14-projects-to-the-value-of-826000-to-facilitate-greater-uptake-and-understanding-of-opportunities-for-the-use-of-efficient-electric-cooking-appliances.

240 Ibid.

241 **Table 7** and **Table 8** are intended to be only indicative of the overall landscape of distributed renewables for energy access policy activity and are not a definitive reference. Generally, listed policies are those that have been enacted by legislative bodies. Some of the listed policies may not yet be implemented, or are awaiting detailed implementing regulations. It is difficult to capture every policy change, so some policies may be unintentionally omitted or incorrectly listed. This report does not cover policies and activities related to technology transfer, capacity building, carbon finance and Clean Development Mechanism projects, nor does it attempt to provide a comprehensive list of broader framework and strategic policies – all of which are still important to renewables-based energy access progress. For the most part, this report also does not cover policies that are still under discussion or formulation. Information on **electricity access policies** comes from a wide variety of sources, including the World Bank Regulatory Indicators for Sustainable Energy (RISE), IRENA, the Global Renewable Energy Policies and Measures Database, press reports and announcements from ministries, rural electrification agencies and energy regulators, and submissions from REN21 regional- and country-specific contributors and reviewers. Information on **clean cooking access policies** comes from a variety of sources, including Clean Cooking Alliance Policy Database; A. Towfiq, CCA, Washington, DC, personal communication with REN21, 2 April 2021, and submissions from REN21 regional- and country-specific contributors and reviewers.

242 Ibid.

243 Ibid.

244 REA, "Solar Power Naija – enabling 5 million new connections", https://rea.gov.ng/solar-power-naija, viewed 28 February 2021.

245 Ibid.

246 ESMAP, *Regulatory Indicators for Sustainable Energy (RISE): Sustaining the Momentum* (Washington, DC: World Bank, 2020), https://rise.esmap.org/data/files/reports/2020-full-report/RiseReport-010421.pdf.

247 **Figure 45** from RISE, "Analytics", https://rise.esmap.org/analytics, viewed 7 March 2021.

248 H. Gebreamlak, "Law arrives to govern off-grid electricity systems", Addis Fortune, 7 November 2020, https://addisfortune.news/law-arrives-to-govern-off-grid-electricity-systems.

249 E. Bellini, "Benin introduces VAT exemption on imports of PV panels", pv magazine, 27 January 2020, https://www.pv-magazine.com/2020/01/27/benin-introduces-vat-exemption-on-imports-of-pv-panels. J. Spaes, "Mali exempts solar from VAT, import duties", pv magazine, 7 April 2020, https://www.pv-magazine.com/2020/04/07/mali-exempts-solar-from-vat-import-duties.

250 GOGLA, "Policy alert: Kenya introduces VAT on off-grid solar products", 26 June 2020, https://www.gogla.org/news/policy-alert-kenya-introduces-vat-on-off-grid-solar-products; F. Sunday, "Treasury to scrap VAT on renewable energy products", The Standard, 24 April 2021, https://www.standardmedia.co.ke/business/article/2001410696/treasury-to-scrap-vat-on-renewable-energy-products.

251 C. Pronami, "PM KUSUM Yojana: Govt is offering 90% discount on solar pumps; earn in Lakhs and get these benefits", Krishi Jagran, 5 January 2021, https://krishijagran.com/agriculture-world/pm-kusum-yojana-govt-is-offering-90-discount-on-solar-pumps-earn-in-lakhs-and-get-these-benefits.

252 "Bboxx, EDF, and SunCulture to accelerate access to solar-powered farming in Togo", African Review, 18 December 2020, https://www.africanreview.com/energy-a-power/power-generation/togo-government-partners-bboxx-edf-and-sunculture-to-accelerate-access-to-sustainable-solar-powered-farming.

253 Global Environment Facility, "Opening doors to greater electricity access", 23 June 2020, https://www.thegef.org/news/opening-doors-greater-electricity-access.

254 Ibid.

255 ESMAP, op. cit. note 246.

256 Ibid.

257 Ibid.

258 See endnote 241.

259 C. K. Mandal, "Nepal submits its second Nationally Determined Contribution document to UN", *Kathmandu Post*, 10 December 2020, https://kathmandupost.com/climate-environment/2020/12/10/nepal-submits-its-second-nationally-determined-contribution-document-to-un.

260 Ibid.

261 "Government prepares RS 1b subsidy to promote use of induction stoves", Republica Nepal, 27 March 2020, https://myrepublica.nagariknetwork.com/news/govt-prepares-rs-1b-subsidy-to-promote-use-of-induction-stove.

262 Shivani, "Union budget 2021: Ujjwala scheme to be extended to 1 crore more beneficiaries, announces finance minister Sitharaman", *Hindustan Times*, 1 February 2021, https://www.hindustantimes.com/budget/union-budget-2021-ujjwala-scheme-to-be-extended-to-1-crore-more-beneficiaries-announces-finance-minister-nirmala-sitharaman-101612162680636.html.

263 PIB Delhi, "Cabinet approves extension of time limit for availing the benefits of 'Pradhan Mantri Garib Kalyan Yojana' for Ujjwala beneficiaries w.e.f. 01.07.20", press release (Delhi: 8 July 2020), https://pib.gov.in/PressReleasePage.aspx?PRID=1637214.

264 CCA, op. cit. note 175.

265 Ibid.

INVESTMENT FLOWS

1 BloombergNEF, *Energy Transition Investment Trends. Tracking Global Investment in the Low-carbon Energy Transition* (London: 2021), p. 1, https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends_Free-Summary_Jan2021.pdf.

2 Ibid., p. 1.

3 International Energy Agency (IEA), *World Energy Investment 2020* (Paris: 2020), https://www.iea.org/reports/world-energy-investment-2020/power-sector#overview-of-power-investment.

4 Ibid.

5 EnergyPolicyTracker.org, "Search policies", https://www.energypolicytracker.org/search-results, viewed 18 April 2021.

6 **Figure 46** based on BloombergNEF, op. cit. note 1, and on A. McCrone, London, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 18 March 2021.

7 BloombergNEF, op. cit. note 1; McCrone, op. cit. note 6.

8 McCrone, op. cit. note 6.

9 Ibid.

10 BloombergNEF, op. cit. note 1; McCrone, op. cit. note 6. **Figure 47** based on idem.

11 Ibid., both references.

12 Ibid., both references.

13 Ibid., both references.

14 Ibid., both references.

15 Ibid., both references.

16 C. Nedopil Wang, *China Belt and Road Initiative (BRI) Investment Report 2020* (Green BRI Center and International Institute of Green Finance: Beijing, 2020), https://green-bri.org/wp-content/uploads/2021/01/China-BRI-Investment-Report-2020.pdf.

17 Ibid.

18 Ibid.

19 Ibid.

20 Global Development Policy Center, Boston University, "China's Global Power Database", http://www.bu.edu/cgp, viewed 6 May 2021; C. Springer, "Greening China's overseas energy projects", China Dialogue, 18 November 2020, https://chinadialogue.net/en/energy/greening-chinas-overseas-energy-projects.

21 Ibid., both references.

22 BloombergNEF, op. cit. note 1; McCrone, op. cit. note 6.

23 Ibid., both references.

24 Ibid., both references.

25 BloombergNEF, op. cit. note 1, p. 6.

26 Ibid., p. 6.

27 Ibid., pp. 6-7.

28 Ibid., p. 7.

29 Ibid.; McCrone, op. cit. note 6. **Figure 48** based on idem.

30 United Nations Industrial Development Organization (UNIDO), *World Small Hydropower Development Report 2019 – Case Studies* (Vienna: 2019), https://www.unido.org/sites/default/files/files/2020-02/WSHPDR%202019%20Case%20Studies.pdf; N. Chhabra Roy et al., "Risk management in small hydropower (SHP) projects of Uttarakhand: An innovative approach", *IIMB Management Review*, September 2020, https://www.sciencedirect.com/science/article/pii/S0970389617303889.

31 World Bank, "Geothermal energy is on a hot path", 3 May 2018, https://www.worldbank.org/en/news/feature/2018/05/03/geothermal-energy-development-investment.

32 International Renewable Energy Agency (IRENA), *Advanced Biofuels: What Holds Them Back?* (Abu Dhabi: 2019), https://irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back.

33 Ibid.

34 Ibid.; A. Salgado and F. Boshell, "Biofuels: slump in investment and innovations must be reversed", Energy Post, 3 December 2019, https://energypost.eu/biofuels-slump-in-investment-and-innovations-must-be-reversed.

35 BloombergNEF, op. cit. note 1; McCrone, op. cit. note 6; Frankfurt School – United Nations Environment Programme Collaborating Centre for Climate & Sustainable Energy Finance (FS-UNEP), *Global Trends in Renewable Energy Investment 2020* (Frankfurt: 2020), https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf.

36 BloombergNEF, op. cit. note 1, p. 5.

37 Ibid., p. 4.

38 Ibid., p. 11.

39 Y. Dagnet and J. Jaeger, "Not enough climate action in stimulus plans", World Resources Institute (WRI), 15 September 2020, https://www.wri.org/blog/2020/09/coronavirus-green-economic-recovery.

40 Ibid.

41 IEA, *Evaluation of Possible Recovery Measures* (Paris: 2020), https://www.iea.org/reports/sustainable-recovery/evaluation-of-possible-recovery-measures#abstract.

42 Ibid.

43 EnergyPolicyTracker.org, op. cit. note 5. The 31 governments are: Argentina, Australia, Bangladesh, Brazil, Canada, China, Colombia, European Institutions, Finland, France, Germany, India, Indonesia, Italy, Japan, Mexico, New Zealand, Norway, Poland, the Republic of Korea, the Russian Federation, Saudi Arabia, South Africa, Spain, Sweden, the Netherlands, Turkey, Ukraine, the United Kingdom, the United States and Vietnam.

44 EnergyPolicyTracker.org, op. cit. note 5. **Figure 49** based on idem, viewed 19 April 2021.

45 Ibid.; EnergyPolicyTracker.org, "Methodology", https://www.energypolicytracker.org/methodology, viewed 18 April 2021.

46 EnergyPolicyTracker.org, op. cit. note 5.

47 Ibid.

48 Ibid.

49 European Council, "Special European Council, 17-21 July 2020", https://www.consilium.europa.eu/en/meetings/european-council/2020/07/17-21; World Future Council, *Renewables in the Post-COVID-19 Recovery Package of the EU* (Hamburg: 2021), https://www.renewablescongress.org/wp-content/uploads/GRC_REcovery_EU_FINAL.pdf; European Commission, "EU's Next Long-term Budget & NextGenerationEU: Key Facts and Figures (Brussels: 11 November 2020), https://ec.europa.eu/info/sites/info/files/about_the_european_commission/eu_budget/mff_factsheet_agreement_en_web_20.11.pdf.

50 European Council, op. cit. note 49; World Future Council, op. cit. note 49.

51 World Future Council, op. cit. note 49.

52 Dagnet and Jaeger, op. cit. note 39; EnergyPolicyTracker.org, op. cit. note 5.

53 EnergyPolicyTracker.org, op. cit. note 5.

54 "Trailblazing PV-storage contract shows growing dispatch skills", Reuters, 12 February 2020, https://www.reutersevents.com/renewables/pv-insider/trailblazing-pv-storage-contract-shows-growing-dispatch-skills.

55 EnergyPolicyTracker.org, op. cit. note 5.

56 Ibid.

57 Dagnet and Jaeger, op. cit. note 39

58 Ibid.; WRI, "Nigeria moves toward a sustainable COVID-19 recovery", 14 January 2021, https://www.wri.org/blog/2021/01/nigeria-moves-toward-sustainable-covid-19-recovery.

59 Government of Colombia, "Con el nuevo 'Compromiso por el Futuro de Colombia', el país está haciendo las grandes apuestas", 20 August 2020, https://idm.presidencia.gov.co/prensa/Paginas/Con-el-nuevo-Compromiso-por-el-Futuro-de-Colombia-el-pais-esta-haciendo-las-grandes-apuestas-Duque-200820.aspx.

60 IRENA, "The COVID-19 recovery offers opportunities to address climate crisis", 12 December 2020, https://irena.org/newsroom/expertinsights/2020/Dec/The-COVID-19-Recovery-Offers-Opportunities-to-Address-Climate-Crisis; BloombergNEF, op. cit. note 1, p. 16.

61 BloombergNEF, op. cit. note 1, p. 16.

62 Ibid., p. 16; WilderHill New Energy Global Innovation Index, https://nexindex.com, viewed 22 March 2021; S&P Global, "S&P Global Clean Energy Index", https://www.spglobal.com/spdji/en/indices/esg/sp-global-clean-energy-index/#overview, viewed 22 March 2021.

63 BloombergNEF, op. cit. note 1, p. 16; WilderHill New Energy Global Innovation Index, op. cit. note 62.

64 BloombergNEF, op. cit. note 1, p. 16.

65 T. Team, "Why has SunPower's stock already tripled this year?" *Forbes*, 30 September 2019, https://www.forbes.com/sites/greatspeculations/2019/09/30/why-has-sunpowers-stock-already-tripled-this-year.

66 S&P Global Clean Energy Index, "Overview", https://www.spglobal.com/spdji/en/indices/esg/sp-global-clean-energy-index/#overview, viewed 22 March 2021.

67 McCrone, op. cit. note 6.

68 R. Macquerie et al., *Updated View on the Global Landscape of Climate Finance 2019* (London: Climate Policy Initiative, 2020), https://www.climatepolicyinitiative.org/wp-content/uploads/2020/12/Updated-View-on-the-2019-Global-Landscape-of-Climate-Finance-1.pdf.

69 Ibid.

70 The target was initially set in Cancun, through decision 1/CP.16, and was reaffirmed in Paris through decision 1/CP.21, paragraph 53. United Nations Framework Convention on Climate Change (UNFCCC), "Background note on the USD 100 billion goal in the context of UNFCCC process, in relation to advancing on SDG indicator 13.a.1", https://unstats.un.org/sdgs/tierIII-indicators/files/13.a.1_Background.pdf, viewed April 2021; UNFCCC, "Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015" (Bonn: 2015), https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf.

71 Organisation for Economic Co-operation and Development (OECD), *Climate Finance Provided and Mobilised by Developed Countries in 2013-18* (Paris: November 2020), https://www.oecd-ilibrary.org/docserver/f0773d55-en.pdf.

72 Ibid.

73 Ibid., p. 21.

74 Ibid., p. 21.

75 Macquerie et al., op. cit. note 68; OECD, op. cit. note 71.

76 OECD, op. cit. note 71.

77 Ibid.

78 Climate Funds Update, "Data dashboard", https://climatefundsupdate.org/data-dashboard, viewed March 2021.

79 Independent Expert Group on Climate Finance, *Delivering on the $100 Billion Climate Finance Commitment and Transforming Climate Finance* (December 2020), https://www.un.org/sites/un2.un.org/files/100_billion_climate_finance_report.pdf.

80 Ibid.

81 Green Climate Fund (GCF), *Status of Pledges and Contributions (Initial Resource Mobilization), Status Date: 31 December 2020* (Incheon, Republic of Korea: 2020), https://www.greenclimate.fund/sites/default/files/document/status-pledges-irm-gcf1_3.pdf.

82 Ibid.

83 GCF, "Status of the GCF Portfolio: Approved Projects and Fulfilment of Conditions, GCF/B.27/Inf.03" (Incheon, Republic of Korea: 23 October 2020), https://www.greenclimate.fund/sites/default/files/document/gcf-b27-inf03.pdf.

84 Ibid.

85 Global Environment Facility, "Renewable energy and energy access", https://www.thegef.org/topics/renewable-energy-and-energy-access, viewed March 2021.

86 Climate Investment Funds (CIF), "Clean technologies", https://www.climateinvestmentfunds.org/topics/clean-technologies, viewed March 2021.

87 CIF, *CTF Results Report* (Washington, DC: 19 November 2020), https://www.climateinvestmentfunds.org/sites/cif_enc/files/meeting-documents/ctf_tfc.25_3.1_results_report.pdf. Note that 2020 is the most recent reporting year and refers either to 1 July 2019 to 30 June 2020, or to 1 January 2019 to 31 December 2019 depending on the reporting cycle of the multilateral development bank.

88 Climate Funds Update, "Clean Technology Fund", https://climatefundsupdate.org/the-funds/clean-technology-fund, viewed March 2021.

89 CIF, op. cit. note 87, p. 20.

90 African Development Bank (AfDB) et al., *Joint Report on Multilateral Development Banks' Climate Finance 2019* (London: European Bank for Reconstruction and Development, 2020), https://www.eib.org/attachments/press/1257-joint-report-on-mdbs-climate-finance-2019.pdf.

91 Ibid., p. 23.

92 Ibid., p. 23.

93 Ibid., p. 40.

94 Multilateral development banks include the AfDB, the Asian Development Bank, the Asian Infrastructure Investment Bank, the EBRD, the European Investment Bank, the Inter-American Development Bank, the Islamic Development Bank and the World Bank. AfDB et al., *Joint Report on Multilateral Development Banks' Climate Finance* (London: European Bank for Reconstruction and Development (EBRD), various editions, 2015-2019), as follows: https://publications.iadb.org/en/2015-joint-report-multilateral-development-banks-climate-finance, https://publications.iadb.org/en/2016-joint-report-multilateral-development-banks-climate-finance, https://publications.iadb.org/en/2017-joint-report-multilateral-development-banks-climate-finance, https://publications.iadb.org/en/2018-joint-report-multilateral-development-banks-climate-finance, https://publications.iadb.org/en/2019-joint-report-on-multilateral-development-banks-climate-finance.

95 Ibid.

96 Ibid. **Figure 50** from idem.

97 OECD, op. cit. note 71.

98 Ibid.

99 Ibid.

100 Ibid.

101 Climate Bonds Initiative (CBI), "Explaining green bonds", https://www.climatebonds.net/market/explaining-green-bonds, viewed March 2021.

102 CBI, "Record $269.5bn green issuance for 2020: Late surge sees pandemic year pip 2019 total by $3bn", 24 January 2021, https://www.climatebonds.net/2021/01/record-2695bn-green-issuance-2020-late-surge-sees-pandemic-year-pip-2019-total-3bn.

103 BloombergNEF, "Record month shoots green bonds past trillion-dollar mark", 10 May 2020, https://about.bnef.com/blog/record-month-shoots-green-bonds-past-trillion-dollar-mark.

104 CBI, op. cit. note 102; CBI, personal communication with REN21, March 2021.

105 CBI, op. cit. note 102; CBI, personal communication, op. cit. note 104.

106 CBI, personal communication, op. cit. note 104; CBI, "Data", https://www.climatebonds.net/market/data, viewed 24 March 2021.

107 CBI, personal communication, op. cit. note 104.

108 GCF, *Tipping or Turning Point: Scaling Up Climate Finance in the Era of COVID-19* (Incheon, Republic of Korea: October 2020), pp. 23-24, https://www.greenclimate.fund/sites/default/files/document/gcf-working-paper-tipping-or-turning-point-scaling-climate-finance-era-covid-19.pdf.

109 Ibid., pp. 23-24.

110 Ibid., pp. 23-24.

111 Ibid., pp. 23-24.

112 Ibid., pp. 23-24.

113 Independent Expert Group on Climate Finance, op. cit. note 79.

114 Gofossilfree.org, "Who has committed to divestment?" https://gofossilfree.org/divestment/commitments, viewed April 2021.

115 Ibid.

116 Ibid.

117 350.org, "Breaking: Biggest-ever joint faith divestment from fossil fuels", 18 May 2020, https://350.org/breaking-biggest-ever-joint-divestment-from-fossil-fuels; S&P Global Market Intelligence, "Vatican's call for fossil fuel divestment could have long-term impacts", 30 June 2020,https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/vatican-s-call-for-fossil-fuel-divestment-could-have-long-term-impacts-59221023.

118 Gofossilfree.org, op. cit. note 114.

119 Ibid.

120 Institute for Energy Economics and Financial Analysis (IIEFA), "Over 100 and counting", https://ieefa.org/finance-exiting-coal, viewed March 2021.

121 IIEFA, "Asset managers are leaving coal", https://ieefa.org/asset-managers-leaving-coal, viewed March 2021.

122 Climate Action 100+, *2020 Progress Report* (2020), p. 44, https://www.climateaction100.org/wp-content/uploads/2020/12/CA100-Progress-Report.pdf.

123 Climate Chance and Finance for Tomorrow, *Global Synthesis Report on Climate Finance. Global Observatory on Non-State Climate Action* (2020), https://www.climate-chance.org/wp-content/uploads/2020/10/global-synthesis-report-on-climate-finance-2020-complete-climate-chance.pdf.

124 Task Force on Climate-related Financial Disclosures, *Recommendations of the Task Force on Climate-related Financial Disclosures* (Basel: 2017), https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf.

125 IIEFA, "Finance is leaving oil and gas", https://ieefa.org/finance-exiting-oil-and-gas, viewed March 2021.

126 Octopus, "Institutional investors set to double allocations to renewables in next five years", 23 November 2020, https://octopusgroup.com/newsroom/latest-news/institutional-investors-set-to-double-allocations-to-renewables-in-next-five-years; Octopus, "Institutional investors set to nearly triple divestment from fossil fuels in the next decade according to survey", 14 October 2019, https://octopusgroup.com/newsroom/latest-news/institutional-investors-to-nearly-triple-divestment-from-fossil-fuels-in-the-next-decade-according-to-survey.

127 "Investors 'raising' renewables share of investments", reNEWS, 23 January 2020, https://renews.biz/64598/investors-raising-renewables-share-of-investments.

128 BankTrack, *Banking on Climate Change. Fossil Fuel Finance Report 2020* (Nijmegen, Netherlands: 2020), https://www.banktrack.org/download/banking_on_climate_change_fossil_fuel_finance_report_2020/banking_on_climate_change__2020_vf_2.pdf.

129 Energy Monitor, "Still banking on fossil fuels", 25 September 2020, https://energymonitor.ai/finance/sustainable-finance/still-banking-on-fossil-fuels.

130 The study concludes that, while divestment campaigns generate positive change, efforts directly allocated to phasing out fossil fuel consumption and carbon dioxide emissions would better serve the cause. R. Pollin and T. Hansen, *Economics and Climate Justice Activism: Assessing the Fossil Fuel Divestment Movement* (Amherst, MA: Political Economy Research Institute, University of Massachusetts at Amherst, 24 April 2018), https://www.peri.umass.edu/economists/robert-pollin/item/1076-economics-and-climate-justice-activism-assessing-the-fossil-fuel-divestment-movement.

131 Ibid.

132 Ibid.

133 T. F. Cojoianu et al., "Does the fossil fuel divestment movement impact new oil and gas fundraising?" *Journal of Economic Geography*, vol. 21, no. 1 (January 2021), pp. 141-64, https://academic.oup.com/joeg/article/21/1/141/6042790.

134 Energy Monitor, op. cit. note 129.

135 Ibid.

136 Ibid.; M. Burton and F. Nangoy, "Asia's coal developers feeling left out by cold shoulder from banks", *Reuters*, 25 June 2019, https://www.reuters.com/article/us-asia-coal-finance/asias-coal-developers-feeling-left-out-by-cold-shoulder-from-banks-idUSKCN1TQ15B.

137 Energy Monitor, op. cit. note 129.

138 End Coal, "Global Coal Public Finance Tracker", https://endcoal.org/finance-tracker, viewed 24 March 2021.

139 Global Policy, "Are fossil fuel divestment campaigns working? A conversation with economist Robert Pollin", 29 May 2018, https://www.globalpolicyjournal.com/blog/29/05/2018/are-fossil-fuel-divestment-campaigns-working-conversation-economist-robert-pollin; F. Mormann, "Why the divestment movement is missing the mark", *Nature Climate Change*, December 2020, https://www.nature.com/articles/s41558-020-00950-2.epdf.

140 IEA, "Global investment in the power sector by technology, 2017-2020", 26 May 2020, https://www.iea.org/data-and-statistics/charts/global-investment-in-the-power-sector-by-technology-2017-2020.

141 **Figure 51** based on Ibid.

142 Octopus, "Institutional investors set to double allocations to renewables in next five years", op. cit. note 126.

143 M. Hutchins, "The weekend read: Behind the curve", pv magazine, 14 November 2020, https://www.pv-magazine.com/2020/11/14/the-weekend-read-behind-the-curve.

144 Ibid.

145 Ibid.

146 C40 Cities, "Mayors of 12 major cities commit to divest from fossil fuel companies, invest in green and just recovery from COVID-19 crisis", press release (New York: 22 September 2020), https://www.c40.org/press_releases/cities-commit-divest-invest.

147 Ibid.

148 Catholic Impact Investing Collaborative, "Catholic Impact Investing Pledge", http://www.catholicimpact.org/catholic-impact-investing-pledge, viewed March 2021.

149 Rockefeller Brothers Fund, "Fossil Fuel Divestment", https://www.rbf.org/mission-aligned-investing/divestment, viewed March 2021.

150 Ibid.

151 Global Policy, op. cit. note 139.

152 Ibid.

ENERGY SYSTEMS INTEGRATION AND ENABLING TECHNOLOGIES

1 M. O' Malley et al., *Energy Systems Integration: Defining and Describing the Value Proposition*, International Institute for Energy Systems Integration (Golden, CO: 2016), https://www.nrel.gov/docs/fy16osti/66616.pdf.

2 M. Roser, "Why did renewables become so cheap so fast? And what can we do to use this global opportunity for green growth?" Our World in Data, 1 December 2020, https://ourworldindata.org/cheap-renewables-growth; International Renewable Energy Agency (IRENA), "Renewables increasingly beat even the cheapest coal competitors on cost", press release (Abu Dhabi: 2 June 2020), https://www.irena.org/newsroom/pressreleases/2020/Jun/Renewables-Increasingly-Beat-Even-Cheapest-Coal-Competitors-on-Cost; US Environmental Protection Agency (EPA), "Local renewable energy benefits and resources", https://www.epa.gov/statelocalenergy/local-renewable-energy-benefits-and-resources, updated 19 February 2021.

3 Organisation for Economic Co-operation and Development (OECD), "Green growth and energy", https://www.oecd.org/greengrowth/greening-energy/greengrowthandenergy.htm, viewed 14 March 2021; International Energy Agency (IEA), "System integration of renewables: Decarbonising while meeting growing demand", https://www.iea.org/topics/system-integration-of-renewables, viewed 14 March 2021.

4 Examples of both public and private efforts to integrate renewables are provided throughout this chapter. For further examples and background, see: IEA, *Power Systems in Transition* (Paris: 2020), https://www.iea.org/reports/power-systems-in-transition; IRENA, *Solutions to Integrate High Shares of Variable Renewable Energy*, Report to the G20 Energy Transitions Working Group (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf.

5 For examples, see the Global Overview and Market and Industry chapters of this report.

6 IEA, "Renewable energy market update", May 2020, https://www.iea.org/reports/renewable-energy-market-update/covid-19-impact-on-renewable-energy-growth; N. Mojarro, "COVID-19 is a game-changer for renewable energy. Here's why", World Economic Forum, 16 June 2020, https://www.weforum.org/agenda/2020/06/covid-19-is-a-game-changer-for-renewable-energy.

7 IEA, op. cit. note 6; Mojarro, op. cit. note 6.

8 G. Parkinson, "Wind and solar hit record grid levels in Europe as pandemic curbs energy demand", RenewEconomy, 20 May 2020, https://reneweconomy.com.au/wind-and-solar-hit-record-grid-levels-in-europe-as-pandemic-curbs-energy-demand-83006; IEA, op. cit. note 6; O. Zinaman, personal communication with Renewable Energy Policy Network for the 21st Century (REN21), 12 January 2021.

9 G. Parkinson, "South Australia fast-tracks energy plan to dodge blackouts and meet 100% renewables goal", RenewEconomy, 19 June 2020, https://reneweconomy.com.au/south-australia-fast-tracks-energy-plan-to-dodge-blackouts-and-meet-100-renewables-goal-43196; J. Deign, "How South Australia is dealing with rampant solar growth", Greentech Media, 21 September 2020, https://www.greentechmedia.com/articles/read/how-south-australia-is-dealing-with-rampant-solar-growth.

10 Mojarro, op. cit. note 6; J. Ambrose and N. Kommenda, "Britain breaks record for coal-free power generation", *The Guardian* (UK), 28 April 2020, https://www.theguardian.com/business/2020/apr/28/britain-breaks-record-for-coal-free-power-generation.

11 Ember, *Global Electricity Review 2021* (London: 2021), https://ember-climate.org/project/global-electricity-review-2021.

12 B. Kroposki, *Summarizing the Technical Challenges of High Levels of Inverter based Resources in Power Grids* (Golden, CO: National Renewable Energy Laboratory (NREL), April 2019), https://www.nrel.gov/docs/fy19osti/73869.pdf.

13 Smart Energy International, "Why digitalization is a key enabler of the energy transition", 30 August 2019, https://www.smart-energy.com/news/why-digitalisation-is-a-key-enabler-of-the-energy-transition.

14 C. Pordage, "Future-proofing the network with smart substations", Utility, 13 May 2020, https://utilitymagazine.com.au/future-proofing-the-network-with-smart-substations; M. Sease, "Grid modernization 2020: Pushing boundaries", Energy Central, 19 June 2020, https://energycentral.com/c/gr/grid-modernization-2020-pushing-boundaries.

15 E. Danziger, "Next-generation load forecasting critical in rapidly changing energy landscape", PowerGrid International, 12 November 2020, https://www.power-grid.com/smart-grid/next-generation-load-forecasting-critical-in-rapidly-changing-energy-landscape; L. Munuera, IEA, personal communication with REN21, 11 November 2020.

16 C. Smith, ESIG, personal communication with REN21, 9 November 2020.

17 **Figure 52** from the following sources: **Denmark** share of net generation based on net generation data of 16,353 GWh from wind power, 1,181 GWh from solar PV, and total net production of 27,907 GWh, from Danish Energy Agency, "Månedlig elstatistik. Oversigtstabeller", in Electricity Supply, https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics, viewed 15 April 2021; **Uruguay** share of wind generation of 5,437.7 GWh, solar generation 525.5 GWh and total 13,470.5 GWh, from Ministerio de Industria, Energía y Minería, "Balance Preliminar 2020", https://ben.miem.gub.uy/preliminar.php; **Ireland** share of wind as percentage of demand, based on provisional 2020 data from EIRGRID, "System & renewable summary report", https://www.eirgridgroup.com/how-the-grid-works/renewables, accessed 16 April 2021; **Germany** share of gross electricity production of wind onshore 103,66 TWh, wind offshore 27,303 TWh (total wind: 130,963 TWh), solar gross electricity production 50,6 TWh, and total gross electricity production 558 TWh, from Federal Ministry for Economic Affairs and Energy and AGEE Stat, "Time series for the development of renewable energy sources in Germany", 2021, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html; Greece share of wind production of 9,323 GWh, Solar PV production 3,898 GWh, solar rooftop PV 494 GWh, and total 42,229.90 GWh, from Dapeep, "Μηνιαίο Δελτίο Ειδικού Λογαριασμού ΑΠΕ & ΣΗΘΥΑ", 2020, https://www.dapeep.gr/wp-content/uploads/ELAPE/2020/08_DEC_2020_DELTIO_ELAPE_v1.0_21.03.2021.pdf, viewed April 2021, all in Greek and provided by I. Tsipouridis, REDPro Consultants, Athens, personal communication with REN21, 12 April 2021; Spain share of demand coverage of wind 22.2%, and solar 6.1%, from Red Eléctrica de España (REE), *The Spanish Electricity System – Preliminary Report 2020* (Madrid: February 2021), with estimated data as of 13 January 2021, p. 15, https://www.ree.es/sites/default/files/publication/2021/03/downloadable/avance_ISE_2020_EN.pdf; **United Kingdom** share of electricity generation of wind onshore 34.95 TWh, wind offshore 40.66 TWh, solar PV 12.8 TWh, and total electricity generation 312.76 TWh, from UK Department for Business, Energy & Industrial Strategy (BEIS), "Fuel used in electricity generation and electricity supplied", March 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972781/ET_5.1_MAR_21.xls; **Portugal** share of 12,067 GWh of wind production and 1,269 GWh of solar PV, and total production of 49,342 GWh, from REN, "Dados Tecnicos / Technical Data 20", p. 9, https://www.centrodeinformacao.ren.pt/PT/InformacaoTecnica/DadosTecnicos/AFnet_RENPRO%20Brochura%20Dados%20T%C3%A9cnicos%202020.pdf; **Australia** share of wind of 22,196 GWh and solar PV of 22,288 GWh, and total generation of 221,957 GWh from OpenNEM, "Western Australia (SWIS)", https://opennem.org.au/energy/wem/?range=all&interval=1y, viewed 23 April 2021; **The Netherlands** provisional data for net production of wind onshore 9,785 TWh and offshore 5,484 TWh, solar 8,056 TWh and total net production of 118,920 TWh, from CBS StatLine, "Electricity balance sheet; supply and consumption", https://opendata.cbs.nl/statline/#/CBS/en/dataset/84575ENG/table?ts=1619216097037, viewed 3 May 2021; **Honduras** power generation data on the National Interconnected Electrical System – Energía Eléctrica Generada en el Sistema Inteconectado Nacional, based on net generation of wind of 707,202.8 MWh, solar of 1,044,775.9 MWh, and total 9,292,817.3 MWh, from Empresa Nacional de Energía Eléctrica (ENEE), *Boletines Estadísticos Año 2020 – Diciembre*, http://www.enee.hn/index.php/planificacionicono/182-boletines-estadisticos; **Sweden** share of wind of 27,589 GWh, solar 805 GWh, and total 159,635 GWh, from Statistics Sweden, "Elproduktion i Sverige efter produktionsslag. Månad 2017M01 – 2021M02", https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__EN__EN0108/Elprod; **Belgium** share of wind onshore generation of 4.1 TWh and offshore 6.7 TWh, and solar generation of 4.3 TWh, from Elia Group, "Belgium's electricity mix in 2020: Renewable generation up 31% in a year marked by the COVID-19 crisis", 7 January 2021,

https://www.elia.be/-/media/project/elia/shared/documents/press-releases/2021/20210107-mix-electrique-2020_en.pdf; **Chile** wind generation of 5,537 GWh, and solar of 7,638 GWh, from Generadoras de Chile, "Generación Eléctrica en Chile", http://generadoras.cl/generacion-electrica-en-chile; **Nicaragua** share of wind net generation of 538,826 MWh and solar of 22,688 MWh, and total generation of 3,379,530 MWh, from Instituto Nicaragüense de Energía, Ente Regulador, *Generación Neta Sistema Eléctrico Nacional Año 2020*, https://www.ine.gob.ni/DGE/estadisticas/2020/generacion_neta_dic20_actfeb21.pdf; **Italy** share of wind generation of 18,547 GWh, solar generation of 25,549 GWh, and total 273,108 GWh, from Terna, *Rapporto mensile sul Sistema Elettrico*, https://download.terna.it/terna/Rapporto_Mensile_Dicembre%202020_8d8b615dca4dafe.pdf.

18 V. Henze, "Scale-up of solar and wind puts existing coal, gas at risk", BloombergNEF, 28 April 2020, https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk.

19 Ibid.; P. Denholm et al., *The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States* (Golden, CO: NREL, 2019), https://www.nrel.gov/docs/fy19osti/74184.pdf; footnote on the 'Duck Curve' effect based on Energy.gov, "Confronting the duck curve: How to address over-generation of solar energy", 12 October 2017, https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy, and on P. N. Patel, "Developments in energy storage could spell the end of the Duck Curve", POWER, 1 June 2018, https://www.powermag.com/developments-in-energy-storage-could-spell-the-end-of-the-duck-curve.

20 reve, "Global demand for corporate renewable electricity sourcing continues to grow despite COVID-19 pandemic", 9 December 2020, https://www.evwind.es/2020/12/09/global-demand-for-corporate-renewable-electricity-sourcing-continues-to-grow-despite-covid-19-pandemic/78451.

21 IRENA, *Innovation Landscape Brief: Innovative Ancillary Services* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovative_ancillary_services_2019.pdf; P. Denholm, Y. Sun and T. Mai, *An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind* (Golden, CO: NREL, 2019), https://www.nrel.gov/docs/fy19osti/72578.pdf.

22 D. Proctor, "FERC order backs grid market for DERs", POWER, 17 September 2020, https://www.powermag.com/ferc-order-backs-grid-market-for-ders.

23 J. St. John, "California's interconnection rules open doors to flexible solar-storage, vehicle-to-grid charging", Greentech Media, 30 September 2020, https://www.greentechmedia.com/articles/read/californias-interconnection-rules-open-doors-to-flexible-solar-storage-vehicle-to-grid-charging.

24 Smart Energy, "New ancillary service market paves the way to a renewables-led future", 6 December 2020, https://www.smart-energy.com/industry-sectors/energy-grid-management/new-ancillary-service-market-paves-the-way-to-a-renewables-led-future; J. Parnell, "Renewable generators are the UK's latest tool to smooth out renewable generation", Greentech Media, 23 June 2020, https://www.greentechmedia.com/articles/read/renewable-generators-are-uks-latest-tool-to-smooth-out-renewable-generation.

25 IRENA, op. cit. note 4.

26 IEA, "Electricity security in tomorrow's power systems", 23 October 2020, https://www.iea.org/articles/electricity-security-in-tomorrow-s-power-systems.

27 IRENA, *Innovation Landscape Brief: Flexibility in Conventional Power Plants* (Abu Dhabi: 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Flexibility_in_CPPs_2019.pdf.

28 IRENA, op. cit. note 21; ScottishPower, "Global first for ScottishPower as COP countdown starts", 3 November 2020, https://www.scottishpower.com/news/amp-pages/global_first_for_scottishpower_as_cop_countdown_starts.html; P. Sanchez Molina, "PV plant providing grid ancillary services in Chile", pv magazine, 21 August 2020, https://www.pv-magazine.com/2020/08/21/pv-plant-providing-grid-ancillary-services-in-chile.

29 Sanchez Molina, op. cit. note 28.

30 ScottishPower, op. cit. note 28.

31 E. Bellini, "GE's 'grid-forming' inverter aims to make solar, wind look like traditional generators", pv magazine, 8 April 2020, https://pv-magazine-usa.com/2020/04/08/ges-grid-forming-inverter-aims-to-make-solar-wind-look-like-traditional-generators.

32 M. McPherson and B. Stoll, "Demand response for variable renewable energy integration: A proposed approach and its impacts", *Energy*, vol. 197(C) (2020), https://www.sciencedirect.com/science/article/abs/pii/S0360544220303121; E. Hale et al., *Potential Roles for Demand Response in High-Growth Electric Systems with Increasing Shares of Renewable Generation* (Golden, CO: NREL, 2018), https://www.nrel.gov/docs/fy19osti/70630.pdf.

33 P. Hines and A. B. Wannop, "FERC Order 2222 should be a watershed moment – grid operators can help ensure that", Utility Dive, 4 November 2020, https://www.utilitydive.com/news/ferc-order-2222-should-be-a-watershed-moment-grid-operators-can-help-ensu/588346; M. Hall, "Toshiba and Next Kraftwerke prepare for Japan's energy transition", pv magazine, 5 November 2020, https://www.pv-magazine.com/2020/11/05/toshiba-and-next-kraftwerke-prepare-for-japans-energy-transition; H. K. Trabish, "Demand response failed California 20 years ago; the state's recent outages may have redeemed it", Utility Dive, 28 September 2020, https://www.utilitydive.com/news/demand-response-failed-california-20-years-ago-the-states-recent-outages/584878.

34 IEA, *Demand Response* (Paris: 2020), https://www.iea.org/reports/demand-response.

35 L. Stoker, "Shut out of UK's capacity market, battery storage registers as DSR instead – and wins", Energy Storage, 5 February 2020, https://www.energy-storage.news/news/shut-out-of-uks-capacity-market-battery-storage-register-as-dsr-instead-and.

36 Ibid.

37 J. Spencer Jones, "National Grid US grows demand response portfolio with EnergyHub's DERMS", 15 September 2020, https://www.smart-energy.com/industry-sectors/energy-grid-management/national-grid-us-grows-demand-response-with-energyhubs-derms.

38 H. Matyjaszek, "GridBeyond named as one of the world-leading technology innovators in advancing global sustainability", Energy Live News, 17 January 2020, https://www.energylivenews.com/2020/01/17/gridbeyond-named-as-one-of-the-world-leading-technology-innovators-in-advancing-global-sustainability; M. Lempriere, "GridBeyond to enable I&C customers to access Dynamic Containment auctions in first for service", Current, 29 October 2020, https://www.current-news.co.uk/news/gridbeyond-to-enable-i-c-customers-to-access-dynamic-containment-auctions-in-first-for-service.

39 Hall, op. cit. note 33.

40 J. Parnell, "The startup helping EVs balance out the renewables that power them", Greentech Media, 9 October 2020, https://www.greentechmedia.com/articles/read/how-european-evs-are-balancing-out-the-renewables-that-power-them.

41 IEA, *Digitalisation and Energy* (Paris: 2017), https://www.iea.org/reports/digitalisation-and-energy.

42 GTM Creative Strategies, "Overcoming forecast uncertainties for better DER planning", Greentech Media, 1 June 2020, https://www.greentechmedia.com/articles/read/overcoming-forecast-uncertainties-for-better-der-planning.

43 S. Vorrath, "Australian solar and wind forecasting technology to be live tested on S.A. grid", RenewEconomy, 24 June 2020, https://reneweconomy.com.au/australian-solar-and-wind-forecasting-technology-to-be-live-tested-on-s-a-grid-93539; K. Ho, "New project to revolutionise weather forecasting for renewables", Energy, 26 June 2020, https://www.energymagazine.com.au/new-project-to-revolutionise-weather-forecasting-for-renewables.

44 O. Cognet, "Changes in energy resources marketplace behaviors usher in new era of AI-driven price forecasting", Schneider Electric, 15 June 2020, https://blog.se.com/energy-management-energy-efficiency/2020/06/15/changes-energy-resources-marketplace-ai-driven-price-forecasting.

45 US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (OEERE), "SETO 2020 – Artificial Intelligence Applications in Solar Energy", 5 February 2020, https://www.energy.gov/eere/solar/seto-2020-artificial-intelligence-applications-solar-energy.

46 GTM Creative Strategies, op. cit. note 42.

47 Danziger, op. cit. note 15.

48 S. Teske, *Citizen Power for Grids: Case Studies on Collaborative Infrastructure Planning Processes for the Energy Transition* (PAC

Consortium, 2021), https://www.pac-scenarios.eu/fileadmin/user_upload/PAC_Citizen_Power_for_Grids_web.pdf.

49 K. Lydersen, "Grid congestion a growing barrier for wind, solar developers in MISO territory", Energy News Network, 29 September 2020, https://energynews.us/2020/09/29/midwest/grid-congestion-a-growing-barrier-for-wind-solar-developers-in-miso-territory; J. St. John, "7 transmission projects that could unlock a renewable energy bounty", Greentech Media, 9 April 2020, https://www.greentechmedia.com/articles/read/9-transmission-projects-laying-the-paths-for-cross-country-clean-energy; A. Dziadosz, "Germany's power grids need 110 billion euros of investment by 2050, operator says", Clean Energy Wire, 30 October 2020, https://www.cleanenergywire.org/news/germanys-power-grids-need-110-billion-euros-investment-2050-operator-says.

50 Lydersen, op. cit. note 49.

51 St. John, op. cit. note 49; R. Chirgwin, "Build It and they will come: Transmission key to 100% renewable energy", Solarquotes, 5 March 2020, https://www.solarquotes.com.au/blog/transmission-renewable-energy; Dziadosz, op. cit. note 49.

52 **Figure 53** from the following sources: Transwest Express LLC, "Critical grid infrastructure to connect the West", www.transwestexpress.net, viewed 14 May 2021; Grain Belt Express, "Grain Belt Express: An energy connection for America's heartland", 2021, https://grainbeltexpress.com/index.html, viewed 14 May 2021; C. Rivera-Linares, "Grain Belt Express will likely seek regulatory approval in Illinois in 2021", Transmission Hub, 21 December 2020, https://www.transmissionhub.com/articles/2020/12/grain-belt-express-will-likely-seek-regulatory-approval-in-illinois-in-2021.html; Republic of Peru, "Private Investment Promotion Plan: Binding Project of the Transmission Plan 2013-2022: '500kV Piura Nueva – Frontera Substation Transmission Line'" October 2020, https://www.proyectosapp.pe/RepositorioAPS/1/2/JER/LT_500KV_PIURA/Plan_de_promocion_rev_final_Eng.pdf; ProInversion, "Strategic Sectors: 500kV Piura Nueva – Frontera Substation Transmission Line", https://www.proyectosapp.pe/modulos/JER/PlantillaProyecto.aspx?ARE=1&PFL=2&JER=8661&SEC=30, viewed 10 May 2021; Juno Gromis Transmission Line from Eskom, "Eskom commences on the 282km 400kV line construction with stakeholder engagements", 2 November 2020, https://www.eskom.co.za/news/Pages/2020Nov2.aspx; I. Shumkov, "S Africa's Eskom secures USD-R104m French loan for grid project", Renewables Now, 14 December 2018, https://renewablesnow.com/news/s-africas-eskom-secures-usd-104m-french-loan-for-grid-project-636687; Changli-to-Guquan Transmission Project from T&DWorld, "World's biggest ultra-high voltage line powers up across China", 2 January 2019, https://www.tdworld.com/overhead-transmission/article/20972092/worlds-biggest-ultrahigh-voltage-line-powers-up-across-china; Project EnergyConnect, http://www.projectenergyconnect.com.au, viewed 11 May 2021; "Ofgem backs Shetland subsea power cable plans", BBC News, 23 April 2020, https://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-52397784; Scottish & Southern Electricity Networks, "Projects: Shetland: Project Overview", https://www.ssen-transmission.co.uk/projects/shetland, viewed 14 May 2021; Business Standard, "POWERGRID Ajmer Phagi Transmission successfully commissions projects", 14 May 2021, https://www.business-standard.com/article/news-cm/powergrid-ajmer-phagi-transmission-successfully-commissions-projects-121051400758_1.html; Government of India, Ministry of Power, Central Electricity Authority, "Monthly Progress Report of Projects awarded through Tariff Based Competitive Bidding (TBCB) Route (Under Construction Projects) (As on 30.09.2020)", 30 September 2020, https://cea.nic.in/wp-content/uploads/transmission/2020/09/competitive_uc.pdf; NS Energy, "SuedLink HVDC Power Transmission Project", https://www.nsenergybusiness.com/projects/suedlink-hvdc-power-transmission-project, viewed 14 May 2021.

53 C. Erickson, "Major power transmission line comes online", Sundance Times, 3 December 2020, https://www.sundancetimes.com/story/2020/12/03/news/major-power-transmission-line-comes-online/3494.html; St. John, op. cit. note 49.

54 St. John, op. cit. note 49; P. Key, "HVDC technology is fueling some big projects and its proponents are aiming bigger", Energy Central, 21 April 2020, https://energycentral.com/c/tr/hvdc-technology-fueling-some-big-projects-and-its-proponents-are-aiming-bigger.

55 S. Mahapatra, "India moves ahead with new renewable energy transmission projects", CleanTechnica, 10 April 2020, https://cleantechnica.com/2020/04/10/india-moves-ahead-with-new-renewable-energy-transmission-projects.

56 S. Dludla, "Eskom on R118bn explansion project to add 30GW over 10 years", IOL, 20 October 2020, https://www.iol.co.za/business-report/energy/eskom-on-r118bn-expansion-project-to-add-30gw-over-10-years-b5e0cdf7-cb08-4d7a-ae99-682e6d5b11d3; C. Yelland, "South Africa's energy policies: Are changes finally coming?" French Institute of International Relations, 10 December 2020, https://www.ifri.org/en/publications/editoriaux-de-lifri/edito-energie/south-africas-energy-policies-are-changes-finally.

57 K. Ross, "UK interconnectivity with Europe to rise despite Brexit", Power Engineering International, 27 October 2020, https://www.powerengineeringint.com/world-regions/europe/uk-interconnectivity-with-europe-to-rise-despite-brexit; Key, op. cit. note 54.

58 Key, op. cit. note 54.

59 R. Walton, "Propelling the transition: New and better transmission is key to zero carbon; here's what's driving it", Utility Dive, 19 August 2020, https://www.utilitydive.com/news/propelling-the-transition-new-and-better-transmission-is-key-to-zero-carbo/582331.

60 J. St. John, "Smart Wires looks to ease transmission grid's mounting challenges with digital controls", Greentech Media, 13 March 2020, https://www.greentechmedia.com/articles/read/smart-wires-tricky-transmission-challenges-solved-with-digital-controls.

61 reve, "Digitalization and Innovation for Remote Centres of Excellence", 2 May 2020, https://www.evwind.es/2020/05/02/digitalization-and-innovation-for-remote-centers-of-excellence/74605.

62 S. Jewkes and C. Steitz, "Coronavirus accelerates European utilities' digital drive", *Reuters*, 10 August 2020, https://www.reuters.com/article/us-health-coronavirus-utilities-tech-foc-idUSKCN2560OK.

63 Pordage, op. cit. note 14; R. Kumar Chauhan et al., "India's first 400kV fully digital substation", 10 June 2020, https://www.tdworld.com/substations/article/21133557/indias-first-400kv-fully-digital-substation.

64 Pordage, op. cit. note 14.

65 E. Boardman, "Simulation, training & testing on the distribution grid: Experiencing the control room", GE Digital, 2020, https://www.ge.com/digital/blog/simulation-training-testing-distribution-grid-experiencing-control-room.

66 L. Brasington, "Smart grid flexibility markets – entering an era of localization", Cleantech Group, 14 April 2020, https://www.cleantech.com/smart-grid-flexibility-markets-entering-an-era-of-localization.

67 H. E. Murdock, "Decarbonising the transport sector with renewables requires urgent action", REN21, 18 November 2020, https://www.ren21.net/decarbonise-transport-sector-2020.

68 J. St. John, "Green hydrogen in natural gas pipelines: Decarbonization solution or pipe dream?" Greentech Media, 30 November 2020, https://www.greentechmedia.com/articles/read/green-hydrogen-in-natural-gas-pipelines-decarbonization-solution-or-pipe-dream; IRENA, *Global Renewables Outlook: Energy Transformation 2050* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_Global_Renewables_Outlook_2020.pdf.

69 IEA, *Renewables 2020* (Paris: 2020), https://www.iea.org/reports/renewables-2020/key-trends-to-watch.

70 Airbus, "Airbus reveals new zero-emission concept aircraft", 21 September 2020, https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html; A. Spaeth, "At Airbus a hydrogen-powered aircraft takes shape", DW, 25 September 2020, https://www.dw.com/en/at-airbus-a-hydrogen-powered-aircraft-takes-shape/a-55051579.

71 D. Selkirk, "Is this the start of an aviation revolution?" BBC, 12 February 2020, https://www.bbc.com/future/article/20200211-the-electric-plane-leading-a-revolution; C. Baraniuk, "The largest electric plane ever to fly", BBC, 18 June 2020, https://www.bbc.com/future/article/20200617-the-largest-electric-plane-ever-to-fly; "Is the time now ripe for planes to run on hydrogen?" *The Economist*, 8 December 2020, https://www.economist.com/science-and-technology/2020/12/08/is-the-time-now-ripe-for-planes-to-run-on-hydrogen.

72 IEA, op. cit. note 69.

73 Ibid.

74 J. Turner, "HySHIP: Inside Europe's flagship hydrogen ship demonstrator project", Ship Technology, 22 December 2020, https://www.ship-technology.com/features/hydrogen-vessel; ShipInsight, "MOL joins Wind Hunter project for wind and hydrogen ship as step to zero emission future", 1 December 2020, https://shipinsight.com/articles/mol-joins-wind-hunter-project-for-wind-and-hydrogen-ship-as-step-to-zero-emission-future; G. Rowles, "Yara takes delivery of autonomous boxship Yara Birkeland", Splash, 30 November 2020", https://splash247.com/yara-takes-delivery-of-autonomous-boxship-yara-birkeland.

75 Transport Scotland, *Rail Services Decarbonisation Action Plan* (Edinburgh: 2020), https://www.transport.gov.scot/media/47906/rail-services-decarbonisation-action-plan.pdf; D. Nag, "Indian Railways plans to use surplus railway land to generate 20 GW of renewable energy; details", Financial Express, 27 August 2020, https://www.financialexpress.com/infrastructure/railways/indian-railways-plans-to-use-surplus-railway-land-to-generate-20-gw-of-renewable-energy-details/2066847.

76 A. Hirschlag, "Next stop, hydrogen-powered trains", BBC, 27 February 2020, https://www.bbc.com/future/article/20200227-how-hydrogen-powered-trains-can-tackle-climate-change.

77 E. Bellini, "Flexible heat pumps ideal for power grids congested by solar and wind", pv magazine, 29 January 2021, https://www.pv-magazine.com/2021/01/29/flexible-heat-pumps-ideal-for-power-grids-congested-by-solar-and-wind.

78 M. Lempriere, "ICE ban brought forward to '2030' in landmark moment as Johnson releases Ten Point Plan", Current, 18 November 2020, https://www.current-news.co.uk/news/ice-ban-brought-forward-to-2030-in-landmark-moment-as-johnson-releases-ten-point-plan.

79 **Figure 54** adapted from IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition* (Abu Dhabi and Paris: 2018), https://www.ren21.net/wp-content/uploads/2019/06/17-8622_Policy_FullReport_web_FINAL.pdf.

80 IEA, *Heat Pumps* (Paris: 2020), https://www.iea.org/reports/heat-pumps.

81 IRENA, *Heat Pumps Technology Brief* (Abu Dhabi: 2013), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/IRENA-ETSAP-Tech-Brief-E12-Heat-Pumps.pdf.

82 Ibid.

83 IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Abu Dhabi and Paris: 2020), p. 50, https://www.ren21.net/wp-content/uploads/2019/05/IRENA_IEA_REN21-Policies_HC_2020_Full_Report.pdf.

84 IRENA, op. cit. note 81; IRENA, IEA and REN21, op. cit. note 83, p 50.

85 IRENA, IEA and REN21, op. cit. note 83, p. 50.

86 Ibid., p. 50.

87 IRENA, IEA and REN21, op. cit. note 83, p. 50.

88 Ibid., p. 50.

89 M. Dyson et al., "Building electrification: A key to a safe climate future", Rocky Mountain Institute, 20 October 2020, https://rmi.org/building-electrification-a-key-to-a-safe-climate-future; J. Gerdes, "Heat pumps unlock the path to building decarbonisation", Energy Monitor, 29 December 2020, https://energymonitor.ai/technology/electrification/heat-pumps-unlock-the-path-to-building-decarbonisation; R. Lowe and T. Oreszczyn, *Building Decarbonisation Transition Pathways: Initial Reflections* (Oxford, UK: CREDS, 2020), https://www.creds.ac.uk/wp-content/uploads/CREDS-decarb-transitions-brief-2020.pdf.

90 IEA Heat Pumping Technologies, *Heat Pumps in District Heating and Cooling Systems* (Paris: 2020), https://heatpumpingtechnologies.org/publications/annex-47-heat-pumps-in-district-heating-and-cooling-systems.

91 IEA, op. cit. note 80.

92 Ibid.

93 BloombergNEF, *Energy Transition Investment Trends* (London: 2021), slide 10, https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends_Free-Summary_Jan2021.pdf.

94 C. Zhao, Chinese Heat Pump Association, personal communication with REN21, March 2021.

95 Chinaiol, "Monthly China's household AC production (ten thousand units)", http://data.chinaiol.com/ecdata/index, viewed 15 March 2021; Chinaiol is a market intelligence firm focusing on the HVAC industry, consumer electronics, intelligent manufacturing areas and provides data, information, and consulting services for global enterprises.

96 Japan Refrigeration and Air Conditioning Industry Association (JRAIA), "Domestic shipment record of home air conditioners (room air conditioners)", https://www.jraia.or.jp/statistic/detail.html?ca=0&ca2=0 (using Google Translate), viewed 20 March 2021; JRAIA, "Domestic shipment record of commercial air conditioners (package air conditioners)", https://www.jraia.or.jp/statistic/detail.html?ca=1&ca2=3 (using Google Translate), viewed 20 March 2021.

97 Ibid., both references.

98 JRAIA, "Household heat pump water heater (Eco Cute) Domestic shipment record", https://www.jraia.or.jp/statistic/detail.html?ca=0&ca2=1 (using Google Translate), viewed 20 March 2021.

99 BloombergNEF, op. cit. note 93.

100 Air Conditioning, Heating & Refrigeration Institute (AHRI), "AHRI releases December 2020 U.S. Heating and Cooling Equipment Shipment Data", 12 February 2021, https://www.ahrinet.org/App_Content/ahri/files/Statistics/Monthly%20Shipments/2020/December_2020.pdf.

101 BloombergNEF, op. cit. note 93.

102 Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI), "Canadian HVACR Equipment Quarterly Statistics", https://www.hrai.ca/hvacr-statistics, viewed 25 March 2021.

103 European Heat Pump Association (EHPA), "Market Data", https://www.ehpa.org/market-data, viewed 30 March 2021; T. Nowak, EHPA, personal communication with REN21, 25 March 2021.

104 EHPA, op. cit. note 103.

105 Ibid.

106 Bundesverband Energiespeicher Systeme (BVES) e.V., "BVES Branchenanalyse 2021 – Entwicklung und Perspektiven der Energiespeicherbranche in Deutschland", 15 March 2021, https://www.bves.de/wp-content/uploads/2021/03/2021_BVES_Branchenanalyse.pdf; S. Amelang, "Germany crosses threshold of one million heat pumps", Clean Energy Wire, 10 December 2020, https://www.cleanenergywire.org/news/germany-crosses-threshold-one-million-heat-pumps.

107 S. Amelang, "Heat pump industry expects strong growth in Germany after tepid increase in 2019", Clean Energy Wire, 31 January 2020, https://www.cleanenergywire.org/news/heat-pump-industry-expects-strong-growth-germany-after-tepid-increase-2019.

108 Ministère de la transition écologique et solidaire, "Coup de pouce 'Chauffage' et "Isolation", 14 April 2021, https://www.ecologie.gouv.fr/coup-pouce-chauffage-et-isolation; Gestore Servizi Energetici, "Conto Termico", https://www.gse.it/servizi-per-te/efficienza-energetica/conto-termico, viewed 20 March 2021; UK BEIS, "Welcome to the Domestic Renewable Heat Incentive payment calculator", https://renewable-heat-calculator.service.gov.uk, viewed 30 March 2021.

109 R. Lowes, J. Rosenow and P. Guertler, *Getting on Track to Net Zero: A Policy Package for a Heat Pump Mass Market in the UK* (Brussels: 2021), https://www.raponline.org/wp-content/uploads/2021/03/RAP-Heat-Pump-Policy-0324212.pdf.

110 EHPA, *Large Scale Heat Pumps in Europe: Vol. 2* (Brussels: 2020), https://www.ehpa.org/fileadmin/user_upload/Large_heat_pumps_in_Europe_Vol_2_FINAL.pdf.

111 R. de Boer et al, *Strengthening Industrial Heat Pump Innovation: Decarbonizing Industrial Heat* (The Hague: SINTEF et al., 2020), https://www.sintef.no/globalassets/sintef-energi/industrial-heat-pump-whitepaper/2020-07-10-whitepaper-ihp-a4.pdf.

112 Ibid.

113 NIBE, *Year-end Report 2020* (Stockholm: 2021), https://www.nibe.com/download/18.a8733e21778fd3d0f07f9/1613500169613/GB-Q4-2020-NIBE-EN.pdf.

114 B. Coyne, "Legal & General buys into heat pump firm Kensa", The Energyst, 17 April 2020, https://theenergyst.com/legal-general-buys-into-heat-pump-firm-kensa.

115 European Commission (EC), "Case M.9858 – BOSCH GROUP/ELCO GROUP/JV REGULATION (EC) No 139/2004 MERGER PROCEDURE" (Brussels: 2020), https://ec.europa.eu/competition/mergers/cases1/202035/m9858_166_3.pdf.

116 K. Uhlenhuth, "Not just solar: Ikea breaking new ground in geothermal, too", Energy News Network, 13 June 2014,

https://energynews.us/2014/06/13/midwest/not-just-solar-ikea-breaking-new-ground-in-geothermal-too; IKEA, "IKEA Clean Energy Services", https://www.ikea.com/ch/de/product-guides/energy-services, viewed 18 March 2021.

117 US DOE, OEERE, *Prefabricated Zero Energy Retrofit Technologies: A Market Assessment* (Washington, DC: 2020), https://rmi.org/wp-content/uploads/2020/04/prefabricated-zero-energy-retrofit-technologies.pdf.

118 LG, *LG Smart Home Energy Package* (Seoul: 2020), https://www.lg.com/cz/download/pdf/LG%20SMART%20HOME%20ENERGY%20PACKAGE.pdf; R. Diermann, "LG Electronics offers hybrid system combining heat pump, PV and storage", pv magazine, 3 February 2021, https://www.pv-magazine.com/2021/02/03/lg-electronics-offers-hybrid-system-combining-heat-pump-pv-and-storage.

119 Ibid., both references.

120 US DOE, OEERE, op. cit. note 117.

121 EHPA, "Virtual tour at Factory Zero – presentations and video now available", 7 October 2020, https://www.ehpa.org/about/news/article/virtual-tour-at-factory-zero-presentations-and-video-now-available; EHPA, "Press release: Heat pumps are now ready to surf the renovation wave", 20 November 2020, https://www.ehpa.org/about/news/article/press-release-heat-pumps-are-now-ready-to-surf-the-renovation-wave; EC, "Towards a smart, efficient and sustainable heating and cooling sector", 16 February 2016, https://ec.europa.eu/commission/presscorner/detail/en/MEMO_16_311.

122 IEA, *Energy Technology Perspectives 2020* (Paris: 2020), p. 164, https://www.iea.org/reports/energy-technology-perspectives-2020.

123 EC, "EU legislation to control F-gases", https://ec.europa.eu/clima/policies/f-gas/legislation_en, viewed 15 March 2021; Nowak, op. cit. note 103.

124 Ibid., both references.

125 IEA Heat Pumping Technologies, "IEA HPT Annex 54: Heat pump systems with refrigerants with low global warming potential", 2019, https://nachhaltigwirtschaften.at/de/iea/technologieprogramme/hpp/iea-hpt-annex-54.php; J. Hughes and J. Juhasz, Chemours, "Low GWP refrigerant solutions for heat pumps", presentation, 12 January 2019, https://heatpumpingtechnologies.org/annex54/wp-content/uploads/sites/63/2019/02/attach2-hughes-iea-hpt-annex-54-heat-pumps-with-low-gwp-refrigerants.pdf; Nowak, op. cit. note 103.

126 J. Gerdes, "Massachusetts pilot project offers gas utilities a possible path to survival", Greentech Media, 6 August 2020, https://www.greentechmedia.com/articles/read/can-gas-companies-evolve-to-protect-the-climate-and-save-their-workers; S. Shemkus, "Innovative geothermal micro-district concept moves ahead in Massachusetts", Energy News Network, 3 December 2020, https://energynews.us/2020/12/03/innovative-geothermal-micro-district-concept-moves-ahead-in-massachusetts.

127 "Stonewater and Kensa pilot smart city scheme", GeoDrilling International, 16 June 2020, https://www.geodrillinginternational.com/ground-source-heat-pumps/news/1388982/stonewater-and-kensa-pilot-smart-city-scheme.

128 NewClimate Institute, *Renewable Heating Virtual Article 6 Pilot* (Cologne: 2020), https://www.energimyndigheten.se/globalassets/webb-en/cooperation/virtual-pilot-executive-summary-mongolia-nci.pdf; M. Lee and T. Dashmunkh, "Ground source heat pumps: Renewable energy opportunities", Breathe Mongolia, 29 January 2020, https://breathemongolia.org/news-article/ground-source-heat-pumps-renewable-energy-opportunities.

129 J. St. John, "Dandelion raises $30M to scale up home geothermal energy", Greentech Media, 18 February 2021, https://www.greentechmedia.com/articles/read/dandelion-raises-30m-to-scale-up-home-geothermal-energy.

130 de Boer et al., op. cit. note 111.

131 Ibid.

132 Ibid.

133 L. Sugden, *The 2020s Is the Decade to Decarbonise Heat* (Edinburgh: Delta Energy & Environment, 2020), https://www.delta-ee.com/downloads/2633-whitepaper-it-is-time-to-decarbonise-heat.html; EHPA, *A Digital Revolution for the Built Environment?* (Brussels: 2020), https://www.ehpa.org/fileadmin/user_upload/EHPA-Digitalisation_White_Paper-06-compressed.pdf.

134 C. Weiller and R. Sioshansi, "The role of plug-in electric vehicles with renewable resources in electricity systems", preprint submitted to *Revue d'Économie Industrielle*, 22 August 2016, https://journals.openedition.org/rei/6008.

135 E. Costello, "Your car could act as a giant battery to power your home", Octopus Energy, 23 July 2019, https://octopus.energy/blog/vehicle-to-grid; E. Wenzel, "Vehicle-to-grid technology is revving up", GreenBiz, 12 November 2019, https://www.greenbiz.com/article/vehicle-grid-technology-revving; OVO Energy, "OVO vehicle-to-grid trial", https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger, viewed 15 March 2021.

136 J. Borrás, "Thailand gets fleet of electric ferries to help clean up Bangkok", CleanTechnica, 26 October 2020, https://cleantechnica.com/2020/10/26/thailand-gets-fleet-of-electric-ferries-to-help-clean-up-bangkok; S. Hanley, "Ellen, Denmark's first electric ferry, passes all tests with flying colors", 12 June 2020, CleanTechnica, https://cleantechnica.com/2020/06/12/ellen-denmarks-first-electric-ferry-passes-all-tests-with-flying-colors; K. Hamilton and T. Ma, "Electric aviation could be closer than you think", *Scientific American*, 10 November 2020, https://www.scientificamerican.com/article/electric-aviation-could-be-closer-than-you-think.

137 IEA, *Global EV Outlook 2021* (Paris: 2021), https://www.iea.org/reports/global-ev-outlook-2021; International Council on Clean Transportation, *Analyzing Policies to Grow the Electric Vehicle Market in European Cities* (Washington, DC: 2020), https://theicct.org/sites/default/files/publications/EV_city_policies_white_paper_fv_20200224.pdf.

138 A. Bertoli, "How many EV drivers have solar power In USA vs. Europe?" CleanTechnica, 23 November 2020, https://cleantechnica.com/2020/11/23/how-many-ev-drivers-have-solar-power-in-usa-vs-europe; R. J. Kuhudzai, "Drivelectric Kenya shows why you should be driving an electric vehicle In Kenya!" 6 June 2020, https://cleantechnica.com/2020/06/06/drive-electric-kenya-shows-why-you-should-be-driving-an-electric-vehicle-in-kenya; M. Holland, "2020 electric vehicle retrospective — prospects for 2021 & beyond", CleanTechnica, 31 December 2020, https://cleantechnica.com/2020/12/31/2020-electric-vehicle-retrospective-prospects-for-2021-and-beyond.

139 IEA, op. cit. note 137.

140 Ibid.

141 Ibid. **Figure 55** based on idem.

142 M. Gorner and L. Paoli, "How global electric car sales defied Covid-19 in 2020", IEA, 28 January 2021, https://www.iea.org/commentaries/how-global-electric-car-sales-defied-covid-19-in-2020.

143 IEA, op. cit. note 137.

144 Ibid.

145 Gorner and Paoli, op. cit. note 142; IEA, op. cit. note 137.

146 IEA, op. cit. note 137.

147 Ibid.

148 Ibid.

149 H. Shukla, "Electric two-wheeler sales decline by 5.46% in 2020", Mercom India, 7 January 2021, https://mercomindia.com/electric-two-wheeler-sales-decline.

150 IEA, op. cit. note 137.

151 Ibid.

152 Ibid.; "Electric bus, main fleets and projects around the world", Sustainable Bus, 19 May 2020, https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world; BloombergNEF, op. cit. note 96, slide 9.

153 BloombergNEF, op. cit. note 93, slide 9.

154 Ibid., slide 9.

155 Ibid., slide 9.

156 "Electric bus, main fleets and projects around the world", op. cit. note 152.

157 IEA, op. cit. note 137; "Electric bus, main fleets and projects around the world", op. cit. note 155; "The pandemic doesn't stop the European e-bus market: +22% in 2020", Sustainable Bus, 19 February 2021, https://www.sustainable-bus.com/news/europe-electric-bus-market-2020-covid.

158 "Denmark, Luxembourg, & Netherlands lead on electric buses In Europe", CleanTechnica, 15 January 2021, https://cleantechnica.com/2021/01/15/denmark-luxembourg-netherlands-lead-on-electric-buses-in-europe.

159 IEA, op. cit. note 137; Dialogo Chino, "La transición hacia buses eléctricos en América Latina es irreversible", 10 December 2020, https://dialogochino.net/es/clima-y-energia-es/38837-la-transicion-hacia-buses-electricos-en-america-latina-es-irreversible.

160 J. Sensiba, "Bogota gets 470 new electric buses, Berlin gets 90", CleanTechnica, 31 December 2020, https://cleantechnica.com/2020/12/31/bogota-gets-470-new-electric-buses-berlin-gets-90; Dialogo Chino, op. cit. note 159; "Bogotá, la ciudad con mayor número de buses eléctricos en Latinoamérica", Semana, 11 January 2021, https://www.semana.com/nacion/articulo/bogota-la-ciudad-con-mayor-numero-de-buses-electricos-en-latinoamerica/202119.

161 IEA, op. cit. note 137.

162 "California pushes for the transition to electric buses: Only zero emission purchases from 2029", Sustainable Bus, 15 December 2018, https://www.sustainable-bus.com/news/california-electric-buses-carb.

163 IEA, op. cit. note 137.

164 BloombergNEF, op. cit. note 93, slide 9.

165 IEA, op. cit. note 137; K. Stock, "Global electric vehicle cords top 1 million", Bloomberg, 5 August 2020, https://www.bloomberg.com/news/articles/2020-08-05/global-ev-charging-points-hit-1-million-threshold.

166 S. Hanley, "China invests in EV charging infrastructure to offset coronavirus economic slump", CleanTechnica, 11 May 2020, https://cleantechnica.com/2020/05/11/china-invests-in-ev-charging-infrastructure-to-offset-coronavirus-economic-slump.

167 IEA, op. cit. note 137.

168 Ibid.

169 Government of Canada, "Building back better: A plan to fight the COVID-19 recession", https://www.budget.gc.ca/fes-eea/2020/themes/building-back-better-rebatir-mieux-en.html, viewed 28 February 2021.

170 IEA, *Rail* (Paris: 2020), https://www.iea.org/reports/rail.

171 A. Chaturvedi, "100% electrification in railways in next 3.5 years, says Piyush Goyal", *Hindustan Times*, 16 July 2021, https://www.hindustantimes.com/india-news/100-electrification-in-railways-in-next-3-5-years-piyush-goyal/story-mlKq8324njLO6G8oeY1oXL.html; "Russian Railways prioritising electrification on freight routes", RailFreight.com, 27 October 2020, https://www.railfreight.com/railfreight/2020/10/27/russian-railways-prioritising-electrification-on-freight-routes.

172 C. Ames, "38% of Britain's rail network now electrified", Transport Network, 5 November 2020, http://www.transport-network.co.uk/38-of-Britains-rail-network-now-electrified/16944.

173 Z. Shahan, "Global plugin vehicle sales up 43% in 2020, European sales up 137%", CleanTechnica, 8 February 2021, https://cleantechnica.com/2021/02/08/global-plugin-vehicle-sales-up-43-in-2020-european-sales-up-137.

174 M. Holland, "Tesla passes 1 million EV milestone & Model 3 becomes all time best seller", CleanTechnica, 10 March 2020, https://cleantechnica.com/2020/03/10/tesla-passes-1-million-ev-milestone-and-model-3-becomes-all-time-best-seller.

175 J. Attwood, "Renault Zoe eclipses Tesla Model 3 as Europe's best-selling EV", Autocar, 27 January 2021, https://www.autocar.co.uk/car-news/new-cars/renault-zoe-eclipses-tesla-model-3-europes-best-selling-ev; J. Pontes, "Record electric vehicle sales in Europe!" CleanTechnica, 29 December 2020, https://cleantechnica.com/2020/12/29/record-electric-vehicle-sales-in-europe.

176 E. Cheng, "Chinese electric car company Nio doubles deliveries in 2020 as local competition ramps up for Tesla", CNBC, 4 January 2021, https://www.cnbc.com/2021/01/04/chinese-electric-car-start-up-nio-doubles-deliveries-as-tesla-competition-rises.html.

177 D. Broom, "2020 was a breakthrough year for electric vehicles. Here's why", World Economic Forum, 20 January 2021, https://www.weforum.org/agenda/2021/01/electric-vehicles-breakthrough-tesla-china.

178 S. Mufson, "General Motors to eliminate gasoline and diesel light-duty cars and SUVs by 2035", *Washington Post*, 28 January 2021, https://www.washingtonpost.com/climate-environment/2021/01/28/general-motors-electric; J. L. Lareau, "GM hopes to eliminate gas vehicles in favor of all-electric vehicle lineup by 2040", USA Today Money, 28 January 2021, https://www.usatoday.com/story/money/cars/2021/01/28/gm-hopes-to-eliminate-gas-vehicles-by-2040/4294733001; T. Leggett, "Jaguar car brand to be all-electric by 2025", BBC, 15 February, https://www.bbc.com/news/business-56072019.

179 J. Rosenholtz, "2022 GMC Hummer EV first look review: An icon goes electric", Carbuzz, https://carbuzz.com/cars/gmc/hummer, viewed 11 May 2021; Leggett, op. cit. note 178; K. Lyons, "Honda plans to sell two electric SUVs in the US in the 2024 model year", The Verge, 14 March 2021, https://www.theverge.com/2021/3/14/22330086/honda-plans-electric-suv-2024-hybrid-toyota-emissions; Automobile Propre, "Audi e-tron", https://www.automobile-propre.com/voitures/audi-q6-e-tron, viewed 11 May 2021; Ford, "Ford Mustang Mach-E: le suv 100 % électrique", https://www.ford.fr/voitures-neuves/mustang-mach-e, viewed 11 May 2021; A. J. Hawkins, "Hyundai's electric Ioniq 5 crossover could be the ultimate camping companion", The Verge, 23 February 2021, https://www.theverge.com/2021/2/23/22296991/hyundai-ioniq-5-electric-suv-ev-battery-range-specs.

180 L. Cozzi and A. Petropoulos, "Carbon emissions fell across all sectors in 2020 except for one – SUVs", IEA, 15 January 2021, https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs.

181 Ibid.

182 Shahan, op. cit. note 173.

183 Ibid.

184 J. Parnell, "Shell, Volvo and Daimler back hydrogen as Europe sets its sights on truck emissions", Greentech Media, 15 December 2020, https://www.greentechmedia.com/articles/read/shell-volvo-daimler-back-hydrogen-as-europe-turns-sights-on-truck-emissions; A. Sergeev, "Truckmakers to kill the combustion engine in Europe by 2040", Moro1.com, 16 December 2020, https://www.motor1.com/news/460579/truckmakers-kill-combustion-engine-europe.

185 J. Crider, "Mercedes-Benz is done chasing the hydrogen fuel cell car dream", CleanTechnica, 23 April 2020, https://cleantechnica.com/2020/04/23/mercedes-benz-is-done-chasing-after-hydrogen-fuel-cell-cars.

186 R. J. Kuhudzai, "1st Ethiopian-assembled all-electric Hyundai Ioniq rolls out of Haile Gebrselassie's Marathon Motor Engineering Plant", CleanTechnica, 27 July 2020, https://cleantechnica.com/2020/07/27/first-ethiopian-assembled-all-electric-hyundai-ionic-rolls-out-of-haile-gebrselassies-marathon-motor-engineering-plant.

187 CNBC, "LG and Magna announce billion dollar joint venture in electric car gear", 22 December 2020, https://www.cnbc.com/2020/12/23/lg-and-magna-announce-billion-dollar-joint-venture-in-electric-car-gear.html; J. Parnell, "A battery giant is born: Total and Groupe PSA launch new European manufacturer", Greentech Media, 4 September 2020, https://www.greentechmedia.com/articles/read/a-battery-giant-is-born-total-and-groupe-psa-launch-new-company; Y. Sun and J. Zhu, "Volkswagen pumps 2 billion euros into China electric vehicle bet", *Reuters*, 29 May 2020, https://www.reuters.com/article/us-volkswagen-jac-m-a/volkswagen-pumps-2-billion-euros-into-china-electric-vehicle-bet-buys-stakes-in-two-firms-idUSKBN235063.

188 Mitsui O. S. K. Lines, "'e5 Consortium' established to promote zero-emission electric vessel; project encompasses development, realization, commercialization", 21 May 2020, https://www.mol.co.jp/en/pr/2020/20028.html.

189 IEA, "A rapid rise in battery innovation is playing a key role in clean energy transitions", 22 September 2020, https://www.iea.org/news/a-rapid-rise-in-battery-innovation-is-playing-a-key-role-in-clean-energy-transitions.

190 BloombergNEF, "Battery pack prices cited below $100/kWh for the first time in 2020, while market average sits at $137/kWh", 16 December 2020, https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh; IEA, op. cit. note 189; ESMAP, "Energy Storage Program", https://www.esmap.org/energystorage, viewed 11 May 2021.

191 BloombergNEF, op. cit. note 190.

192 H. Shukla, "Daily news wrap-up: Tesla to make cobalt free batteries", Mercom India, 24 September 2020, https://mercomindia.com/daily-news-wrap-up-tesla-batteries.

193 D. Robinson, "Six electric vehicle charging innovations that could be crucial to green transport revolution", NS Energy, 27 April 2020, https://www.nsenergybusiness.com/features/electric-vehicle-charging-innovations; D. Robinson, "Electric taxis can now be charged wirelessly in UK city in £3.4m trial", NS Energy, 17 January 2020, https://www.ns-businesshub.com/transport/wireless-charging-electric-vehicles-nottingham; Momentum Dynamics, "Link Transit, Wenatchee WA celebrates 50 mwh of energy delivered wirelessly to electric bus fleet", 19 May 2020, https://momentumdynamics.com/2020/05/19/link-transit-wenatchee-wa-celebrates-50-mwh-of-energy-delivered-wirelessly-to-electric-bus-fleet; J. Bellington, "China announces national standard for wireless electric vehicle charging", Electric & Hybrid Vehicle Technology News, 7 May 2020, https://www.electrichybridvehicletechnology.com/news/charging-technology/china-announces-national-standard-for-wireless-electric-vehicle-charging.html.

194 Robinson, op. cit. note 193; InsideEVs, "These pop-up public charging points by Urban Electric are pretty neat", 16 May 2020, https://insideevs.com/news/423649/urban-electric-discrete-pop-up-public-charge-points; Urban Electric, "Convenient on-street electric vehicle charging", https://www.urbanelectric.london, viewed 11 May 2021; J. S. Murray, "Seeing the light: Siemens powers up UK's first 'Electric Avenue'", Business Green, 19 March 2020, https://www.businessgreen.com/news/4012735/seeing-light-siemens-powers-uk-electric-avenue.

195 C. Hanvey, "EV managed charging: Lessons from utility pilot programs", Smart Electric Power Alliance, 25 July 2019, https://sepapower.org/knowledge/ev-managed-charging-lessons-from-utility-pilot-programs.

196 R. Lee and S. Brown, "How superfast charging batteries can help sell the transition to electric vehicles", The Conversation, 26 January 2021, https://theconversation.com/how-superfast-charging-batteries-can-help-sell-the-transition-to-electric-vehicles-153872; SoreDot, "Technology", https://www.store-dot.com/technology, viewed 11 May 2021.

197 V2G Hub, "Insights", https://www.v2g-hub.com/insights/status#graphs, viewed 28 February 2021.

198 Ibid.

199 T. Casey, "Scotland banks on hydrogen fuel cell trains for zero emission railway by 2035", CleanTechnica, 1 January 2021, https://cleantechnica.com/2021/01/01/scotland-banks-on-hydrogen-fuel-cell-trains-for-zero-emission-railway-by-2035; A. Davis, "Transport for the North hails region as a pioneer of hydrogen transport technologies", Highways Today, 5 October 2020, https://highways.today/2020/10/05/transport-north-hydrogen-transport.

200 Hirschlag, op. cit. note 76.

201 T. Casey, "Hard sails & green hydrogen for the cargo ships of the future", CleanTechnica, 3 December 2020, https://cleantechnica.com/2020/12/03/hard-sails-green-hydrogen-for-the-cargo-ships-of-the-future.

202 T. Mullaney, "Rolls-Royce thinks it can make a plane Greta Thunberg would fly in", CNBC, 15 December 2019, https://www.cnbc.com/2019/12/16/rolls-royce-thinks-it-can-make-a-plane-greta-thunberg-would-fly-in.html; Air race E, https://airracee.com, viewed 11 May 2021; Rolls-Royce, "ACCEL: Entering the era of zero-emissions aviation", https://www.rolls-royce.com/innovation/accel.aspx, viewed 11 May 2021; Airbus, "Electric flight", https://www.airbus.com/innovation/zero-emission/electric-flight.html, viewed 11 May 2021.

203 Wisk, "What's happening at Wisk", https://wisk.aero/news, viewed 11 May 2021.

204 Environmental and Energy Study Institute, "Fact Sheet: Energy Storage" (Washington, DC: 22 February 2019), https://www.eesi.org/files/FactSheet_Energy_Storage_0219.pdf; M. Stanley Whittingham, "History, evolution, and future status of energy storage", *Proceedings of the IEEE*, vol. 100 (13 May 2012), https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6184265.

205 IRENA, "Energy storage", https://www.irena.org/costs/Power-Generation-Costs/Energy-Storage, viewed 11 May 2021; Energy Storage (IEA), "Flexible sector coupling – annex 35", https://iea-eces.org/annex-35, viewed 11 May 2021.

206 See Energy Systems Integration and Enabling Technologies chapters in REN21, *Renewables 2019 Global Status Report* (Paris: 2019), https://www.ren21.net/gsr-2019 and REN21, *Renewables 2018 Global Status Report* (Paris: 2018), https://www.ren21.net/gsr-2018.

207 A. Colthorpe, "Energy storage markets 'resilient to the pandemic', says Wärtsilä CEO", Energy Storage News, 28 January 2021, https://www.energy-storage.news/news/energy-storage-markets-resilient-to-the-pandemic-says-waertsilae-ceo; European Association for Storage of Energy (EASE), "Energy storage and the COVID-19 recovery: Time for policymakers to step up their commitments", 7 July 2020, https://ease-storage.eu/news/energy-storage-and-the-covid-19-recovery-time-for-policymakers-to-step-up-their-commitments; IEA, "Energy integration", in *The Covid-19 Crisis and Clean Energy Progress* (Paris: 2020, https://www.iea.org/reports/the-covid-19-crisis-and-clean-energy-progress/energy-integration#energy-storage.

208 China Energy Storage Alliance (CNESA), "The White Paper on Energy Storage Industry Research 2021 was released, and the new scale of electrochemical energy storage in China broke through the GW mark", 24 April 2021, http://www.cnesa.org/index/inform_detail?cid=6083e524b1fd37c5358b456e (using Google Translate); Sacred Sun, "CNESA officially released "Energy Storage Industry White Paper 2021", 26 April 2021, https://www.sacredsun.com/News/Industry/2021/0426/Energy-Storage-Industry-White-Paper-2021.html; IEA, "Energy storage", in *Tracking Energy Integration 2020* (Paris: 2020), https://www.iea.org/reports/tracking-energy-integration-2020; IEA, op. cit. note 207.

209 See Investment chapter in this report. F. Mayr, "Energy storage in a post-pandemic world: Taking stock and preparing for future success – part two", Energy Storage News, 13 July 2020, https://www.energy-storage.news/blogs/energy-storage-in-a-post-pandemic-world-taking-stock-and-preparing-for; Colthorpe, op. cit. note 207; S. Yubo, "2020 energy storage industry summary: A new stage in large-scale development", CNESA, 1 March 2021, http://en.cnesa.org/latest-news/2021/2/28/2020-energy-storage-industry-summary-a-new-stage-in-large-scale-development.

210 CNESA, op. cit. note 208. **Figure 56** from idem and from CNESA, *Energy Storage Industry White Paper 2020* (Beijing: 2020), http://en.cnesa.org/white-paper-access-multyear.

211 Yubo, op. cit. note 209.

212 Wood Mackenzie, "U.S. Energy Storage Monitor", https://www.woodmac.com/research/products/power-and-renewables/us-energy-storage-monitor, viewed 4 March 2020; Wood Mackenzie, "US energy storage market shatters quarterly deployment record", 3 March 2021, https://www.woodmac.com/press-releases/us-energy-storage-market-shatters-quarterly-deployment-record; Center for Sustainable Systems, University of Michigan, "U.S. Energy Storage Factsheet" (Ann Arbor, MI: 2020), http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet.

213 EASE, "EMMES 5.0 – March 2021", https://ease-storage.eu/publication/emmes-5-0-march-2021.

214 N. El Chami, "Europe's energy storage transformation", Energy Storage News, 9 November 2020, https://www.energy-storage.news/blogs/europes-energy-storage-transformation.

215 CNESA, op. cit. note 208.

216 Ibid.

217 Ibid.

218 CNESA, "Global energy storage market analysis – 2020.Q3 (summary), November 2020", 17 November 2020, http://en.cnesa.org/latest-news/2020/11/17/cnesa-global-energy-storage-market-analysis 2020q3-summary.

219 CNESA, op. cit. note 208; Yubo, op. cit. note 209; BloombergNEF, op. cit. note 93.

220 Wood Mackenzie, "An attempted shortlist of the major breakthroughs in the energy storage industry's biggest year ever", Greentech Media, 28 December 2019, https://www.greentechmedia.com/articles/read/the-top-10-energy-storage-stories-of-2020; American Clean Power, "American Clean Power Market Report Q4 2020", slide 25/26, 2020, https://cleanpower.org/resources/american-clean-power-market-report-q4-2020.

221 Ibid., both references; BloombergNEF, op. cit. note 93, slide 9. Other projects from the following: C. Katz, "In boost for renewables, grid-scale battery storage is on the rise", Yale e360, 15 December 2020, https://e360.yale.edu/features/in-boost-for-renewables-grid-scale-battery-storage-is-on-the-rise; K. Pickerel, "World's largest lithium-based energy storage system storing 1,200 MWh of power now online in California", Solar Power World, 6 January 2021 https://www.solarpowerworldonline.com/2021/01/worlds-largest-lithium-based-energy-storage-system-storing-1200-mwh-of-power-now-online-in-california; "In a first, TVA to install

its own 40-MWh battery storage system", Renewable Energy World, 23 September 2020, https://www.renewableenergyworld.com/2020/09/23/in-a-first-tva-to-install-its-own-40-mwh-battery-storage-system; C. Galford, "Southern California Edison contracts four projects to add 590 MW of battery energy storage", Daily Energy Insider, 9 December 2020, https://dailyenergyinsider.com/news/28269-southern-california-edison-contracts-four-projects-to-add-590-mw-of-battery-energy-storage; J. St. John, "California shifts $100M in behind-the-meter battery incentives to low-income communities", Greentech Media, 23 October 2020, https://www.greentechmedia.com/amp/article/california-shifts-backup-battery-incentives-to-help-low-income-communities.

222 American Clean Power, op. cit. note 220, slide 26; J. Spector, "LS Power energizes world's biggest battery, just in time for California's heat wave", Greentech Media, 19 August 2020, https://www.greentechmedia.com/articles/read/ls-power-energizes-worlds-biggest-battery-near-san-diego-just-in-time-for-heatwave; P. Ciampoli, "Texas utility plans first utility-scale storage projects", American Public Power Association, 3 January 2020, https://www.publicpower.org/periodical/article/texas-utility-plans-first-utility-scale-storage-projects; A. Bertola, "World's largest energy storage system proposed in Morro Bay", KSBY News, 18 February 2021, https://www.ksby.com/news/local-news/worlds-largest-energy-storage-system-proposed-in-morro-bay.

223 Wood Mackenzie, "US energy storage market shatters quarterly deployment record", 3 March 2021, https://www.woodmac.com/press-releases/us-energy-storage-market-shatters-quarterly-deployment-record.

224 BVES, op. cit. note 106, slide 6.

225 BSW Solar, "Solar battery boom", 18 February 2021, https://www.solarwirtschaft.de/en/2021/02/18/solar-battery-boom.

226 Clean Energy Regulator, "State data for battery installations with small-scale systems", http://www.cleanenergyregulator.gov.au/DocumentAssets/Pages/State-data-for-battery-installations-with-small-scale-systems.aspx, viewed 10 May 2021.

227 Electricity Markets & Policy, "Hybrid power plants are growing rapidly: Are they a good idea?" 13 March 2020, https://emp.lbl.gov/news/hybrid-power-plants-are-growing-rapidly-are; BloombergNEF, *How PV-Plus Storage Will Compete With Gas Generation in the U.S.* (London: 2020), https://assets.bbhub.io/professional/sites/24/BloombergNEF-How-PV-Plus-Storage-Will-Compete-With-Gas-Generation-in-the-U.S.-Nov-2020.pdf.

228 A. Colthorpe, "Large-scale renewables-plus-storage projects in US more than doubled from 2016 to 2019", Energy Storage, 26 May 2020, https://www.energy-storage.news/news/large-scale-renewables-plus-storage-projects-in-us-more-than-doubled-from-2; BloombergNEF, op. cit. note 227. Example of projects from the following: "Trailblazing PV-storage contract shows growing dispatch skills", *Reuters*, 12 February 2020, https://www.reutersevents.com/renewables/pv-insider/trailblazing-pv-storage-contract-shows-growing-dispatch-skills; List Solar, "New Mexico energy plans nearly 1GW of solar-plus-storage to change coal plant", 13 October 2020, https://list.solar/news/new-mexico-energy; S. Hanley, "Solar, storage, and wind — success stories In Australia, US, and Vietnam", CleanTechnica, 18 October 2020, https://cleantechnica.com/2020/10/18/solar-storage-and-wind-success-stories-in-australia-us-and-vietnam/amp; J. St. John, "Southern California Edison contracts huge storage portfolio to replace gas plants", Greentech Media, 1 May 2020, https://www.greentechmedia.com/articles/read/southern-california-edison-picks-770mw-of-energy-storage-projects-to-be-built-by-next-year.

229 Energy Iceberg, "Renewable hybrid 'great leap forward'", 25 November 2020, https://energyiceberg.com/china-renewable-hybrid-hype.

230 Saur Energy International, "Sungrow supplies 21 MWh solar-plus-storage plant in Japan", 8 February 2021, https://www.saurenergy.com/solar-energy-news/sungrow-supplies-21-mwh-solar-plus-storage-plant-in-japan; E. Bellini, "Solar-plus-storage as an antidote to grid congestion in Japan's northern island of Hokkaido", pv magazine, 8 February 2021, https://www.pv-magazine.com/2021/02/08/solar-plus-storage-as-an-antidote-to-grid-congestion-in-japans-northern-island-of-hokkaido.

231 CNESA, op. cit. note 208.

232 IRENA, *Innovation Outlook: Thermal Energy Storage* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Innovation_Outlook_TES_2020.pdf; M. Farmer, "Thermal energy storage set to triple – lessons from IRENA", Power Technology, 6 January 2021, https://www.power-technology.com/features/thermal-energy-storage-set-to-triple-lessons-from-irena.

233 See CSP section in Market and Industry chapter of this report. IRENA, op. cit. note 232.

234 IRENA, op. cit. note 232.

235 Ibid., p. 46. See Solar Heating and Cooling section in Market and Industry chapter of this report.

236 Ibid.; IEA Energy Conservation Through Energy Storage (IEA-ECES), *Applications of Thermal Energy Storage in the Energy Transition – Benchmarks and Developments* (Paris: 2018), https://www.eces-a30.org/wp-content/uploads/Applications-of-Thermal-Energy-Storage-in-the-Energy-Trenasition-Annex-30_Public-Report.pdf.

237 State of Green, "Large-scale thermal storage pit", https://stateofgreen.com/en/partners/ramboll/solutions/large-scale-thermal-pit-storage, viewed 10 May 2021.

238 IEA-ECES, op. cit. note 236; IRENA, op. cit. note 232.

239 Asian Development Bank, *Solar District Heating in the People's Republic of China* (Manila: 2019), https://www.adb.org/sites/default/files/publication/514916/solar-district-heating-peoples-republic-china.pdf.

240 IRENA, *Green Hydrogen: A Guide to Policy Making* (Abu Dhabi: 2020), https://www.irena.org/publications/2020/Nov/Green-hydrogen.

241 Ibid.; D. Leitch, "Hydrogen: The great energy hope, or a whole lot of hype?" RenewEconomy, 15 July 2020, https://reneweconomy.com.au/hydrogen-the-great-energy-hope-or-a-whole-lot-of-hype-16691; J. Parnell, "Europe's green hydrogen revolution is turning blue", Greentech Media, 1 July 2020, https://www.greentechmedia.com/articles/read/europes-green-hydrogen-revolution-is-turning-blue; CarbonBrief, "In-depth Q&A: Does the world need hydrogen to solve climate change?" 30 November 2020, https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change.

242 IRENA, op. cit. note 240; Energy Transitions Commission, *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy*, April 2021, https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf.

243 IRENA, op. cit. note 240; Wood Mackenzie, *2050: The Hydrogen Possibility* (2020), https://www.woodmac.com/our-expertise/focus/transition/2050---the-hydrogen-possibility; CarbonBrief, op. cit. note 241; IHS Markit, *Top 10 Cleantech Trends in 2021* (London: 2021), p. 9, https://cdn.ihsmarkit.com/www/prot/pdf/0221/IHS-MarkitTopCleanTechTrends2021-Whitepaper.pdf.

244 Australia, Chile, the EU, France, Germany, the Netherlands, Norway, Portugal and Spain have hydrogen strategies with provisions to support renewable hydrogen. Canada, Japan and the Republic of Korea have hydrogen strategies that do not specifically support renewable hydrogen. Italy, Finland, New Zealand, the Russian Federation and others have published either an unofficial roadmap or vision document for renewable hydrogen development. IRENA, op. cit. note 241; Government of Canada, *Hydrogen Strategy for Canada* (Ottawa: 2020), https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf; Ministerio para la Transición Ecológica y el Reto Demográfico, "Una apuesta por el hidrógeno renovable", https://www.miteco.gob.es/es/ministerio/hoja-de-ruta-del-hidrogeno-renovable.aspx, viewed 10 May 2021.

245 M. Burgess, "Portugal eyes a hydrogen-fuelled future", Hydrogen View, 8 April 2021, https://www.h2-view.com/story/portugal-eyes-a-hydrogen-fuelled-future; Energy Iceberg, "China's green hydrogen effort in 2020: Gearing up for commercialization", 7 October 2020, https://energyiceberg.com/china-renewable-green-hydrogen; ETEnergyWorld, "National Hydrogen Mission: Leapfrogging towards India's cleaner future", 16 February 2021, https://energy.economictimes.indiatimes.com/news/renewable/national-hydrogen-mission-leapfrogging-towards-indias-cleaner-future/80991679.

246 IHS Markit, "Investment in green hydrogen production set to exceed $1billion USD by 2023, according to IHS Markit", 3 December 2020, https://news.ihsmarkit.com/prviewer/release_only/slug/2020-12-03-investment-in-green-hydrogen-production-set-to-exceed-1-billion-usd-by-2023.

247 G. Hering, "Air Liquide completes world's largest green hydrogen machine in Canada", S&P Global, 26 January 2021,

https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/air-liquide-completes-world-s-largest-green-hydrogen-machine-in-canada-62297835; L. Collins, "World's largest green-hydrogen plant inaugurated in Canada by Air Liquide", Recharge, 27 January 2021, https://www.rechargenews.com/transition/worlds-largest-green-hydrogen-plant-inaugurated-in-canada-by-air-liquide/2-1-952085; A. Lee, "Japan opens world's largest green-hydrogen plant near Fukushima disaster site", Recharge, 9 March 2020, https://www.rechargenews.com/transition/japan-opens-worlds-largest-green-hydrogen-plant-near-fukushima-disaster-site/2-1-769361; J. S. Hill, "Japan begins solar powered hydrogen production at Fukushima plant", RenewEconomy, 11 March 2020, https://reneweconomy.com.au/japan-begins-solar-powered-hydrogen-production-at-fukushima-plant-89645.

248 L. Collins, "Growing ambition: The world's 20 largest green-hydrogen projects", Recharge, 21 December 2020, https://www.rechargenews.com/energy-transition/growing-ambition-the-worlds-20-largest-green-hydrogen-projects/2-1-933755.

249 R. Nair, "Over 60 GW of green hydrogen projects in the pipeline globally, says report", Mercom India, 20 October 2020, https://mercomindia.com/over-60-gw-green-hydrogen-projects.

250 J. S. Hill, "European consortium to deliver 95GW of solar and 67GW of hydrogen by 2030", RenewEconomy, 16 February 2021, https://reneweconomy.com.au/30-european-companies-form-hydeal-ambition-project-to-deliver-95gw-of-solar-67gw-of-hydrogen.

251 Asian Renewable Hub, https://asianrehub.com, viewed 10 May 2020.

252 Collins, op. cit. note 248; Asian Renewable Hub, op. cit. note 251.

253 A. Frangoul, "Green hydrogen project combining tidal power and battery tech aims for continuous production", CNBC, 10 November 2020, https://www.cnbc.com/2020/11/10/project-combining-batteries-tidal-power-aims-for-hydrogen-production.html.

254 J. Spector, "So, what exactly is long-duration energy storage?" Greentech Media, 26 October 2020, https://www.greentechmedia.com/articles/read/so-what-exactly-is-long-duration-storage-explained.

255 Ibid.

256 IEA, op. cit. note 189.

257 Ibid.

258 BloombergNEF, op. cit. note 190.

259 S. Vorrath, "Solar flow battery breakthrough combines PV generation and storage in one device", RenewEconomy, 14 July 2020, https://reneweconomy.com.au/solar-flow-battery-breakthrough-combines-pv-generation-and-storage-in-one-device-21647; J. Deign, "Investors still betting on next big energy storage technology: Solid-state batteries", Greentech Media, 8 July 2020, https://www.greentechmedia.com/articles/read/us-storage-companies-quietly-grow-bets-on-solid-state-batteries; M. Willuhn, "Mercedes-Benz teams up with Hydro-Québec for solid-state battery development", pv magazine, 5 February 2020, https://www.pv-magazine.com/2020/02/05/mercedes-benz-teams-up-with-hydro-quebec-for-solid-state-battery-development; M. Slovick, "Solid-state batteries advancing toward promise of fast charging, long life, safer use", Electronic Design, 17 December 2020, https://www.electronicdesign.com/markets/automotive/article/21150718/electronic-design-solidstate-batteries-advancing-toward-promise-of-fast-charging-long-life-safer-use.

260 J. Spector, "Long duration breakthrough? Form Energy's first project tries pushing storage to 150 hours", Greentech Media, 7 May 2020, https://www.greentechmedia.com/articles/read/form-energys-first-project-pushes-long-duration-storage-to-new-heights-150-hour-duration.

261 J. McMahon, "California sees zinc as likely successor to lithium-ion in energy storage", *Forbes*, 6 October 2020, https://www.forbes.com/sites/jeffmcmahon/2020/10/06/california-shifts-attention-from-lithium-ion-to-zinc-energy-storage; J. Spector, "Updated: Form Energy attracted 4 new investors for $76M Series C", Greentech Media, 30 November 2020, https://www.greentechmedia.com/articles/read/form-energy-raises-another-70m-for-long-duration-storage.

262 Eos, "Eos raises millions from listing on Nasdaq, in rare battery startup move to public markets", https://eosenergystorage.com/eos-raises-millions-from-listing-on-nasdaq-in-rare-battery-startup-move-to-public-markets, viewed 10 May 2021.

263 O. Balch, "The curse of 'white oil': Electric vehicles' dirty secret, *The Guardian* (UK), 8 December 2020, https://www.theguardian.com/news/2020/dec/08/the-curse-of-white-oil-electric-vehicles-dirty-secret-lithium; T. Doshi, "The dirty secrets of 'Clean' electric vehicles", *Forbes*, 2 August 2020, https://www.forbes.com/sites/tilakdoshi/2020/08/02/the-dirty-secrets-of-clean-electric-vehicles; C. Early, "The new 'gold rush' for green lithium", BBC, 24 November, https://www.bbc.com/future/article/20201124-how-geothermal-lithium-could-revolutionise-green-energy; Sonnenseite, "World's first zero carbon lithium extraction project to start in Germany", 23 July 2020, https://www.sonnenseite.com/en/science/worldas-first-zero-carbon-lithium-extraction-project-to-start-in-germany.

264 World Bank, "New international partnership established to increase the use of energy storage in developing countries", press release (Washington, DC: 28 May 2019), https://www.worldbank.org/en/news/press-release/2019/05/28/new-international-partnership-established-to-increase-the-use-of-energy-storage-in-developing-countries; World Bank, "Batteries can help renewables reach full potential in Africa", 28 February 2019, https://www.worldbank.org/en/news/feature/2019/02/28/batteries-can-help-renewables-reach-full-potential-in-africa.

265 Ibid., both references.

266 World Bank, "New international partnership", op. cit. note 264; World Bank, *Warranties for Battery Energy Storage Systems in Developing Countries* (Washington, DC: 2020), http://documents1.worldbank.org/curated/en/339531600374280939/pdf/Warranties-for-Battery-Energy-Storage-Systems-in-Developing-Countries.pdf.

267 "UK solar developers deploy storage to capture peak returns", *Reuters*, 2 September 2020, https://www.reutersevents.com/renewables/solar/uk-solar-developers-deploy-storage-capture-peak-returns.

268 Ibid.

269 IRENA, op. cit. note 232.

270 J. Spector, "The 5 most promising long-duration storage technologies left standing", Greentech Media, 31 March 2020, https://www.greentechmedia.com/articles/read/most-promising-long-duration-storage-technologies-left-standing.

271 IRENA, op. cit. note 232, p. 74; National Energy Technology Laboratory, "NETL explores concrete solutions to store thermal energy", https://www.netl.doe.gov/node/9624, viewed 20 March 2021; "China buys 49% of ACWA Power renewables; US to build concrete thermal storage plant", *Reuters*, 3 July 2019, https://www.reutersevents.com/renewables/csp-today/china-buys-49-acwa-power-renewables-us-build-concrete-thermal-storage-plant.

272 Malta Inc., "Malta raises $50M to commercialize its long duration energy storage system", 24 February 2021, https://www.maltainc.com/malta-raises-50-million.

273 Wood Mackenzie, op. cit. note 243; H. Shukla, "Daily news wrap-up: Siemens and WUN H2 to build a CO_2 free hydrogen production facility", Mercom India, 30 September 2020, https://mercomindia.com/daily-news-wrap-up-siemens-wun-h2.

274 J. Deign, "Coalition aims for 25GW of green hydrogen by 2026", Greentech Media, 8 December 2020, https://www.greentechmedia.com/articles/read/coalition-aims-for-25-gw-of-green-hydrogen-by-2026.

275 US DOE, OEERE, "Collaboration between the United States and the Netherlands focuses on hydrogen technology", 6 October 2020, https://www.energy.gov/eere/articles/collaboration-between-united-states-and-netherlands-focuses-hydrogen-technology; D. Mavrokefalidis, "Netherlands and Portugal strengthen their ties for green hydrogen transportation", Energy Live News, 24 September 2020, https://www.energylivenews.com/2020/09/24/netherlands-and-portugal-strengthen-their-ties-for-green-hydrogen-transportation; T. Smith, "Exploring hydrogen resources in Africa gains momentum", ESI Africa, 9 September 2020, https://www.esi-africa.com/industry-sectors/renewable-energy/exploring-hydrogen-resources-in-africa-gains-momentum.

276 IEA, Clean Energy Ministerial Hydrogen Initiative, https://www.iea.org/programmes/cem-hydrogen-initiative. Current 21 participating countries: Australia, Austria, Brazil, Canada, Chile, China, Costa Rica, the EU, Finland, Germany, India, Italy, Japan, the Netherlands, New Zealand, Norway, Saudi Arabia, South Africa, the Republic of Korea, the United Kingdom and the United States.

277 IHS Markit, op. cit. note 243.

278 Energy Transitions Commission, op. cit. note 242, p. 27.

279 F. Schulz, "Germany plans to promote 'green' hydrogen with €7 billion", EURACTIV, 11 June 2020, https://www.euractiv.com/section/energy/news/germany-plans-to-promote-green-hydrogen-with-e7-billion; S. Goncalves, "Portugal selects multi-billion post-coronavirus hydrogen projects", *Reuters*, 28 July 2020, https://www.reuters.com/article/us-portugal-energy-hydrogen/portugal-selects-multi-billion-post-coronavirus-hydrogen-projects-idUSKCN24T1S5; J. Stones, "French government announces support for hydrogen projects", ICIS, 23 October 2020, https://www.icis.com/explore/resources/news/2020/10/23/10566918/french-government-announces-support-for-hydrogen-projects.

280 "European energy giants partner on Portugal green hydrogen project", Power Engineering International, 10 August 2020, https://www.powerengineeringint.com/renewables/european-energy-giants-partner-on-h2sines-green-hydrogen-production-project; S. Djunisic, "Portugal-led partnership to assess viability of 1-GW green hydrogen cluster", Renewables Now, 30 July 2020, https://www.renewablesnow.com/news/portugal-led-partnership-to-assess-viability-of-1-gw-green-hydrogen-cluster-708266.

281 J. Parnell, "2020: The year of green hydrogen in 10 stories", Greentech Media, 29 December 2020, https://www.greentechmedia.com/articles/read/2020-the-year-of-green-hydrogen-in-10-stories.

282 Schulz, op. cit. note 279; SolarPower Europe, newsletter, 5 June 2020, https://www.solarpowereurope.org/solarpower-europe-newsletter-4.

283 X. Yihe, "Sinopec to shift gears from grey to green hydrogen", Upstream Online, 12 March 2021, https://www.upstreamonline.com/energy-transition/sinopec-to-shift-gears-from-grey-to-green-hydrogen/2-1-975983; Argus Media, "China's Sinopec outlines hydrogen aspirations", 24 February 2021, https://www.argusmedia.com/en/news/2189848-chinas-sinopec-outlines-hydrogen-aspirations; L. Moffitt, "China's Sinopec, Longi team up for green hydrogen", Argus Media, 16 April 2021, https://www.argusmedia.com/en/news/2205975-chinas-sinopec-longi-team-up-for-green-hydrogen; D. Murtaugh, "World's biggest solar company joins the hydrogen game", Bloomberg Green, 5 April 2021, https://www.bloomberg.com/news/articles/2021-04-05/world-s-biggest-solar-company-joins-the-hydrogen-game.

284 J. St. John, "Plug Power raises $1B for US green hydrogen infrastructure build-out", Greentech Media, 24 November 2020, https://www.greentechmedia.com/articles/read/plug-power-raises-1b-for-u.s-green-hydrogen-infrastructure-buildout.

285 J. St. John, "Xcel targets $1.4B in wind and solar investments, outlines broader carbon-reduction goals", Greentech Media, 30 October 2020, https://www.greentechmedia.com/articles/read/xcel-targets-1.4b-in-wind-solar-investments-outlines-broader-carbon-reduction-goals.

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1 United Nations Environment Programme (UNEP), "Why does energy matter?" https://www.unenvironment.org/explore-topics/energy/why-does-energy-matter, viewed 30 January 2021; International Energy Agency (IEA), *Global Energy & CO_2 Status Report 2019* (Paris: 2019), https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions#abstract.

2 Of the NDC data analysed, 105 of the commitments were accessed from United Nations Framework Convention on Climate Change, "NDC Registry", https://www4.unfccc.int/sites/NDCStaging/Pages/Search.aspx, viewed February 2020. The remaining data were retrieved from International Renewable Energy Agency (IRENA), "Renewable energy in the NDCs", https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Renewable-Energy-in-the-NDCs, viewed February 2020.

3 See Box 2 in Energy Efficiency chapter in Renewable Energy Network for the 21st Century (REN21), *Renewables 2020 Global Status Report* (Paris: 2020), https://www.ren21.net/gsr-2020.

4 IEA, *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020.

5 IEA, "Decoupling of global emissions and economic growth confirmed", press release (Paris: 16 March 2016), https://www.iea.org/news/decoupling-of-global-emissions-and-economic-growth-confirmed.

6 Based on IEA, World Energy Statistics database, 2020, www.iea.org/statistics (all rights reserved; as modified by REN21), and on M. Fischedick et al., "Industry", in O. Edenhofer et al., eds., *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK and New York, NY: Cambridge University Press, 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter10.pdf.

7 G. P. Peters et al., "Key indicators to track current progress and future ambition of the Paris Agreement", *Nature Climate Change*, vol. 7 (2017), pp. 118-22, https://jacksonlab.stanford.edu/sites/g/files/sbiybj15141/f/nclimate3202.pdf.

8 For more on the combined impact of energy efficiency and renewables on energy intensity, see REN21, op. cit. note 3.

9 **Sidebar 7** from the following sources: IEA, op. cit. note 4; IEA, *Global Energy Review 2020, Electricity* (Paris: 2020), https://www.iea.org/reports/global-energy-review-2020/electricity; IEA, *Energy Efficiency 2020* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020/covid-19-and-energy-efficiency; S. Watson, "Moving forward with sustainable mobility in the post-COVID world", SLOCAT Partnership for Sustainable, Low Carbon Transport, 17 September 2020, https://slocat.net/moving-forward-with-sustainable-mobility-in-the-post-covid-world; M. Liebreich, "Energy efficiency key to Covid recovery", BloombergNEF, 26 June 2020, https://about.bnef.com/blog/liebreich-energy-efficiency-key-to-covid-recovery; A. Harder, "The pandemic is destroying energy efficiency", Axios, 19 October 2020, https://www.axios.com/pandemic-energy-efficiency-004eaa80-0fc6-4ca7-a212-3c248125f148.html; D. Crow and A. Millot, "Working from home can save energy and reduce emissions. But how much?" IEA, 12 June 2020, https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much; RICS, *Global Construction Monitor*, Third Quarter 2020, https://www.rics.org/globalassets/rics-website/media/knowledge/research/market-surveys/construction-monitor/rics-global-construction-monitor-q3-2020.pdf.

10 Institut du Développement et des Relations Internationales (IDDRI), "Key indicators for tracking 2030 strategies towards decarbonisation in the EU: Which indicators, why and what process for using them?" *Working Papers*, no. 8 (Paris: 2016), https://www.iddri.org/sites/default/files/import/publications/wp0816_os_indicators-eu.pdf.

11 Based on IEA, op. cit. note 6; European Commission Joint Research Centre (EU JRC), EDGAR v5.0 Global Greenhouse Gas Emissions, https://data.jrc.ec.europa.eu/collection/edgar, viewed December 2020; M. Crippa et al., *Fossil CO_2 and GHG Emissions of All World Countries – 2019 Report* (Luxembourg: Publications Office of the European Union, 2019), https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/fossil-co2-and-ghg-emissions-all-world-countries-0.

12 IEA, op. cit. note 6; EU JRC, op. cit. note 11; World Bank, "GDP, PPP (current international $)", World Development Indicators, https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD, viewed 20 November 2020.

13 EU JRC, op. cit. note 11; World Bank, op. cit. note 12.

14 IEA, op. cit. note 4. **Figure 57** from the following sources: IEA, op. cit. note 6; EU JRC, op. cit. note 11; World Bank, op. cit. note 12.

15 IEA op. cit. note 4.

16 Based on IEA, op. cit. note 6.

17 Ibid.

18 EU JRC, op. cit. note 11.

19 Ibid.

20 Based on IEA, op. cit. note 6.

21 **Figure 58** based on IEA, op. cit. note 6; IEA, *Energy Transitions Indicators* (Paris: December 2019), https://www.iea.org/reports/energy-transitions-indicators.

22 Ibid., both references.

23 Ibid.

24 Ibid.

25 IDDRI, op. cit. note 10; IEA, *World Energy Statistics and Balances, 2020 edition* (Paris: 2020); EU JRC, op. cit. note 11. **Sidebar 8** based on the following sources: World Bank Group, *Regulatory Indicators for Sustainable Energy: Sustaining the Momentum* (Washington, DC: 2020), https://rise.esmap.org/data/files/reports/2020-full-report/RiseReport-010421.pdf; African Development Bank and World Bank, "Benchmarking the quality of electricity regulation", 2020, https://africa-energy-portal.org/reports/electricity-regulatory-index-2020; V. Foster and A. Rana, *Rethinking Power Sector Reform in the Developing World* (World Bank: Washington, DC: 2020); International Carbon Action Partnership, "China National ETS", https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems%5B%5D=55, updated 12 April 2021. **Figure 59** from World Bank Group, op. cit. this note.

26 Based on IEA, op. cit. note 6.

27 Ibid.

28 IEA, *Tracking Buildings 2020* (Paris: 2020), https://www.iea.org/reports/tracking-buildings-2020.

29 Ibid.

30 Ibid.

31 IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Abu Dhabi and Paris: 2020), https://www.ren21.net/wp-content/uploads/2019/05/IRENA_IEA_REN21-Policies_HC_2020_Full_Report.pdf; J. Gerdes, "So, what exactly is building electrification?" Greentech Media, 5 June 2020, https://www.greentechmedia.com/articles/read/so-what-exactly-is-building-electrification.

32 Ibid.

33 Energy Saver, "Heat pump systems", https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems, viewed December 2020.

34 IEA, op. cit. note 28; IEA, *The Critical Role of Buildings* (Paris: 2019), https://www.iea.org/reports/the-critical-role-of-buildings.

35 IEA, "Buildings", https://www.iea.org/topics/buildings, viewed December 2020; REN21, *Renewables Global Status Report 2019* (Paris: 2019), https://www.ren21.net/gsr-2019; IEA, op. cit. note 28; IEA, *The Critical Role of Buildings*, op. cit. note 34; IEA, op. cit. note 6; Global Alliance for Buildings and Construction (GlobalABC), *2020 Global Status Report for Buildings and Construction: Towards a Zero-emissions, Efficient and Resilient Buildings and Construction Sector* (Nairobi: UNEP, 2020), https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf.

36 IEA, *World Energy Outlook 2019* (Paris: 2019), https://www.iea.org/reports/world-energy-outlook-2019/electricity.

37 Based on IEA, Energy Efficiency Indicators database (2020 edition), extended version (Paris: 2020), https://www.iea.org/reports/energy-efficiency-indicators.

38 Programme for Energy Efficiency in Buildings, *Smart and Efficient: Digital Solutions to Save Energy in Buildings* (Paris: 2019), https://www.peeb.build//imglib/downloads/PEEB_DigitalSolutions_web.pdf.

39 GlobalABC, op. cit. note 35; Deepki, "Real estate", https://www.deepki.com/en/secteurs/real-estate, viewed November 2020; Energisme, https://energisme.com/en, viewed November 2020.

40 GlobalABC, op. cit. note 35.

41 Considering several commercial building types, including offices, retail, hotels and hospitals, the American Council for an Energy-Efficient Economy concluded that smart technologies can reduce a building's energy use nearly 20%, from Ingram Micro Inc., "IOT Power Innovations for Smart Buildings" (Irvine, CA: 2019), https://img.en25.com/Web/PentoniNET/%7Bc90d9525-354b-4906-ba74-1cdd293183c5%7D_A2020706-Ingram_Micro_IoT_Primer_-_IoT_Powers_Innovations_for_Smart_Buildings.pdf.

42 CBRE, "Smart homes", https://www.cbre.co.jp/es-es/united%20kingdom/research-and-reports/our-cities/smart-homes, viewed January 2021.

43 Buildings Performance Institute Europe (BPIE), *A Guidebook to European Building Policy: Key Legislation and Initiatives* (Brussels: 2020), https://www.bpie.eu/publication/a-guidebook-to-european-building-policy-key-legislation-and-initiatives.

44 EU Building Stock Observatory, "Fact sheet: Nearly zero-energy buildings", https://ec.europa.eu/energy/eu-buildings-factsheets_en, viewed 9 December 2020.

45 Ibid.

46 Team Zero, *Zero Energy Residential Buildings Study* (2020), https://drive.google.com/file/d/1TC2NAUr1slFkVi_PZF6QKOw2KKNplTAD/view.

47 Energy Efficiency chapter in REN21, op. cit. note 3.

48 B. Lebot, Senior Policy Advisor, Ministère de la Transition Ecologique et Solidaire, Paris, personal communication with REN21, 16 November 2020.

49 BPIE, op. cit. note 43.

50 Based on IEA, op. cit. note 37.

51 Ibid.

52 BPIE, op. cit. note 43.

53 Energiesprong, "About", https://energiesprong.org/about, viewed 9 December 2020; "Efforts to make buildings greener are not working", *The Economist*, 3 January 2019, https://amp.economist.com/international/2019/01/05/efforts-to-make-buildings-greener-are-not-working.

54 Ibid., both references.

55 Based on IEA, op. cit. note 6; EU JRC, op. cit. note 11.

56 EU JRC, op. cit. note 11.

57 **Figure 60** based on IEA, op. cit. note 6, and on Fischedick et al., op. cit. note 6.

58 O. Roelofsen et al., "Plugging in: What electrification can do for industry", McKinsey, 28 May 2020, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry.

59 Ibid.

60 S. Porter et al., "Electrification in industrials: Transitioning to a lower-carbon future through electrification of industrial processes, spaces, and fleets", Deloitte, 12 August 2020, https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/electrification-in-industrials.html; Roelofsen et al., op. cit. note 58; D. Schüwer and C. Schneider, "Electrification of industrial process heat: Long-term applications, potentials and impacts", *ECEEE Industrial Summer Study Proceedings*, 2018, https://www.eceee.org/library/conference_proceedings/eceee_Industrial_Summer_Study/2018/4-technology-products-and-system-optimisation/electrification-of-industrial-process-heat-long-term-applications-potentials-and-impacts/2018/4-051-18_Schuewer.pdf.

61 US Department of Energy, Office of Energy Efficiency and Renewable Energy, *Industrial Heat Pumps for Steam and Fuel Savings* (Washington, DC: 2014), https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf.

62 Ibid.

63 J. Ling-Chin et al., "State-of-the-art technologies on low-grade heat recovery and utilization in industry", in Ibrahim H. Al-Bahadly, ed., *Energy Conversion: Current Technologies and Future Trends* (IntechOpen, 2019), https://www.intechopen.com/books/energy-conversion-current-technologies-and-future-trends/state-of-the-art-technologies-on-low-grade-heat-recovery-and-utilization-in-industry.

64 European Heat Pump Association, "Large heat pump booklet: 4 new stories strengthen the argument that heat pumps are fit for purpose for the industry", 4 December 2019, https://www.ehpa.org/about/news/article/large-heat-pump-booklet-4-new-stories-strengthen-the-argument-that-heat-pumps-are-fit-for-purpose-f.

65 IEA Solar Heating and Cooling Programme (SHC), *Solar Heat Integrations in Industrial Processes*, Technology Position Paper (Paris: 2020), https://task49.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Technology-Position-Paper--Solar-Heat-Integrations-Industrial-Processes--May2020.pdf; United Nations Industrial Development Organization (UNIDO), "Efficiency Solutions for Industrial Heat: Energy Efficiency Solutions Series", brochure (Geneva: 2020), https://www.industrialenergyaccelerator.org/wp-content/uploads/Corrected-SSO_brochure_3-DIC.pdf.

66 IEA SHC, *Solar Heat Worldwide, Edition 2020* (Paris: 2020), https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2020.pdf.

67 i-SCOOP, "Industry 4.0", https://www.i-scoop.eu/industry-4-0/energy-efficiency-industry-4-0, viewed December 2020.

68 UNIDO, "Energy Management System (EnMS): Energy Efficiency Solutions Series", brochure (Geneva: 2020), https://www.industrialenergyaccelerator.org/wp-content/uploads/EnMS_brochure-1.pdf.

69 Ibid.; R. Ghoneim, "Opinion: Industrial energy efficiency is the invisible climate solution", Devex, 25 September 2019, https://www.devex.com/news/opinion-industrial-energy-efficiency-is-the-invisible-climate-solution-95681.

70 Based on IEA, op. cit. note 6.

71 Based on Ibid.

72 Based on Ibid.; EU JRC, op. cit. note 11.

73 EU JRC, op. cit. note 11.

74 IEA, *Energy Efficiency 2018: Analysis and Outlook to 2040* (Paris: 2018), https://www.iea.org/efficiency2018.

75 L. Cozzi and A. Petropoulos, "Carbon emissions fell across all sectors in 2020 except for one – SUVs", IEA, 15 January 2021, https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs.

76 Ibid.

77 **Figure 61** based on IEA, op. cit. note 37, for a selection of countries. Calculation includes an extrapolation based on historical compound annual average growth rates of carbon intensity and/or kilometres travelled in 2018 for Austria, Belgium, Canada, the Czech Republic, Denmark, Greece, the Netherlands, the Slovak Republic and Spain.

78 International Council on Clean Transportation, *2017 Global Update Light-Duty Vehicle Greenhouse Gas and Fuel Economy Standards* (Washington, DC: 2017), https://theicct.org/publications/2017-global-update-LDV-GHG-FE-standards.

79 Ibid.

80 Ibid.

81 IEA, *Fuel Consumption of Cars and Vans* (Paris: 2020), https://www.iea.org/reports/fuel-consumption-of-cars-and-vans.

82 UNEP, *Used Vehicles and the Environment Global Overview of Used Light Vehicles – Flow, Scale and Regulation* (Nairobi: 2020), https://wedocs.unep.org/bitstream/handle/20.500.11822/34298/KFUVE.pdf.

83 Ibid. Note that while bans prevent polluting used vehicles from circulating in importing countries, they can also reduce access to affordable advanced vehicles, especially where new vehicles are imported or produced under weak vehicle standards and policy regulations. Many countries block the import of used vehicles not (only) for environment and safety reasons, but also to protect their own manufacturing industry.

84 Ibid.

85 Ibid.

86 US Department of Energy, "All-electric vehicles", https://www.fueleconomy.gov/feg/evtech.shtml, viewed February 2021.

87 European Commission, "Powering a climate-neutral economy: An EU Strategy for Energy System Integration" (Brussels: 8 July 2020), p. 5, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF.

88 European Environment Agency, "Range of life-cycle CO_2 emissions for different vehicle and fuel types", 2017, https://www.eea.europa.

eu/signals/signals-2017/infographics/range-of-life-cycle-co2/view; Transport and Environment, *How Clean Are Electric Cars?* (Brussels: 2020), https://www.transportenvironment.org/sites/te/files/T%26E%E2%80%99s%20EV%20life%20cycle%20analysis%20LCA.pdf.

89 SLOCAT, "E-mobility trends and targets", https://slocat.net/e-mobility, viewed November 2020; IEA, *Global EV Outlook 2020* (Paris: 2020), https://www.iea.org/reports/global-ev-outlook-2020.

90 Based on IEA, op. cit. note 6.

91 Organisation for Economic Co-operation and Development (OECD), Working Party on Integrating Environmental and Economic Policies, *Exploring the Impact of Shared Mobility Services on* CO_2 (Paris: 2020), http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPIEEP(2020)6/FINAL&docLanguage=En.

92 J. Johnson, "Are shared e-scooters good for the planet? Only if they replace car trips", Greenbiz, 6 August 2019, https://www.greenbiz.com/article/are-shared-e-scooters-good-planet-only-if-they-replace-car-trips; F. Van den steen, "Do scooters replace cars?" Fleet Europe, September 2019, https://www.fleeteurope.com/en/last-mile/europe/features/do-scooters-replace-cars.

93 IEA, *Energy Efficiency 2020, Urban Transport* (Paris: 2020), https://www.iea.org/reports/energy-efficiency-2020/urban-transport#abstract.

94 IEA, op. cit. note 9; D. Crow and A. Millot, "Working from home can save energy and reduce emissions. But how much?" IEA, 12 June 2020, https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much.

FEATURE: BUSINESS DEMAND FOR RENEWABLES

1 BloombergNEF, "Corporate clean energy buying grew 18% in 2020, despite mountain of adversity", 26 January 2021, https://about.bnef.com/blog/corporate-clean-energy-buying-grew-18-in-2020-despite-mountain-of-adversity.

2 Ibid.

3 See "Corporate sourcing of renewable energy" chapter in Renewable Energy Network for the 21st Century (REN21), *Renewables 2018 Global Status Report* (Paris: 2018), https://www.ren21.net/gsr-2018.

4 H. Kopnina and J. Blewitt, *Sustainable Business* (London: Routledge, 2018); P. McAteer, *Sustainability Is the New Advantage: Leadership, Change, and the Future of Business* (London: Anthem Press, 2019); S. Ponte, Business, *Power and Sustainability in a World of Global Value Chains* (London: Zed Books, 2019).

5 M. Coppola et al., "Feeling the heat? Companies are under pressure on climate change and need to do more", Deloitte, 12 December 2019, https://www2.deloitte.com/us/en/insights/topics/strategy/impact-and-opportunities-of-climate-change-on-business.html.

6 Global Reporting Initiative, "GRI Standards", https://www.globalreporting.org/how-to-use-the-gri-standards/gri-standards-english-language, viewed 15 May 2021; CDP, "How 100% renewable electricity is fast becoming the new normal", 21 January 2018, https://www.cdp.net/en/articles/companies/how-100-renewable-electricity-is-fast-becoming-the-new-normal.

7 BloombergNEF, op. cit. note 1; BloombergNEF, *2021 Energy Transition Investment Trends* (London: 2021), https://about.bnef.com/energy-transition-investment, based on WilderHill New Energy Global Innovation Index data for clean energy firms and the NYSE Arca Oil Index for oil company data.

8 International Renewable Energy Agency (IRENA), *Renewable Energy Generation Costs in 2020* (Abu Dhabi: forthcoming 2021).

9 Solar Power Europe, "Global market outlook 2019-2023", 10 May 2019, https://www.solarpowereurope.org/global-market-outlook-2019-2023.

10 BloombergNEF, *BNEF Executive Factbook 2020* (London: 22 April 2020), https://data.bloomberglp.com/promo/sites/12/678001-BNEF_2020-04-22-ExecutiveFactbook.pdf.

11 RE-Source, "Risk mitigation for corporate renewable PPAs", March 2020, https://resource-platform.eu/wp-content/uploads/files/statements/RE-Source%203.pdf.

12 For example, company sustainability reporting frameworks such as the Global Reporting Initiative and CDP are used for this and other purposes. Deloitte, "Clarity in financial reporting", February 2020, https://www2.deloitte.com/content/dam/Deloitte/au/Documents/audit/deloitte-au-audit-clarity-disclosure-climate-related-risks-070220.pdf.

13 Current members from RE100, "RE100 members", https://www.there100.org/re100-members, viewed 6 May 2020; 2019 members from RE100, idem, viewed 20 May 2019.

14 EV100, "EV100 members", https://www.theclimategroup.org/ev100-members, viewed 20 March 2021.

15 Many companies also have made commitments to support wider international and global efforts on climate action, such as the Paris Pledge (COP21 Paris Agreement), the United Nations (UN) Global Compact and the UN Sustainable Development Goals (especially SDG 7 on clean energy, SDG 12 on responsible consumption and production, and SDG 13 on climate action)). **Box 9** from the following sources: Renewable Energy Buyers Alliance, "Our vision", https://rebuyers.org/about/vision, viewed 28 April 2021; RE-Source, "About us", https://resource-platform.eu/about-us, viewed 28 April 2021; Renewable Thermal Collaborative, "About us", https://www.renewablethermal.org/about-us, viewed 28 April 2021; Renewable Thermal Collaborative, "Our strategy", https://www.renewablethermal.org/our-strategy, viewed 6 May 2021; We Mean Business, "What we do", https://www.wemeanbusinesscoalition.org/about, viewed 28 April 2021; Mission Possible Partnership, "Action areas", https://missionpossiblepartnership.org/action-areas, viewed 6 May 2021; The Climate Group, "Energy", https://www.theclimategroup.org/energy, viewed 6 May 2021; The Climate Group, "Transport", https://www.theclimategroup.org/transport, viewed 6 May 2021; The Climate Group, "Industry", https://www.theclimategroup.org/industry, viewed 6 May 2021; Renewable Energy Institute, "Joint Initiatives", https://www.renewable-ei.org/en/joint_initiatives, viewed 6 May 2021.

16 See World Business Council for Sustainable Development (WBCSD), "Guidelines for an integrated energy strategy: Electricity", https://wbcsdpublications.org/electricity, viewed 10 May 2021.

17 M. Bandyk, "Green tariffs drive big increases in corporate renewable procurement", Utility Dive, 13 March 2020, https://www.utilitydive.com/news/green-tariffs-drive-big-increases-in-corporate-renewable-procurement/574060; US Environmental Protection Agency (EPA), "Utility green tariffs", https://www.epa.gov/greenpower/utility-green-tariffs, viewed 15 May 2021.

18 US EPA, "Unbundled Renewable Energy Certificates (RECs)", https://www.epa.gov/greenpower/unbundled-renewable-energy-certificates-recs, viewed 15 May 2021.

19 Certificates are convenient to obtain, but there is a significant degree of distance between the buyer and the renewable energy provider. EACs are often an initial procurement choice for companies, but firms can switch to more direct sourcing methods as they become more accessible and attractive. Renewable Energy Buyers Alliance, "Renewable energy procurement", https://rebuyers.org/programs/education-engagement/renewable-energy-procurement, viewed 10 May 2021.

20 BloombergNEF, op. cit., note 1.

21 Ibid.

22 Ibid.

23 Ibid.

24 J. Bebon, "Corporate renewables purchases hit record 23.7 GW in 2020", pv magazine, 27 January 2021, https://www.pv-magazine.com/2021/01/27/corporate-renewables-purchases-hit-record-23-7-gw-in-2020.

25 **Figure 62** from BloombergNEF, op. cit. note 1; Bebon, op. cit. note 24.

26 DNV-GL, "2020's hot topics in renewable energy procurement", www.dnvgl.com/article/2020-s-hot-topics-in-renewable-energy-procurement-171046, viewed 10 May 2021.

27 Ibid.

28 M. Pariser, "The next step for corporate sustainability: 24/7/365 carbon-free energy matching", Greentech Media, 3 September 2020, https://www.greentechmedia.com/articles/read/transforming-corporate-sustainability-with-24-7-365-carbon-free-energy-matching; S. Lacey, "24/7 renewables: The emerging art of matching renewables with demand", Greentech Media, 5 February 2020, https://www.greentechmedia.com/articles/read/24-7-renewables-the-emerging-art-of-matching-renewables-with-demand.

29 LO3 Energy, "The quest for 24/7 renewable energy", 27 March 2020, https://lo3energy.com/the-quest-for-24-7-renewable-energy.

30 Vattenfall, "Vattenfall to deliver renewable energy 24.7 to Microsoft's Swedish datacenters", press release (Stockholm: 24 November 2020), https://group.vattenfall.com/press-and-media/pressreleases/2020/vattenfall-to-deliver-renewable-energy-247-to-microsofts-swedish-datacenters; Statkraft, "Statkraft receives Daimler Supplier Award 2020 in the category Sustainability", 12 February 2020,www.statkraft.com/newsroom/news-and-stories/archive/2020/daimler-sustainability-award.

31 International Energy Agency (IEA), *Tracking Report on Data Centres and Data Transmission Networks* (Paris: June 2020), https://www.iea.org/reports/data-centres-and-data-transmission-networks.

32 A. Winston, G. Favaloro and T. Healy, "Energy strategy for the C-Suite", *Harvard Business Review*, January-February 2017, https://hbr.org/2017/01/energy-strategy-for-the-c-suite.

33 A. Jasi, "Suppliers commit to achieving 100% renewable Apple production", The Chemical Engineer, 12 August 2020, www.thechemicalengineer.com/news/suppliers-commit-to-achieving-100-renewable-apple-production.

34 Walmart, "Walmart and Schneider Electric announce groundbreaking collaboration to help suppliers access renewable energy", press release (Bentonville, AR: 10 September 2020), https://corporate.walmart.com/newsroom/2020/09/10/walmart-and-schneider-electric-announce-groundbreaking-collaboration-to-help-suppliers-access-renewable-energy.

35 WBCSD, op. cit. note 16.

36 WBCSD, *Cross-Border Renewable PPAs in Europe: An Overview for Corporate Buyers* (Geneva: December 2020), https://www.wbcsd.org/contentwbc/download/10878/160801/1.

37 Ibid.

38 S. Enkhardt, "Rollercoaster for the European PPA market in 2020", pv magazine, 21 January 2021, https://www.pv-magazine.com/2021/01/21/rollercoaster-for-the-european-ppa-market-in-2020; Pexapark, "2021 European PPA market outlook", https://pexapark.com/blog/european-ppa-market, viewed 10 May 2021.

39 RE100, "Growing renewable power: Companies seizing leadership opportunities: RE100 progress and insights annual report 2020", December 2020, https://www.there100.org/growing-renewable-power-companies-seizing-leadership-opportunities.

40 Ibid.

41 RE100 members include high-profile firms such as Apple, Bank of America, BMW, eBay, GlaxoSmithKline, HP, Ikea, Kellogg, Lego, Mars Group, Nike, Panasonic, Sony, Starbucks, Tata Motors, Tetra Pak, Unilever, Walmart and Zurich Insurance. See RE100, op. cit. note 13, viewed 10 May 2021.

42 **Box 10** from the following sources: Amazon, "Amazon around the globe", https://sustainability.aboutamazon.com/about/around-the-globe, viewed 10 May 2021; J. Parnell,"Amazon adds 3.4GW of renewables, overtakes Google as top corporate clean power buyer", Greentech Media, 10 December 2020, https://www.greentechmedia.com/articles/read/amazon-adds-3.4-gw-of-renewable-power-capacity-knocks-google-of-cppa-perch; Day One Team, "Amazon announces its largest single renewable energy project yet", Amazon, 8 February 2021, https://blog.aboutamazon.eu/sustainability/amazon-announces-its-largest-single-renewable-energy-project-yet; The Climate Pledge, www.theclimatepledge.com, viewed 10 May 2021.

43 "Denmark's Orsted, Taiwan's TSMC sign world's largest renewable corporate power deal", *Reuters*, 8 July 2020, https://www.reuters.com/article/us-renewables-offshore-orsted-tsmc-idUSKBN24910Q

44 BloombergNEF, op. cit. note 1.

45 S. Golden, "Q4 2020: Amazon, AT&T, McDonald's and Starbucks lead the way as clean energy procurement matures", GreenBiz, 14 January 2021, https://www.greenbiz.com/article/q4-2020-amazon-att-mcdonalds-and-starbucks-lead-way-clean-energy-procurement-matures.

46 BloombergNEF, "Corporate PPA Deal Tracker", March 2020, www.bnef.com/core/insights/22615.

47 IEA, op. cit. note 31.

48 K-E. Stromsta, "Microsoft eyes new tool in decarbonization quest: Green hydrogen", Greentech Media, 27 July 2020, www.greentechmedia.com/articles/read/microsoft-eyes-new-tool-in-its-decarbonization-quest-green-hydrogen.

49 IEA, *Tracking Report on Industry 2020* (Paris: June 2020), www.iea.org/reports/tracking-industry-2020.

50 IEA, *World Energy Balances 2020* (Paris: 2020), https://www.iea.org/reports/world-energy-balances-overview; J. Friedmann, Z. Fan and K. Tang, *Low-carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today* (New York: Columbia Center on Global Energy Policy, October 2019), https://energypolicy.columbia.edu/sites/default/files/file-uploads/LowCarbonHeat-CGEP_Report_100219-2_0.pdf.

51 IRENA, IEA and REN21, *Renewable Energy Policies in a Time of Transition: Heating and Cooling* (Paris: 2020), https://www.ren21.net/heating-and-cooling-2020.

52 Ibid.; IRENA, *Reaching Zero with Renewables: Eliminating CO_2 Emissions from Industry and Transport in Line with the 1.5°C Climate Goal* (Abu Dhabi: 2020), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Sep/IRENA_Reaching_zero_2020.pdf.

53 IEA, op. cit. note 49.

54 Ibid.

55 Efficiency and use of carbon capture, utilisation and storage have been cited as more immediately feasible strategies for at least partial decarbonisation. However, full decarbonisation would be out of reach if companies continue to rely on fossil fuels. Ibid.; A. Hasangeigi et al., *Electrifying US Industry: A Technology- and Process-Based Approach to Decarbonization* (Arlington: Renewable Thermal Collaborative, January 2021), https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/6018bf7254023d49ce67648d/1612234656572/Electrifying+U.S.+Industry+2.1.21.pdf; BloombergNEF, *2020 Executive Yearbook* (London: April 2020), https://data.bloomberglp.com/promo/sites/12/678001-BNEF_2020-04-22-ExecutiveFactbook.pdf.

56 A. Aston, "This carbon challenge is bigger than cars, aviation and shipping combined", GreenBiz, 13 August 2020, www.greenbiz.com/article/carbon-challenge-bigger-cars-aviation-and-shipping-combined; IEA, op. cit. note 49.

57 See Box 1 in "Global overview" chapter of REN21, *Renewables 2019 Global Status Report* (Paris: 2019), https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.

58 IRENA, *Companies in Transition Towards 100% Renewable Energy: Focus on Heating and Cooling* (Abu Dhabi: 2021), pp. 27-30, 34-36, https://coalition.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_Coalition_Companies_in_Transition_towards_100_2021.pdf. **Box 11** from idem and from Elpitiya, "Environment", https://www.elpitiya.com/environment, viewed 25 March 2021.

59 IRENA, op. cit. note 58, p. 15.

60 Ibid., pp. 24-26.

61 Ibid.

62 European Committee for Electrotechnical Standardization (CENELEC), *Standards in Support of the European Green Deal Commitments* (Brussels: 2020), p. 6, https://www.cencenelec.eu/news/policy_opinions/PolicyOpinions/CEN-CENELEC%20Green%20Deal%20Position%20Paper.pdf; see also IRENA, op. cit. note 58.

63 Buyers included L'Oréal USA and the University of California System working with the Renewable Thermal Collaborative (RTC) and the Centre for Resource Solutions. Aston, op. cit. note 56.

64 Ibid.

65 N. Kareta, ed., "BMW Group sources aluminum produced using solar energy", Spotlight Metal, 2 February 2021, https://www.spotlightmetal.com/bmw-group-sources-aluminum-produced-using-solar-energy-a-996983; Hydro, "Hydro to explore hydrogen opportunities", 7 April 2021, https://www.globenewswire.com/en/news-release/2021/04/07/2205516/0/en/Norsk-Hydro-Hydro-to-explore-hydrogen-opportunities.html; Hydro, "Would you like to shape the next phase of green industrial development?" http://www.hydro.com/en-FR/careers/experienced-professionals/join-our-new-green-growth-journey, viewed 14 May 2021.

66 A. Frangoul, "German steel powerhouse turns to 'green' hydrogen produced using huge wind turbines", CNBC, 12 March 2021, https://www.cnbc.com/2021/03/12/german-steel-firm-uses-green-hydrogen-produced-with-wind-turbines.html.

67 T. K. Blank, "A new Swedish iron processing project could disrupt the global steel industry", GreenBiz, 17 December 2020, https://www.greenbiz.com/article/new-swedish-iron-processing-project-could-disrupt-global-steel-industry; T. M. Blank, "Green steel: A multi-billion dollar opportunity", RMI, 29 September 2020, https://rmi.org/green-steel-a-multi-billion-dollar-opportunity.

68 Ibid., both references.

69 L. Blain, "World's largest hydrogen 'green steel' plant to open in Sweden by 2024", New Atlas, 26 February 2021, https://newatlas.com/energy/h2gs-green-hydrogen-steel; Greenfact, "Gigascale green hydrogen plant planned for northern Sweden", 24 February 2021, https://www.greenfact.com/News/1399/Gigascale-green-hydrogen-plant-planned-for-northern-Sweden.

70 This was to be achieved over six priority areas of engagement: 1) accelerate cost-effective renewable thermal technologies; 2) create market approaches and instruments; 3) increase market transparency; 4) standardise renewable thermal energy products; 5) create innovative financing and project structures; 6) expand collaboration among market stakeholders. Renewable Thermal Collaborative, "Renewable Thermal Energy Buyers' Statement", www.renewablethermal.org/buyers-statement, viewed 24 March 2021.

71 Ibid.

72 The Climate Group, "Building demand for net zero steel", https://www.theclimategroup.org/steelzero, viewed 15 May 2021.

73 Ibid.

74 Ibid.

75 The Climate Group, "New SteelZero initiative receives backing from major businesses, ramping up demand for clean steelmaking", press release (London: 1 December 2020), https://www.theclimategroup.org/our-work/press/new-steelzero-initiative-receives-backing-major-businesses-ramping-demand-clean.

76 Eurelectric, "Accelerating fleet electrification", February 2021, https://evision.eurelectric.org.

77 See Transport section in Global Overview chapter. IEA, *Tracking Report on Electric Vehicles* (Paris: August 2020), www.iea.org/fuels-and-technologies/electric-vehicles.

78 Eurelectric, op. cit. note 76.

79 Ibid.

80 J. Lund, "2021 is the year for electric trucks", GreenBiz, 19 January 2021, https://www.greenbiz.com/article/2021-year-electric-trucks.

81 See Road Transport section in this chapter for examples.

82 Eurelectric, op. cit. note 76.

83 For example, in the EU, by 2030, cars must reduce CO_2 emissions by 37.5% compared with 2021, and vans 31% less. For every gram by which a vehicle exceeds the emissions limits, an EUR 95 fine applies. In many countries, emission regulations generally are becoming increasingly stringent. See REN21, *Renewables in Cities 2021 Global Status Report* (Paris: 2021), https://www.ren21.net/wp-content/uploads/2019/05/REC_2021_full-report_en.pdf.

84 See Road Transport section in this chapter for examples.

85 Firms also tend to replace their vehicle fleets more often than individual owners do, so business demand could play a key role in EV market expansion. Regular company purchases of new EVs could provide a steady supply of relatively new, affordable EVs to the used vehicle market. S. Colle et al., "Accelerating fleet electrification in Europe", EY and Eurelectric, 2021, https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/energy/ey-accelerating-fleet-electrification-in-europe-02022021-final.pdf.

86 BloombergNEF, op. cit. note 7.

87 Ibid. For comparison, investment in this road transport technology was only 0.7% of that for EVs in 2020.

88 Neste, *Annual Report 2020* (Espoo, Finland: 2021), https://www.neste.com/sites/neste.com/files/release_attachments/wkr0006.pdf; Biofuels International, "Neste drives forward with renewable diesel expansion in Finland", 19 May 2020, https://biofuels-news.com/news/neste-drives-forward-with-renewable-diesel-expansion-in-finland; Neste, "Neste MY Renewable Diesel – high-performing low-carbon biofuel", https://www.neste.com/products/all-products/renewable-road-transport/neste-my-renewable-diesel, viewed 7 May 2021.

89 Neste, "Neste and IKEA Finland to reduce the carbon footprint of home deliveries – IKEA is aiming towards emission-free deliveries by 2025", press release (Espoo, Finland: 21 February 2021), https://www.neste.com/releases-and-news/renewable-solutions/neste-and-ikea-finland-reduce-carbon-footprint-home-deliveries-ikea-aiming-towards-emission-free.

90 Neste, "Neste, McDonald's Netherlands and HAVI enter into circular economy collaboration in the Netherlands", press release (Espoo, Finland: 24 June 2020), https://www.neste.com/releases-and-news/circular-economy/neste-mcdonalds-netherlands-and-havi-enter-circular-economy-collaboration-netherlands.

91 Iveco, "Lidl, IVECO, LC3 and Edison introduce the first biomethane-fuelled vehicles in the retailer's Italian fleet", press release (Turin: 23 January 2020), https://www.iveco.com/en-us/press-room/release/Pages/Lidl-IVECO-LC3-and-Edison-introduce-the-first-biomethane-fuelled-vehicles-in-the-retailer-Italian-fleet.aspx.

92 EV100, op. cit. note 14.

93 NextEra Energy, "First Student, First Transit and NextEra Energy Resources agree to jointly pursue electrification of tens of thousands of school and public transportation vehicles across the U.S. and Canada", press release (June Beach, FL: 26 January 2021), https://newsroom.nexteraenergy.com/2021-01-26-First-Student-First-Transit-and-NextEra-Energy-Resources-agree-to-jointly-pursue-electrification-of-tens-of-thousands-of-school-and-public-transportation-vehicles-across-the-U-S-and-Canada.

94 EV100, op. cit. note 14.

95 Transport Decarbonisation Alliance, "Getting zero emission vans and trucks on the road!" http://tda-mobility.org/getting-zero-emission-vans-and-trucks-on-the-road, viewed 10 May 2021.

96 Drive to Zero, https://globaldrivetozero.org, viewed 10 May 2021.

97 G. Revill, *Railway* (London: Reaktion Books, 2012).

98 IEA, *The Future of Rail* (Paris: 2019), https://www.iea.org/futureofrail.

99 Ibid.

100 IEA, *Tracking Report on Rail* (Paris: June 2020), https://www.iea.org/reports/rail.

101 O. Cuenca, "Indian Railways targets net zero emissions by 2030", International Railway Journal, 16 July 2020, https://www.railjournal.com/technology/indian-railways-to-achieve-net-zero-emissions-by-2030; Carbon Intelligence, "Network Rail", https://carbon.ci/case-studies/network-rail-becomes-the-first-railway-organisation-to-set-science-based-targets-aligned-to-1-5-degrees, viewed 10 May 2021.

102 N. Hunt, "All aboard Europe's first biodiesel express", *Reuters*, 7 June 2007,https://www.reuters.com/article/us-biofuels-branson-idUSL0779077820070607; N. Dinesh Nayak, "Train running on bio-diesel flagged off, The Hindu, 4 December 2015, https://www.thehindu.com/news/national/karnataka/train-running-on-biodiesel-flagged-off/article7947215.ece; "Western Railway runs trains on biodiesel across Gujarat", *Times of India*, 6 June 2019, https://timesofindia.indiatimes.com/city/rajkot/wr-runs-trains-on-biodiesel-across-state/articleshow/69668616.cms.

103 FPL, "Florida's energy is on the move", https://www.fpl.com/landing/brightline.html, viewed 15 May 2021; J. Lane, "Florida's new high-speed intercity rail chooses biodiesel", Biofuels Digest, 27 June 2017, https://www.biofuelsdigest.com/bdigest/2017/06/27/floridas-new-high-speed-intercity-rail-chooses-biodiesel.

104 Biofuels International, "18 new biodiesel fuelled trains coming to the Netherlands", 13 July 2017, https://biofuels-news.com/news/18-new-biodiesel-fuelled-trains-coming-to-the-netherlands; Biofuels International, "Dutch are all aboard with cleaner biodiesel trains", 2 July 2020, https://biofuels-news.com/news/dutch-are-all-aboard-with-cleaner-biodiesel-trains.

105 Energy News, "Amp Energy installs 7.8 MW solar plant for Hyderabad Metro Rail", 9 February 2020, *Economic Times*, https://energy.economictimes.indiatimes.com/news/renewable/amp-energy-installs-7-8-mw-solar-plant-for-hyderabad-metro-rail/80749956.

106 Japan for Sustainability, "Japanese Railway Company to build a mega solar power plant in rail yard", 23 March 2013, https://www.japanfs.org/en/news/archives/news_id032818.html; Nikkei Asia, "JR East to boost renewable energy use in railway operations", 5 March 2021, https://asia.nikkei.com/Spotlight/Environment/Climate-Change/JR-East-to-boost-renewable-energy-use-in-railway-operations.

107 P. Gordon, "ENGIE refuels the world's first renewable hydrogen passenger train", Smart Energy International, 27 March 2020, https://www.smart-energy.com/renewable-energy/engie-refuels-the-worlds-first-renewable-hydrogen-passenger-train.

108 Ibid.

109 Ibid.

110 IEA, *Tracking Report on International Shipping* (Paris: June 2020), www.iea.org/reports/international-shipping.

111 IEA, *Energy Technology Perspectives 2020* (Paris: 2020), p. 118, https://www.iea.org/reports/energy-technology-perspectives-2020.

112 J. Jordan, "Interview: The falling cost of biofuel – now a 'commercially and technically viable' alternative to fossil bunkers", Ship and Bunker News, 18 May 2020, https://shipandbunker.com/news/world/939386-interview-the-falling-cost-of-biofuel-now-a-commercially-and-technically-viable-alternative-to-fossil-bunkers.

113 Advanced Biofuels USA, "Jan De Nul's Dredger becomes the first to sail 2,000 hours on 100% sustainable marine biofuel", 19 June 2020, https://advancedbiofuelsusa.info/jan-de-nuls-dredger-becomes-the-first-to-sail-2000-hours-on-100-sustainable-marine-biofuel.

114 Biofuels International, "Höegh Autoliners completes its first carbon neutral voyage", 16 March 2021, https://biofuels-news.com/news/hoegh-autoliners-completes-its-first-carbon-neutral-voyage.

115 GoodFuels, "Marine", https://goodfuels.com/marine, viewed 10 May 2021; Biofuels International, "Tanker prepares to set sail on 100% biofuel", 31 March 2020, https://biofuels-news.com/news/tanker-prepares-to-set-sail-on-100-biofuel.

116 Biofuels International, "EPS works with Goodfuels for marine biofuel bunkering trial", 16 October 2020, https://biofuels-news.com/news/eps-works-with-goodfuels-for-marine-biofuel-bunkering-trial.

117 This formed part of BMW's broader sustainability strategy to reduce carbon emissions by scaling up demand across the company's supply chain relationships. GoodShipping, https://goodshipping.com, viewed 10 May 2021; Biofuels International, "BMW sets sail on new marine biofuels programme", 10 June 2020, https://biofuels-news.com/news/bmw-sets-sail-on-new-marine-biofuels-programme.

118 "Preem signs agreement for renewable maritime fuel", Renewable Energy Magazine, 25 March 2020, https://www.renewableenergymagazine.com/biogas/preem-signs-agreement-for-renewable-maritime-fuel-20210325; "Hurtigruten buys fish-based fuel for its future fleet", The Maritime Executive, 24 May 2019, https://www.maritime-executive.com/article/hurtigruten-buys-fish-based-fuel-for-its-future-fleet; "Finnish firms testing liquefied biogas as shipping fuel", Bioenergy Insight, 12 June 2020, https://www.bioenergy-news.com/news/finnish-firms-testing-liquefied-biogas-as-shipping-fuel.

119 J. Timperley,"The fuel that could transform shipping", 29 November 2020, BBC Future Inc, www.bbc.com/future/article/20201127-how-hydrogen-fuel-could-decarbonise-shipping; J. Saul and N. Chestney, "First wave of ships explore green hydrogen as route to net zero", *Reuters*, 30 October 2020, www.reuters.com/article/uk-shipping-energy-hydrogen-focus-idUKKBN27F19L.

120 S. Morgan, "Norway's green hydrogen ship granted €8m in EU funding", EURACTIV, 27 October 2020, https://www.euractiv.com/section/shipping/news/norways-green-hydrogen-ship-granted-e8m-in-eu-funding.

121 "Offshore vessel to run on ammonia-powered fuel cell", The Maritime Executive, 25 January 2020, https://www.maritime-executive.com/article/offshore-vessel-to-run-on-ammonia-powered-fuel-cell.

122 World Ports Climate Action Program, https://sustainableworldports.org/wpcap, viewed 10 May 2021.

123 The IMO's stricter energy efficiency targets and new fuel and emission standards adopted in 2019 were implemented starting in 2020. Working with the Global Industry Alliance, the organisation set goals to reduce emissions in the ship-port interface. Also in 2020, the International Chamber of Shipping, the global shipping trade association, announced plans to invest USD 5 billion to fund research and development related to alternative fuels. Poseidon Principles, https://www.poseidonprinciples.org, viewed 10 May 2021; International Maritime Organisation, "Reducing greenhouse gas emissions from ships", https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx, viewed 23 April 2021.

124 GreenAir, "Biofuelled Virgin Boeing 747 takes to the skies on pioneering first flight", 24 February 2008, https://www.greenaironline.com/news.php?viewStory=116; European Parliament, *Sustainable Aviation Fuels* (Brussels: 2019), p. 4, https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659361/EPRS_BRI(2020)659361_EN.pdf.

125 IEA, *Tracking Report on Aviation* (Paris: June 2020), https://www.iea.org/reports/aviation; International Civil Aviation Organization (ICAO), "Environment", https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx, viewed 12 March 2021.

126 IEA, op. cit. note 125.

127 Blending typically must be carried out for larger aircraft. The first 100% biofuel flight occurred in 2012. See "Flights that have been fuelled by biofuels: Canada claims world's first 100% biofuel-powered civil jet flight", Airportwatch, 12 October 2012, https://www.airportwatch.org.uk/biofuels/flights-that-have-been-fuelled-by-biofuels.

128 IRENA, *Biofuels for Aviation. Technology Brief* (Abu Dhabi: 2017), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Biofuels_for_Aviation_2017.pdf.

129 J. Makower, "Can Shell help pilot a new era of sustainable aviation?" GreenBiz, 14 December 2020, https://www.greenbiz.com/article/can-shell-help-pilot-new-era-sustainable-aviation.

130 P. Le Feuvre, "Are aviation biofuels ready for take off?" IEA, March 2019, https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off.

131 See, for example: B. Cogley, "World's first commercial electric plane takes off near Vancouver", Dezeen, 17 December 2019, https://www.dezeen.com/2019/12/17/worlds-first-commercial-electric-plane-canada-seaplane; Green Car Congress, "Wright Electric begins motor development program for 186-seat electric aircraft; 1.5MW motor, 3 kV inverter", 31 January 2020, https://www.greencarcongress.com/2020/01/20200131-wright.html.

132 See Aviation Transport section in this chapter.

133 IEA, op. cit. note 125.

134 IEA, op. cit. note 125; C. Cooper, "Sustainable aviation fuel: A journey to greener skies", 1 December 2020, https://www.greenbiz.com/article/sustainable-aviation-fuel-journey-greener-skies; Makower, op. cit. note 129.

135 Ibid., all references.

136 Green Car Congress, op. cit. note 131.

137 World Economic Forum, Clean Skies for Tomorrow Coalition, www.weforum.org/projects/clean-skies-for-tomorrow-coalition, viewed 10 May 2021.

138 Ibid.

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