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XPRESS

Facilitating green
public procurement
in the energy sector

Deliverable 4.1

Deliverable 4.1

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Deliverable 4.1

Construction of a specific framework for the assessment of the whole sustainability of RES technology application in GPP

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XPRESS

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Table of contents

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 857831

Index of tables

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 857831

Index of figures

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 857831

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1. WP4

1.1. Goal

WP4 is labelled "Assessment of environmental, socio-economic impact of RES innovations" and it aims to perform a whole sustainability assessment of renewable energy sources (RES) and the technologies in a life-cycle perspective. WP4 has four main goals that can be summarised as follows:

To create a replicable framework for the sustainability assessment of RES Technologies;

To perform a whole sustainability assessment of RES Technologies by quantifying key environmental and socio-economic performance indicators (KPI). This will allow their comparison on a common ground and a scientific basis, in order to assess their benefits and trade-offs respect to conventional fossil energy systems;

To provide a database with selected sustainability KPI available to small and medium-sized enterprises (SMEs) and Public Authorities (PA) on the XPRESS platform;

New eco-design rules addressed to Public Authorities, in order for them to purchase the best available solutions, and to manufacturers in order for them to improve their devices' environmental, energetic, economic and social performance.

From a general point of view, the adoption of RES technologies is considered to have positive impacts on the society in every sector and in every condition of applications. Unfortunately, this perception may not be true in some situations and under particular conditions; therefore, in a research project that involves many European Countries it is essential to adopt a scientific method that allows to verify the sustainability of the proposed solutions. The "life-cycle perspective" concept indicates the choice to observe and analyse a phenomenon by taking into consideration all the relationships it activates with the context, in a vision as broad as possible. More in detail, we decide not to adopt the common model of investigation which focuses exclusively on the interactions of a product or a service during its operational stage. On the contrary, the life-cycle approach takes into account the upstream processes of production and downstream processes of waste management and end of life (EoL) activities. The XPRESS project adopts the life-cycle

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perspective with the aim to provide a full assessment of the environmental, economic and social sustainability of a number of the RES technologies implemented in different European Countries through Green Public Procurement (GPP) processes.

The XPRESS project choses the life-cycle approach to evaluate the sustainability of technological solutions because of the widespread use of this method, both on the business side for products evaluation and on the government side to consider the implications of the development policies. The Life Cycle Assessment (LCA), based on the life-cycle approach, has a solid methodological basis, is scientifically recognized and is regulated by two ISO standards in the application aspects.

The concept of sustainability is considered in a broad sense through the three common pillars of sustainability, i.e. covering the triple relationship between the environment, the economy and social dynamics. Focusing on global sustainability allows the XPRESS project to support the United Nations Sustainable Development Goals (SDGs), namely regarding goals n. 7 “Affordable and clean energy”, n. 9 “Industry, innovation and infrastructure”, n. 11 “Sustainable cities and communities” and n. 13 “Climate action”.

1.2. Scope

As discussed in the previous section, the aim of WP4 is to measure the sustainability level of some RES Technologies. Even though the adopted method (Life Cycle Assessment) is scientifically based and standardised in its general application, it is necessary to set up some methodological aspects to have a common basis in the analysis and to guarantee that outputs are comparable. In the literature review, a few dozen scientific papers were identified; they present a few hundred studies focused on verifying the sustainability of the renewable energy sources and of the devices for the exploitation of these sources. The disparity in the methodological settings of the studies often does not allow the comparison among the obtained results because they refer to different analysis scenarios (i.e.: object of the study, system boundaries, reference units, impact indicators). To enable such comparison and a consistent assessment of a variety of RES technologies in different countries, the purpose of WP4 is to define a framework for the sustainability assessment of RES Technologies that will also be replicable downstream of the XPRESS project.

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The substitution of conventional energy systems with renewable sources is commonly considered an always positive option but to affirm this with certainty it is necessary to analyse the problem in depth, taking into consideration several aspects. The analysis from the energy point of view does not allow to understand all the environmental implications (i.e.: about the impacts due to the construction of new systems and devices) but, above all, it does not allow to establish the socio-economic effects of a choice that may be replicated at the national level or at the European scale. The transition from the conventional energy sources to the renewable ones, particularly in cases of self-production and self-consumption, generates a clear change in the usage patterns and in the users' consumption habits, with potentially deep economic and social implications. The XPRESS project will apply the life-cycle approach to model the environmental, energetic, economic and social performance of several RES Technology applications. Some undoubted benefits (i.e.: the reduction of greenhouse gas emissions thanks to the removal of the fossil fuels combustion) must be compared and balanced with the resource management in the production and EoL phases of such technologies and with the changes in the use and consumption models.

All the results that will be achieved by the XPRESS project will be shared through an online platform, which will be available both for Public Authorities (PA) and for small and medium-sized enterprises (SME) operating in the renewable energy sector. The whole sustainability level of some products for the exploitation of the renewable energy resources will be evaluated and the outcomes will be inserted in the public database, available on the XPRESS platform, in order to allow PA and common users to know the strengths and weaknesses of the technologies and the devices considered. On the one hand, the PA will be able to know the level of whole sustainability of the products available on the market and make informed GPP choices. On the other hand, SMEs operating in this sector will be able to know the performance guaranteed by competitors and then activate virtuous technological improvement processes, also in cooperation. The database is built with the aim of being supported in the future and continuously expanded , including new products and new technologies. In order to maintain the possibility to compare the sustainability level of the objects in the database, the evaluation framework for the sustainability defined by the XPRESS project shall be continuously applied to new products.

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Lastly, some new eco-design rules will be provided to PA to support them in GPP processes for the acquisition of the best available solutions in the market. Additional eco-design rules will be made available to SMEs, to improve the sustainability profile of their products.

1.3. Descriptive models

Besides the sustainability assessment, WP4 aims also to verify the possibilities of improving the exploitation of renewable sources in the European Countries, starting from the countries that participate in the XPRESS project. For this reason, three descriptive models will be defined to be analysed. They are called: *Energy Usage Model*, *Abatement Model* and *Productive Model*.

1.3.1. Energy Usage Model

The *Energy Usage Model* will describe the characteristics of the energy mix specific for each European Country. The energy mix is defined as the list of resources and technologies adopted to produce the electricity sent to the end users through the national electricity grid. The relative percentage is indicated for each resource and is updated every year to take into account the technological and supply changes that can occur.

1.3.2. Abatement Model

The *Abatement Model* will reflect the energy policy defined by each country and the goals for the substitution of non-renewable resources with the renewable ones. Through this evaluation model, it is possible to understand the potential reductions in the environmental impacts for each Country and to speed up possible improvement in the European context.

1.3.3. Productivity Model

The *Productivity Model* will consider the characteristics of the RES Technologies production sector in each Country that takes part in the XPRESS project. Also, the potential innovations will be considered to quantify the potential reduction in dependence from non-renewable sources and the potential improvements in RES device efficiency. In each Country, the actual availability of RES Technologies will be evaluated together with the perception of new resources from the end users.

The three models just described will aim to clearly present the positive effects of adopting renewable resources in terms of improving the level of environmental, economic and social sustainability. The LCSA method will be used to assess the sustainability of the adopted solutions

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and the results will be communicated through the impact indicators described in chapter 4. The descriptive models (Energy Usage, Abatement, Productivity) will aim to construct some significant comparison scenarios: the variation of the energy mix from actual to future conditions, the effects of the energy policies with the improvement of RES Technologies, the evolution of the production sector to follow the growing demand for devices to produce energy from renewables.

The potential future improvements will be described on the basis of different reference time thresholds that will be: the short term (5 year), the middle term (10 years) and the long term (20 years). They will be considered in the Energy Usage, Abatement and Productivity models to integrate the time variable in the sustainability assessment.

1.4. Structure

The activities that will be conducted in WP4 of XPRESS projects are subdivided in five tasks with specific goals. The structure can be summarised as follow:Task 4.1 – Framework definition: objectives;

- Task 4.2 – Environmental Assessment;
- Task 4.3 – Cost Analysis;
- Task 4.4 – Social Analysis;
- Task 4.5 – Eco-design & Good Practise Examples.

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TASK	LEAD.	CONTRIB.	PERIOD	OBJECTIVE
4.1	eA	ELE	M1-6	Construction of a specific framework for the assessment of the whole sustainability of RES technology application in GPP
4.2	eA	ELE	M6-36	Conduction of LCA – Life Cycle Assessment
4.3	eA	OV, ELE	M18-36	Conduction of LCC – Life Cycle Cost
4.4	eA	CIRCE	M18-36	Conduction of SLCA – Social Life Cycle Assessment
4.5	eA	CIRCE	M24-36	Developing design recommendation for RES construction solutions, according to the sustainability assessment results

Table 1 - Main information of the WP4 Tasks: lead, contributors, period and objective

1.5. List of deliverables

The list of WP4 deliverables is reported in **Table 2**

TASK	DEL.	TITLE
4.1	D4.1	Framework definition and recommendations - Report
4.2	D4.2	Environmental assessment: goal&scope and life cycle inventory
4.2	D4.3	Environmental assessment: life cycle impact assessment and results
4.3	D4.4	Cost analysis: goal&scope and life cycle inventory
4.3	D4.5	Cost analysis: economic assessment and results
4.4	D4.6	Social LCA analysis: goal&scope and dashboard
4.4	D4.7	Social LCA analysis: assessment results
4.5	D4.8	Eco-design Guidelines: general contents
4.5	D4.9	Eco-design Guidelines: detailed guidelines & good practice

Table 2 - List of WP4 deliverables

2. The D4.1 deliverable

2.1. Goal and scope

D4.1 is the first deliverable of WP4 and is entitled "Framework definition and recommendation".

As discussed in the introduction, the overall goal of WP4 in the XPRESS project is to conduct a whole sustainability assessment of RES Technologies to provide information both to the PA that purchase the devices and to the SMEs that produce and deliver them to the market.

In order to take advantage of the results of the evaluations which will constitute the first nucleus of a European public database of its kind and an information exchange platform, it is necessary to encourage the replicability of the conducted assessments. It can only be ensured through the definition of a framework that can be used even after the closure of the XPRESS project and which is based on methodological rules suitable for the technologies under study. This way, it will be possible to compare the assessment results within the project but also in the future. The effective comparison of the results is important in order to push manufacturers to continuous improvement and the PA to look for the best and most functional solutions to their objectives and operating conditions.

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The purpose of the document is to define a common objective for the assessments, to identify the functional unit to which relate the results, the technological, geographical and temporal boundaries of the systems to be analysed, the methods for quantifying the environmental impacts, the stakeholders to be involved in the socio-economic investigations, the indicators for presenting the final outputs. The effectiveness of comparative evaluations also depends on the definition of coordinated rules for conducting environmental, economic and social assessments on a comparable basis.

2.2. Life Cycle Assessment: definition

The Life Cycle Assessment - LCA is defined as a method "to address the environmental aspects and potential environmental impacts (i.e. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)". This definition is commonly accepted and set up by the standards ISO 14040: Environmental management — Life Cycle Assessment — Principles and Framework, 2006 and ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines, 2006.

There are four phases in an LCA study (Figure 1):

1. the goal and scope definition phase,
2. the inventory analysis phase (LCI),
3. the impact assessment phase (LCIA),
4. the interpretation phase.

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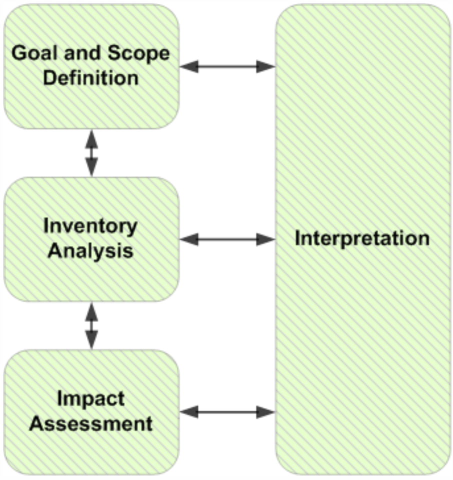

Figure 1 - General phases of a life-cycle assessment, as described by the ISO 14040 and ISO 14044

As set up by the rule, the scope, which includes also the system boundaries and the level of detail, depends on the subject and the intended use of the study. Therefore, the depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA. The life cycle inventory analysis phase (LCI) is an inventory of input/output data with regard to the system under evaluation and it involves the collection of the information necessary to meet the goals defined in the first phase. The life cycle impact assessment phase (LCIA) has the purpose to provide additional information to evaluate the environmental significance of the product, process or service under study. Life cycle interpretation is the final phase of the LCA procedure, in which the results of the LCI and the LCIA are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope defined for the study.

LCA, sometimes also called "life cycle analysis", helps companies and PA in environmental management and in longer term sustainable development, identifying the opportunities to improve the environmental performance of products at various points in their life cycle, informing the decision-makers in industry, government or non-government organizations, allowing the selection of relevant indicators of environmental performance including measurement techniques and improving the communication of the environmental aspects.

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2.3. Life Cycle Costing: definition

Life cycle costing (LCC) has been incorporated to the LCA framework to make LCSA a robust and complete sustainability assessment methodology. However, LCC is rather old, as it has been methodically carried out by companies long before the birth of LCA in order to calculate their costs, evaluate the final price of their products and help them optimize their processes. LCC is thus a systematic method to assess all costs incurred by multiple stakeholders during the whole life of a product or a service. LCC does not replace traditional cost accounting or cost management practices, but it is rather the adaptation of this old economic tool to the ISO 14040:2006 framework. LCC does add the final EoL stage which in traditional costing calculations was not included, as this phase was generally outside the jurisdiction of companies, and thus beyond the financial (and operational) boundaries of companies. Taking into consideration the future costs of the disposal (or recycling) of products, which will be normally covered by the PA, LCC becomes the economic pillar of LCA. This way, it allows to estimate relevant differences between technology alternatives, based on estimated monetary flows or economic improvement potentials within a product's life cycle. It allows practitioners to put in relation the environmental and the economic aspects, taking into account different perspectives (producer, end user, end of life actor, society).

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The EU commission defines the LCC as the means to consider all the costs that will be incurred during the lifetime of products and services by different stakeholders:

1. purchase price and all associated costs (such as delivery, installation, insurance, taxes…);
2. operating costs (such as energy, fuel and water use, waste, maintenance, repair, parts replacement, consumables…);
3. EoL costs (such as decommissioning, transport, disassembly, disposal...) or residual value (such as revenue from sale of recycled materials or components as spare parts…).

All the financial costs are included, together with taxes and tax reliefs. The LCC may also consider the environmental externalities, such as greenhouse gasses emissions, under specific calculation conditions laid out by EU directives. The current EU directives require that where LCC is used, the calculation method and the data to be provided by tenderers are set out in the procurement documents. Specific rules also apply regarding methods for assigning costs to environmental externalities, which aim to ensure that these methods are fair and transparent. LCC makes good sense also regardless of a PA's environmental objectives because they take into account the costs of resource use, maintenance and disposal which are not reflected in the purchase price. Often this will lead to win-win situations whereby a greener product, work or service is also cheaper overall. The main potential for savings costs over the life-cycle of a product, work or service are:

1. supply chain in products production;
2. energy, fuels, water and waste during operation;
3. EoL and disposal.

The capital costs represent the total construction costs of a power plant, including land, planning, construction, commissioning and working capital costs (May and Brennan, 2006). Total annualised costs are related to the annual costs of operating the system while levelized or unit costs are the average costs over the lifetime of a plant/system expressed per unit of product/electricity generated (Rubin et al., 2013). The "Capital Energy Costs" indicator includes the energy requirements to extract and process all raw materials, manufacture and install the capital equipment including any site preparation and grid interconnection. "Operating Energy Costs" includes energy requirements for the maintenance of the system, and "Life-Cycle Energy Costs" indicates the total life-cycle energy requirements for the system.

2.4. Social Life Cycle Assessment: definition

The Social Life Cycle Assessment is a comprehensive (and relatively recent) assessment methodology to quantify the social impacts created along the life cycle of a product, the processes involved and/or a service, which is aligned with the mentioned ISO 14040:2006 and ISO 14044:2006 standards. In 2009, the UNEP, together with SETAC, developed the guideline and methodological framework (UNEP/SETAC, 2009) to support pioneering studies of S-LCA. According to the Social LCA guidelines, different stakeholder groups should be considered and a comprehensive set of indicators and social themes (equivalent to "impact categories" of the environmental impact assessment) shall be selected fit for the purpose of the study. Various barriers will need to be considered and overcome while collecting social data because of the different stakeholder groups involved.

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3. State of the art of LCA on RES Technologies

3.1. Literature review

A literature review was conducted to acquire information about the state of the art in the analysis of the sustainability of RES Technologies. About 100 papers on LCA applications in the sector of renewable energy generation systems were considered to understand methodologies, objects under assessment, technologies, geographical locations, environmental and socio-economic indicators, main results. In **Table 3** there is a list of the most important analyzed papers. The articles were collected from scientific journals and were sourced through scientific research tool; all the geographical area were considered due to the interest in methodological aspects besides the specificity of each installation; the time scenario were limited to the last 10 years and 40% of the articles have been written in the past 5 years, because of the improvements both in technologies and in LCA applications. Where possible, review articles were considered to have an overview of the most important technologies, assessment methodologies and indicators; beyond those, case studies, technology comparisons and methodological papers provide a wide set of information.

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About 40% of the articles focus on the comparison among different renewable energy sources (photovoltaic, solar thermal collector, geothermal, wind turbines, small hydropower) and 30% of them compare the environmental impacts of different photovoltaic (PV) technologies (i.e. mono-crystalline silicon, multi-crystalline silicon, ribbon-silicon, and cadmium telluride). Whereas, 20% of the studies analyse life-cycle environmental impacts of single energy systems different from photovoltaic systems: solar thermal collectors (Brown et al., 2012), wind and hydropower (Arvesen & Hertwich, 2012; Raadal et al., 2011) and geothermal (Basosi et al., 2018).

AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
Varun et al., 2009	Offshore & onshore wind farms	kWh	Net energy analysis	CO2, Net Energy Direct energy; indirect energy.	all phases	Global	20	x		
Petrillo et al., 2016	compressed air energy storage system	kWh	AHP; MCDA; Eco-indicator 99		All phases but EoL; disposal costs only for LCC	Egypt (application site)	20 years			x
Evans et al., 2009	PV, Wind, Hydro, Geo, (Coal), (Gas)	kWh	GWP 100	Price of electricity generation; GHG emissions; Land use requirements; Water consumption; Social impacts.	All phases	Global	-	x	x	
Turconi et al., 2013	Coal, lignite, natural gas, oil, nuclear, biomass, hydropower, PV, wind	MWh	Input-Output Analysis, Process Chain Analysis and hybrid	GHG, NOx, SO2	All phases	Global	-	x		
Arvesen et al., 2012	Small (< 100 kW) Medium (100 -1000 kW) Large (>1MW) on site offshore	kWh	CML 2001; Usetox	Climate change; Cumulative energy demand; Resource requirements, abiotic depletion; Acidification; Ozone depletion; Human toxicity; PM formation; Ecotoxicity; Smog; Eutrophication; Waste generation; Land transformation;	Production of components; transportation, on site construction and O&M; EoL.	Global		x		

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
Varun et al., 2012	Small hydro power schemes: - run of river; - canal based; - dam-toe.	kWhe	Environmental Input-Output + LCA	GHG emissions	All	India (US EIO-LCA)	30	x		
Desideri et al., 2012	polycrystalline silicon photovoltaic modules	kWh	EcoIndicator 99	Energy Pay-Back Time Energy Return on Energy Invested CO_2 avoided emissions and GWP100	all	Europe	25	x		
Li et al., 2019	wind power, small-scale hydropower, photovoltaic, centralized solar; thermal power plant and a biogas power plant	kWh	LCA Cradle-to-Grave with ReCiPe 2016 and Fuzzy Rough sets	CO_2; Human health, ecosystem quality and resources	upstream biogas supply, energy devices construction, corresponding freight and possible retired processing	Yanqing District, Beijing, China	wind: 20; small-scale hydropower: 50; biogas: 30; solar thermal: 30; photovoltaic: 25	x		
Cellura et al., 2019	PV/geothermal power plants/mix (hydropower, wind, geothermal, PV)	1 kWh / 1MWh	GWP 100Y, USeTox, Soil Organic Matter Lost, Accumulated Exceedance, ReCiPE	All from ReCiPe methodology	All	Sicily, Tuscany		x		

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
Cellura et al., 2019	thermal power plants, hydroelectric plants, wind, turbines, photovoltaic	1 kWh	Cumulative Energy Demand method was used to assess primary energy consumption; ILCD 2011 midpoint	GWP, ODP, HT-ce, HT-nce, PM, IR-hh, IR-e, POFP, AP, T-EU, F-EU, M-EU, F-E, LU, WRD, MFRD	All	sicily		x		
Girardi et al., 2019	amorphous silicon (a-Si), copperindium–gallium-selenium thin film (CIS), cadmium telluride thin film (CdTe), single-crystalline silicon (single-Si), multi-crystalline silicon (multi-Si), ribbonsilicon (ribbon-Si)	1 kWh	GWP 100Y, USeTox, Soil Organic Matter Lost, Accumulated Exceedance, ReCiPE	GWP, Ecotox-F, HT-nc, HT-c, Land use, PM, Acidification, Phot-Ozone formation, CED-renewable, CED-non renewable	All but EoL	italy	30	x		
Parisi et al., 2019	Geothermal power plants for electricity production	1 MWh	CML 2001	Indicators from CML methodology	the operational phase of geothermal power plants	tuscany	25	x		
Kouloumpis et al., 2015	Coal with and w/o CCS; GAS with and w/o CCS; Nuclear,	kWh	CML 2001	Indicators from CML methodology	Cradle-to-gate	uk		x		

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
	Biomass, Wind, PV, Hydro, Oil									
Amponsah et al., 2014	Wind (on e off), Hydro, Wave, Geothermal, Photovoltaic, Solar thermal, Biomass, Waste treatment	kWh	Carbon Footprint	GWP100	cradle to grave	UK		x		
Haddad et al., 2017	solar, Wind energy, geothermal, biomass, hydro	n.s.	MCDM	Energy production capacity; Costs & payback period; GHG emissions; Social (qualitative)	N.s.	Algeria				x
García-Gusano et al., 2017	CHP Oil, NGCC, CHP gas, hydro dam, hydro RoR, wind onshore, solar PV, solar thermal, biomass, Solid Oxide Fuel Cell, CHP wood, CHP MSW, Waves	kWh	ILCD 2011 ReCiPe 2008 endpoint; TIMES	Selection of ILCD midpoint categories; Two endpoints from ReCiPe: Human Health and Ecosystems	Cradle-to-grave	Spain		x		
Dolan et al., 2012	Utility-scale Wind power	kWh	GWP	GHG emissions	All	World	average: 20y	x		
Ellabban et al., 2014	Wind, Marine, Solar, Hydro,			Global installed capacity (MW)		World		x		

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
	Geothermal, Bioenergy									
Gerbinet et al., 2014	PV: silicon, thin layers, miscellaneous	kWh	CML, Ecoindicator99, ReCiPe, EPS	EPBT, GHG, NER	Production, installation, use, EoL	Worldwide	20-30y	x		
Dombi et al., 2014	CSP, Hydro, Geothermal, Wind, Biogas plant, PV, Solar thermal, Biomass	kWh	MCA, CE, LCOE	levelised cost of energy; operation costs; New jobs, 'land demand' and 'GHG emission		Worldwide				x
Asdrubali et al., 2014	Solar power, wind, geothermal, hydro, PV	kWh	IPCC, CED method, Ecoindicator99 ;	Acidification (AP), Eutrophication (EP), GWP Smog, Land Use (LU) and Water Consumption (WC). CED and Energy Pay-Back Time (EPBT).	Full life cycle	worldwide	Solar: 30 Wind: 20 Hydro: 70 Geothermal: 30 PV: 30	x		
Wong et al., 2016	PV systems: single crystalline and multi crystalline silicon	kWh		EPBT, GHG	All	worldwid	20-30	x		
Atilgan et al., 2016	Coal, Natural Gas, Hydropower, Wind, Geothermal	1 kWh	CML2001; MCDA	All indicators from CML 2001	'cradle to grave'	Turkey	Coal: 30 Gas: 25 Hydro: 80 Wind: 30			x

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
Hussain et al., 2017	5 emerging RET: marine (wave, tidal), geothermal, solar (CSP), 2nd gen. ethanol	-	review of literature	-		World		x		
Koroneos et al., 2012	Solar Water Heating system	1 MW hot water	LCA; Ecoindicator 95	several environmental (GW, acidification, smog, eutrophication...), energy savings, payback time		Greece		x		
Nugent et al., 2013	PV, wind	kWh	GHG	GHG	Cradle to grave	worldwide	20-30	x		
Paridaa et al., 2011	PV: si-a, si-c, CdTe, CdS, Organic, Hybrid, Thin, others	kWh	GHG; IOA; MCA	GHG emissions; EPBT	Cradle to grave	worldwide		x		
Strantzali et al., 2015	Natural gas, nuclear energy, solar, wind, hydropower, biomass, geothermal energy		LCA, CBA;, MCDA methods & FUZZY set theory.	technical, environmental, economic, social criteria		worldwide				x
Sumper et al., 2011	PV roof top, polycrystalline SI vs monocrystalline and thin-film	kWh	Net energy pay-back and GHG	energy pay-back time and GHG emissions; PM10; SO2; NOx	All but EoL	Spain		x		

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
Zhong et al., 2011	Polycrystalline PV module and Wind turbine	kWh	Eco-indicator 99	All from Eco-indicator 99	all	singapore		x		
Hadiana et al., 2014	Ethanol, Biomass , Solar, Wind, Hydro, Coal, Gas, Nuclear, Oil	kWh, GWh, GJ	Relative Aggregate Footprint (aggregates the ranking results of several MCDA methods)	Carbon Footprint, Water Footprint, Land Footprint, Cost of generation (levelized cost)	ns			x		
Kaldellis et al., 2017	off-shore wind energy	kWh	embodied energy ; CARBON FOOTPRINT; Energy payback time	EPBT; GHG:	All	worldwide		x		
Santoyo-Castelazo et al., 2014	Electricity mix: Biomass, Coal, Coal CCS, Gas, Gas CCS, Geothermal, Heavy fuel oil, Hydro, Nuclear, Ocean, Solar thermal, Solar PV, Wind	MWh/y	CML 2001 method; MCDA	All indicators from CML 2001	‘cradle to grave’	mexico	30 y	x		
Al Garni et al., 2016	/	/	LCC, AHP	Costs	Cradle-to-gate	Saudi Arabia			x	x
Dale, 2013	off-shore & on-shore wind; all PV and CSP	kWh		Life-Cycle Energy Costs (LCEC) - Total life-cycle energy requirements	All	Worldwide	25y		x	
Henriques et al., 2016	Hydro, Wind, Coal, Geothermal,	€/kW	IO Analysis	number of jobs, changes in employment; Gross	1) manufacturing and istallatio 2) Operation and	Portugal	/		x	

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AUTHOR	TECH. DETAILS	FU	METHODS	MIDPOINT INDICATORS	PHASES	AREA	SERVICE LIFE	LCA	LCC	LCSA/ MCDA
	Natural Gas, Biomass, Oil, PV, Biogas			Value Added; installed capacity	Maintenance 3) Fuel Input					
Bigerna et al., 2014			WTP -Survey method	/	/	Italy	/		x	
Liu, 2014				LCC, Return on investment. Payback. Social indicators.						x
Marszal et al., 2012			LCC	Net Savings (NS), Savings-to-Investment Ratio (SIR) and Adjusted Internal Rate of Return (AIRR)	Investment, operation and maintenance (O&M), replacement and demolition.	Denmar k	50 (building)		x	
Karunath ilake et al., 2016			Four energy management scenarios	Costs at household level Costs at community level Multi stakeholder benefit/cost	Costing data for RE systems. Capital O&M Capacity Generation output	Canada	commu nity energy plans (25 yrs)		x	
Fan et al., 2015	Green residential districts	no	AHP, Interviews and Surveys	Social and Humanity demand: see table 1 for the whole list of social indicators	construction phase, maintenance phase		50 y			x
Takeda et al., 2019	Biomass, solar PV and hydro	kWh & unit-cost (US$)	S-LCA; risk-weighted and equal weight for normalization	702 social indicators, aggregated into 24 Social Themes (risk-weighted) and 5 Social Categories	cradle-to-gate, no EoL	Malaysia				x

Table 3 -Methodological checklist of the most important reviewed papers

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3.2. TED data

The Tender Electronic Daily (TED) platform, the online version of the "Supplement to the Official Journal" of the EU dedicated to European Public Procurement, has been adopted to analyse the European tenders performed to procure RES Technologies and devices. The calls for tenders published in the platform have been selected on the basis of filters like the procured object, the year of publication, the enterprise dimensions and the geographic area; finally they have been included in an excel database. Details about the first selection of filters and tenders on TED platform will be defined more in-depth in WP2.

3.2.1. Four-Step method

The strategy to collect the data needed for the conduction of the environmental, economic and social life-cycle assessment, is based on a four-step approach:

1. document check from TED;
2. contacting SMEs and PAs to request additional information;
3. survey address to SMEs and Public Authorities;
4. survey output analysis.

Document check

The goal of this first step is to get a clear vision of the most common Green Public Procurement categories (i.e. photovoltaic panels) for each country and to collect as many technical details as possible, that are deemed more consistent with the framework of our analysis.

In this first step, we start from the list of tenders provided by the WP2 partners and chose at least 10 tenders for each country partner (Italy, United Kingdom, Germany, Norway, Sweden, Portugal, Denmark, Slovakia and Belgium).

The first data collection is about the information provided by the TED platform through the summary page of each tender, indicated by "ted_notice_url" in reviewed database from WP2 partners. These are some of the available data on the platform:

- Contracting entity: Name and addresses;
- Object: Title and Short Description of the tender;
- Procedure: Form of procedure;

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- Award of concession: Date of concession award decision, Name and address of the concessionaire and Information on value of the concession and main financing terms.

For each of the selected tenders, an in-depth analysis was performed to find more details about the procurement procedures: in **Section I: Contracting authority,** was find the main address or on the address of the buyer profile, to visit the web-page "Transparent Administration" or "Calls for tenders and contracts". In these sections, the specific procurement procedure was searched, using a part of the title as a keyword, or scroll the list of procurement procedures to the year of the contract award notice (column "year").

The most useful attachments to the procurement documents to be analysed, are:

- tender disciplinary;
- technical specification;
- project documents.

Subsequently, a deeper check of the available documents was performed with the aim to gather the technical details that will be useful to build the Life Cycle Inventory for the sustainability assessment. The key parameters to be collected: **specific technology, producer, specific technical data of the product/system/service, energy efficiency, Operation & Maintenance, Reference Service Life**.

In some cases the tender documents are not available, so it is not possible to find any information (e.g. id tenders 2016338561[1], 2018574586[2] and 2016242374[3]).

In some other cases the tender documents are available in the contracting entities websites, but the technical details are incomplete (e.g. id tenders 201713293[4] and 2017143210[5]).

Table 4 shows four examples of outputs produced by the technical document checks performed:

[1][ted.europa.eu/udl?uri=TED:NOTICE:338561-2016:TEXT:EN:HTML];
[2][ted.europa.eu/udl?uri=TED:NOTICE:574586-2018:TEXT:EN:HTML];
[3][ted.europa.eu/udl?uri=TED:NOTICE:242374-2016:TEXT:EN:HTML];
[4][ted.europa.eu/udl?uri=TED:NOTICE:13293-2017:TEXT:EN:HTML];
[5][ted.europa.eu/udl?uri=TED:NOTICE:143210-2017:TEXT:EN:HTML]

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	Data needed					TED Info		
Technology	Energy efficiency	Service Life	O&M	Producer	Specific Technology	TED Reference	General Info	Tender technical documents
Solar PV	n.a.	n.a.	yes	n.a.	Hybrid PV: 190 wp, 200m2 and accumulating system	id notice: 2018241636 URL: ted.europa.eu/udl?uri=TED:NOTICE:241636-2018:TEXT:EN:HTML	Solar PV installation for el. production and sanitary water (hybrid)	https://contrataciondelestado.es/wps/wcm/connect/4852b21b-f101-4621-abc3-981104ecd6f0/DOC_CD2018-020872.pdf?MOD=AJPERES
Solar thermal	no tender detected							
Hydro	n.a.	25-30	n.a.	n.a.	micro-dam (50-250 kW)	id notice: 2017342426 URL: ted.europa.eu/udl?uri=TED:NOTICE:342426-2017:TEXT:EN:HTML	Construction work for hydroelectric plant (small scale)	http://www.bradanometaponto.it/Bandi Dettagli_Impiantildroelettrici6.html

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Wind tubines	39,4%	20	yes	Gamesa	WTG G-87 / 2 MW; asynchronous generator 2 MW / 690V; nominal output: 2 MW	**id notice:** 2018340935 **URL:** ted.europa.eu/udl?uri=TED:NOTICE:340935-2018:TEXT:EN:HTML	Wind energy farm (installation and maintenance included)	https://drive.google.com/drive/folders/0B4Kh8VPOHkKtRlZuVDJjZ2szTHM

Table 4 - Examples of outputs of technical document checks

In most of the cases, the technical data that can be collected in tender documents, made available by the Public Authorities, are inadequate (quantitatively and qualitatively) for the Life Cycle Sustainability Assessment purposes. Therefore, in order to find the missing information it is fundamental to directly contact the contracting entities (PA) and contractors (SME) mentioned by each TED tender, inviting them to participate in the XPRESS survey tool on the Official Website.

Contacting SMEs and PAs

The steps to directly address TED stakeholders (contracting entities and contractors) are the following:

- Consult the list of TED tenders on the selected database prepared by the WP2 partners: "TED_can2015_2018_filtered_SME_subsample".
- Select the tender of interest and click on the related URL in the column "ted_notice_url".
- On the TED tender page, tab "Current language", Section I: Contracting entity, take note of the name, e-mail and telephone of the "contact person" and transcribe them in the contact list.
- On the TED tender page, tab "Current language", Section V: Award of contract, "Name and address of the contractor", take note of the official name (no contact person is indicated here) and transcribe it in the contact list.
- On the TED tender page, tab "Current language", Section II: Object, Title, take note of the title of the tender procurement procedure and transcribe it in the contact list.

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- Call the contracting entity using the telephone number indicated in the TED platform, introduce yourself as a partner of XPRESS H2020 European project and kindly ask to talk with the contact person or with the Public Procurement Office.
- Briefly introduce yourself to the contact person as XPRESS H2020 European project, explain the purpose of the project, ask if he/she was directly involved in the specific procurement procedure "______" mentioning the Title previously transcribed in the contact list:
    a. if yes: explain the reason why you are contacting him/her;
    b. if not: ask him/her the contact of the person who directly dealt with the procurement procedure and then repeat step 6 .
- Ask the person who was effectively involved in the procurement procedure if you can invite him/her to answer the online survey available in XPRESS website:
    a. if yes: ask for confirmation of the email address you will send the website link and send the invitation to participate;
    b. if not: thanks for the time and collaboration offered so far and try to ask on the phone just some of the questions included in the survey.
- Ask the person who was effectively involved in the procurement procedure if he/she can address you to the contact person in the contractor structure who was effectively involved in the procurement procedure.
- Arrange a new follow-up appointment in 3-5 days.
- Take note of the outcome of the phone call in the contact list.

The mentioned contact list could be structured as in **Table 5**:

TED tender	
id notice	
Description	
Title	
Contracting entity	
URL	
- contact person 1	

Contractor	
- contact person 1	
Output	
4 STEPS BOX	
1. Checked docs	
2. Contact	
3. Survey	
4. Output analysis	

Table 5 - Example of Contact list with the 4-Steps box

Examples of contact list for each country

This general procedure needs to be followed to collect the data of TED tenders from each involved Country partner. In the following paragraphs an example for each Country is described.

IT - Italy

TED tender	
id notice	2017342426
Description	Hydro-electric plant construction work
Title	Concessione del diritto di uso dei canali e/o delle condotte in gestione al Consorzio di Bonifica di Bradano e Metaponto Impianto Idroelettrico da 250 KW in c.da Cerchiarito. Reference number: CIG: 6954174DEA
Contracting entity	**Consorzio di Bonifica di Bradano e Metaponto - www.bradanometaponto.it**
URL	https://ted.europa.eu/udl?uri=TED:NOTICE:342426-2017:TEXT:EN:HTML
contact person	....
Contractor	**Ghiggia Ingegneria d'impianti Srl - www.ghiggiaeng.com**
contact person	...

Table 6 - Example of Contact List Italy

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UK - United Kingdom

TED tender	
id notice	2018417255
Description	Solar energy
Title	Solar PV Installation
Contracting entity	**Dover Harbour Board**
URL	ted.europa.eu/udl?uri=TED:NOTICE:417255-2018:TEXT:EN:HTML
contact person	……
Contractor	**EvoEnergy Ltd**
contact person	…

Table 7 - Example of Contact List UK

DE - Germany

TED tender	
id notice	201879338
URL	https://ted.europa.eu/udl?uri=TED:NOTICE:79338-2018:TEXT:EN:HTML
Description	Solar photovoltaic modules
Title	Austausch von Photovoltaik-Dünnschichtmodulen in der Photovoltaik-Freiflächenanlage Kenn
Contracting entity	**Solarkraftwerk Kenn GmbH**
contact person	……
Contractor	not available
contact person	…

Table 8 - Example of Contact List DE

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NO - Norway

TED tender	
id notice	2018473848
URL	ted.europa.eu/udl?uri=TED:NOTICE:473848-2018:TEXT:EN:HTML
Description	Solar panel roof-covering work
Title	Holmlia School — K602 — Solar Panels on the Roof
Contracting entity	**Oslo kommune v/ Undervisningsbygg Oslo KF**
contact person	...
Contractor	**Sivilingeniør Calr Christian Strømberg AS**
contact person	...

Table 9 - Example of Contact List NO

SE - Sweden

TED tender	
id notice	2016242374
URL	ted.europa.eu/udl?uri=TED:NOTICE:242374-2016:TEXT:EN:HTML
Description	Wind-energy generators
Title	...
Contracting entity	**Uppsala universitet**
contact person	not available
Contractor	**In Situ Instrument Aktiebolag**
contact person	...

Table 10 - Example of Contact List SE

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PT - Portugal

TED tender	
id notice	201876161
URL	ted.europa.eu/udl?uri=TED:NOTICE:76161-2018:TEXT:EN:HTML
Description	Electricity, heating, solar and nuclear energy
Title	Aquisição de energia elétrica em média tensão, baixa tensão, baixa tensão especial e baixa tensão normal
Contracting entity	**Município de Santa Maria da Feira**
contact person	…
Contractor	**Galp Power, S. A.**
contact person	…

Table 11 - Example of Contact List PT

ES - Spain

TED tender	
id notice	2018340935
URL	ted.europa.eu/udl?uri=TED:NOTICE:340935-2018:TEXT:EN:HTML
Description	Wind-energy generators
Title	Suministro, instalación, puesta en marcha y mantenimiento durante el plazo de garantía de un aerogenerador y las infraestructuras complementarias para la puesta en marcha de un parque eólico Reference number: S6/17/18
Contracting entity	**Cabildo Insular de Fuerteventura**
contact person	…
Contractor	**Suez Treatment Solutions, S. A. U.**
contact person	…

Table 12 - Example of Contact List ES

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DK - Denmark

TED tender	
id notice	2016454143
URL	ted.europa.eu/udl?uri=TED:NOTICE:454143-2016:TEXT:EN:HTML
Description	Solar installation
Title	Solcelleanlæg til Sønderborg Andelsboligforening, Afd. 22: Kløvermarken/Hvedemarken.
Contracting entity	**Sønderborg Andelsboligforening**
contact person	...
Contractor	**Sustain Solutions ApS**
contact person	...

Table 13 - Example of Contact List DK

SK - Slovakia

TED tender	
id notice	201861791
URL	ted.europa.eu/udl?uri=TED:NOTICE:61791-2018:TEXT:EN:HTML
Description	Electricity
Title	Dodávka elektriny a prenesenie zodpovednosti odberateľa za odchýlku na dodávateľa v plnom rozsahu v súlade s vyhláškou č. 24/2013 Z. z., ktorou sa ustanovujú pravidlá pre fungovanie vnútorného trhu s elektrinou a zabezpečenie distribúcie elektriny. Predpokladané množstvo odberu elektriny za 47 mesiacov je 193.262 MWh.
Contracting entity	**Bratislavská vodárenská spoločnosť, a.s.**
contact person	....
Contractor	**Východoslovenská energetika a.s.**
contact person	...

Table 14 - Example of Contact List SK

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BE - Belgium

TED tender	
id notice	2018429544
URL	ted.europa.eu/udl?uri=TED:NOTICE:429544-2018:TEXT:EN:HTML
Description	Solar energy
Title	Raamovereenkomst Energieleveringscontract (ESC) Zonne-energie Mechelen Zonneklaar Reference number: VEB-EE_17_P0040_002-F03_0
Contracting entity	**Vlaams EnergieBedrijf**
contact person	...
Contractor	**Perpetum Energy BVBA**
contact person	...

Table 15 - Example of Contact List BE

Trial test

To better understand how to structure the survey together with the WP2 partners, a first test was carried out with contracting entities and contractors to ask them for more technical details about the services/technologies procured.

In detail, for each of the two selected tenders, both the Public Authorities and the contractors were contacted.

1. Tender id 2018241636 - Solar panels - "Suministro de fabricación de estructura especializada para la reducción de energías no renovables mediante uso de fuentes energéticas sostenibles y optimización de calidad de agua", (ES); Contracting entity: Universidad de Cádiz; Contractor: Setolazar Energía y Medioambiente - URL ted.europa.eu/udl?uri=TED:NOTICE:241636-2018:TEXT:EN:HTML.
2. Tender id 2017384848 - Hydraulic turbines - "Supply and installation of electromechanical equipment for the hydroelectric power station on the industrial irrigation canal âin the "Municipality of Scurelle", (IT); Contracting entity: Provincia

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Autonoma di Trento, on behalf of Comune di Scurelle; Contractor: Lumiei Impianti Srl - URL ted.europa.eu/udl?uri=TED:NOTICE:384848-2017:TEXT:EN:HTML.

On one hand, the elements requested to contracting entities were the tender documents, especially technical specifications: the requested documents were obtained in both cases.

On the other hand, the following elements were asked to contractors:

- data sheet of the supplied RES Technology;
- name of the RES Technology producer if different from the supplier.

In this phase, it is essential to contact the contractors and build a dialogue and a close cooperation with each one of them in order to collect all the technical data needed.

Consequently, the XPRESS survey will have to include at least a specific question for each technical criteria as shown in the table above.

Survey (outline)

The XPRESS survey will be used to evaluate the availability of the PAs and SMEs that concurred in previous TED calls and who can potentially participate in future ones, to involve them in a second round of a more targeted data gathering process, with a specific focus on the Life Cycle Sustainability Assessment. This second round of data gathering shall be carried out in a face-to-face interview or similar and with some specific surveys, where the collaborating PAs and SMEs should be able to provide more detailed (and perhaps reliable) data related to the technology, the devices and the production processes, under a previous data privacy (confidentiality & non-disclosure) agreement.

The final survey needs to be done in collaboration with CIRCE, leader of WP2 and responsible for the survey.

At this preliminary stage, two types of surveys are suggested: one for PAs based on the "System Approach" and one for SMEs based on the "Product Approach", due to the different types of data that will be required in the evaluations.

The first point of the PAs survey will be focused on their overall strategy for the national/local GPP. The idea is to figure out whether this GPP is channelled through the provision of services (as seen in many tenders to procure electricity/heat from renewable sources) or via acquisition of

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products/technologies (some tenders purchased and installed RES Technologies as devices or plants).

To make a first screening, this action will give the possibility to contact a larger pool of PAs from the European Country of XPRESS Partners, with the possibility to focus the second part of the data collection, that will be a specific survey, on the most farsighted PAs/Country in terms of GPP and RES Technologies tenders. The specific survey will include detailed questions regarding the costs that are under the direct control of the PA, like purchasing, management, operation & maintenance, final disposal (i.e. recycling, disassembly, etc.) and the financial costs.

A second specific survey with more technologic details concerning the three aspects of the life-cycle evaluation will be setup and addressed to SMEs; it will be in line with Table 16.

Afterwards a plan will be put in place to raise awareness among the other actors involved.

In any case, every information will be merged with the ones in the TED platform.

PAs	SMEs
Environmental Assessment	
Weighting criteria	Specific technology
	Detailed technical data
	Energy efficiency
	Reference Service Life
	Production origin
	Operation & maintenance requirements (parts, supplier, maintenance plan)
	End of Life treatment: recycling potential, design, disassembly potential
Economic Assessment	
Economic weighting criteria	Production costs: components, materials, labour, fixed costs (infrastructure, rent...), running costs (energy, water...)
Management costs	Installation costs (including transport)
Operation & Maintenance costs	Operation & Maintenance costs

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Disposal/Recycling costs	Disposal/Recycling costs
Financial costs, taxes, tax relief	
Social Assessment	
Social quality criteria	Human Health
Job generation	Value chain actors
Stakeholders	Related Risks
…	

Table 16 - Example of specific questionnaire

Output analysis

All the data collected from TED tender documents and from RES survey will support a number of in-depth case studies, good practice examples and the sustainability assessment based on the life-cycle approach.

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4. Framework for the life-cycle sustainability assessment of RES technologies

4.1. Goal and scope

In order to fulfil with the four **goals** of the WP4 defined in Section 1.1, the main goal of the current D4.1 has been presented in Section 2.1 in terms of a whole sustainability assessment of RES technologies for decision-support of European PA. As laid out in Chapter 2, to carry out this task we are taking a life-cycle approach that covers environmental, energetic, economic and social aspects. Such a holistic, life-cycle based approach is also known as Life Cycle Sustainability Assessment (LCSA), which defines our framework and its goal:

"To analyse, calculate and describe the environmental and socio-economic profile of RES Technologies procured, or potentially to be purchased, by the European Public Authorities and which are mainly produced, assembled and/or traded by European small and medium enterprises"

In this context, the RES Technologies can be assessed both at the product-level (looking into technology-specific impacts) and at the system-level (looking into context-specific impacts when the technology is installed and operating in specific conditions). For this reason, the present framework for the LCSA takes into consideration two approaches: the Product and the System approach (see Section 4.1.2).

To cover the different environmental, economic, energetic and social aspects related to RES Technologies, this framework adopts selected methods and indicators from LCA, to cover the environmental aspects, LCC, to address the economic issues and SLCA, to analyse the social matters. General settings, calculation methods and indicators are preliminary chosen (as *interim*) on the basis of the reviewed papers and the own expertise of eAmbiente. In this phase of the project, the proposed metrics and methods are considered as starting point for further discussion with other project members, but were deemed to be the most relevant for the stated goal. The selected indicators will be later assembled with a multi-criteria decision analysis (MCDA) method so as to rank the RES Technologies, via weighting. The weighting factors will be left to every PA

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to be decided upon, that is according to the preferences of the stakeholders and final decision-makers in the EU Countries participating in XPRESS project.

4.1.1. System boundaries

The system boundaries are defined to distinguish the aspects that are to be included in the perimeter of a life-cycle study from those that are otherwise to be excluded. From the technological point of view, all the RES systems under study will be considered as a whole, including in the evaluation all the parts and components that constituted the system and that allowed it to operate in full efficiency.

The geographical area of application for this framework is Europe, with specific attention to the origin Countries of the partners in the XPRESS consortium. The time boundary of the study is based on the nominal lifetime, or the Reference Service Life, of the RES Technologies under assessment that can be found on the market. This means a minimum of 20 years from now (from 2020 to 2040) but it can be extended to 30 years (from 2020 to 2050), taking into account a probable extension of the useful life, thanks to the technological quality improvements.

The time boundaries of the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) will necessarily go beyond this horizon, so as to include long-term emissions and environmental impacts from persistent and cumulative substances from production, operation or end-of-life stages, like carbon dioxide or methane emissions to air, heavy metals dispersion into soils and water systems, emissions from landfill or incineration, etc. For example, the global warming impacts (GWP) will be calculated taking into account a 100 years horizon (i.e. the GWP_{100} metric), to consider future implications, to follow the common practice and to allow the comparison with other studies.

The precise selection of the included impact categories, impact assessment methods and indicators is taken in section 4.3.

Problematic tender categories

Some problematic tender categories have been identified regarding their modelling, due to the difficulty to differentiate them between *pure* RES and *potentially* RES Technologies and/or services, like electricity procurement tenders. More specifically, the identified problematic tender categories are:

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i. bioenergy systems: they are all renewable by definition, but exists an enormous number of possible configurations in terms of technology, application, functional unit, type of biomass, sourcing, etc.; consequently, there is a great variety of impact potential among them, even within a well-defined and delimited case study.
ii. fuel dependent applications: heating services; district heating and cogeneration plants; municipal waste cogeneration; fuel supply services;
iii. electricity and electricity-dependent applications: electricity supply services; EV and Heat Pumps;
iv. replacements, components, spare parts and maintenance services (depends where they are applied to, but in any case, they do not form a RES Technology or a service by themselves).

Bioenergy systems

The considerable modelling efforts required by this RES category may not, in most of the cases, translate into increased information for decision-makers, due to the large variability of bioenergy sourcing options, bioenergy technology solutions and applications. Their modelling usually involves an additional agricultural or forest-management model, which are very complex due to their market interactions with other product systems, indirect effects (rebound and leakage effects) and, thereby, a considerable result uncertainty. More specifically, food-competing biofuels will induce a leakage or outsourcing effect known as *indirect land use changes* (iLUC), which can turn to be worse than the fossil counterpart (Fargione et al., 2008; Lapola et al., 2010; Plevin et al., 2010; Saez de Bikuña et al., 2017), while forest-based bioenergy systems crucially depend on a span of variables (mainly: forest and fuel type, forest management, end-use application), which makes difficult a prospective assessment without a specific, well defined case-study and system boundaries (Dwivedi et al., 2019; McKechnie et al., 2011; Withey et al., 2019; Zanchi et al., 2012). Given all the difficulties identified and the uncertainties involved in the impact modelling of such TED categories, we preliminarily suggest to leave them out of the scope of the LCSA tool of WP4.

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Electricity and electricity-dependent applications: EVs and heat pumps

Electricity provisioning services will be country-specific and will depend on the evolution of the respective national energy grid-mix. Heating and power generation or supply services will be assessed in combination with the Energy and Abatement Models (see Section 1.3) and will fall in the System Approach.

One way to overcome the difficulties related to the impact modelling of such devices depending on a diverse (case-specific) energy commodity as electricity, it is to consider a Product Approach that excludes the Use phase of their life-cycle. Results can be depicted with a little warning or comment that says "it does not include the Use stage, for it depends on the specific el-contract and market evolution of this service".

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Fuel dependent applications: district heating and cogeneration plants, biofuel supply services

Similar to previous approaches, a way to overcome the inherent uncertainty related to the fuel used in these types of plants or the biofuel type, and given the nature of the prospective assessment of the LCSA tool, it is suggested that the sourcing part is left out of the scope. That is, the Use phase for the district heating and cogeneration plants, as well as the bioenergy systems and biofuel supply services altogether are recommended to be left out of the scope for the Product Approach, while for the System Approach the Energy and Abatement Models will come into play.

Technology dependent applications: components, spare parts, maintenance services

As for the provisioning tenders related to component, spare parts and general maintenance, it is suggested to be left **out of scope** of the LCSA tool. The reasons for this are their marginality (few tenders identified) and the fact that they do not conform a RES Technology or service *per se* or alone by themselves, but in combination with the whole system – which may be or may be not RES-based. Components, spare parts and maintenance services will be included only as Operation & Maintenance phase related to RES Technologies under whole-life sustainability assessment.

4.1.2. Product and System approaches

The first approach, named "Product Approach", concerns the sustainability assessment of certain types of RES products and devices, regardless of their way of use and the installation characteristics. Their sustainability is considered from the point of view of the producing and distributing companies. This approach allows us to take into account the environmental and socio-economic implications of the production processes, in a life-cycle perspective called *cradle to gate*. In the field of RES Technologies, the majority of the environmental burdens are linked to the infrastructure and thus to the production stage or the installation, so the responsibility of the environmental performance of these technologies lies within the manufacturer. Thus, the "Product Approach" focuses on the analysis of the product design choices and the key production parameters that fall under the responsibility of the producer. Since the environmental performance of RES Technologies during the operational phase depends on the technical characteristics (i.e. energy conversion efficiency, energy losses, etc.) and on the installation conditions (i.e. the effective solar radiation, outdoor ambient temperature, etc.), the "Product Approach" is handy to investigate the sustainability performance which is strongly dependent on product features. The "Product Approach" places all the devices for the exploitation of a specific RES on the same basis to allow the comparison among several alternative products for that type of energy. For example, the "Product Approach" can be used to compare single-crystalline vs. multi-crystalline silicon (Si) photovoltaic panels, with the assumption of the same electrical performance, or to compare the multi-crystalline Si PV panels produced by different companies.

The second approach is the "System Approach" and concerns the sustainability assessment of RES Technology products within their specific application contexts. The performance of RES Technologies is strongly dependent on the geographical location and on the installation specifications, as these aspects determine the efficiency and the effective energy harvested by such devices. Moreover, the socio-economic conditions in each European Country determine the specific market status, the product availability, the national laws and regulations, the funding and incentive policies implemented at the local level and the habits of the local population. This more holistic approach is based on a whole life-cycle perspective, namely *cradle to grave,* and allows the comparison among alternative RES Technologies and across different indicators. For example, the "System Approach" could help to determine whether a photovoltaic system is convenient or not in a certain location versus a wind energy technology solution. Moreover, the effectiveness of the RES Technologies in increasing the conditions of sustainability is given by the difference between the use of the traditional energy solutions, defined by the local energy mix, and the exploitation of the renewable resource in the specific geographical context.

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The LCSA of RES Technologies is set to allow the analysis, quantification and comparison among alternative solutions, both from a RES-type basis (Product Approach) and from an implementation and operational basis (System Approach) in various European Countries.

4.1.3. Life-cycle stages

In the articles examined through the literature review, the life-cycle stages included in the studies vary according to the adopted approaches or the defined scopes. When a single technology product is studied, the included stages are generally the raw materials extraction, the manufacture of the components and the operational phase as in (Amponsah et al., 2014; Arvesen & Hertwich, 2012; Basosi et al., 2018; Fthenakis & Kim, 2011; Petrillo et al., 2016; Varun, Prakash, et al., 2009; Varun et al., 2012). On the contrary, when an energy system is analysed, the included life-cycle stages are energy production and infrastructure construction as in (Atilgan & Azapagic, 2016; García-Gusano et al., 2017; Garcia et al., 2014; Li et al., 2019; Santoyo-Castelazo & Azapagic, 2014; Turconi et al., 2013). The phases of maintenance and end-of-life are taken into account only in few articles as underlined in (Gerbinet et al., 2014), sometimes with difference scenarios according to the examined technology (Amponsah et al., 2014; Asdrubali et al., 2015; Atilgan & Azapagic, 2016; Basosi et al., 2018; Dolan & Heath, 2012; Kaldellis & Apostolou, 2017; Koroneos & Nanaki, 2012; Nugent & Sovacool, 2014; Parida et al., 2011; Wong et al., 2016). The transports between the production site and the installation site are included only in few studies (Nugent et al., 2013; Asdrubali et al., 2014; Dolan et al., 2012; Garcia-Gusano et al., 2017; Cellura et al., 2019) as they are often considered of negligible importance or consistent data are not available.

In theory, life-cycle costs of RES Technologies have to be considered in a from *cradle to grave* scenario. This means to include the costs of the raw materials extraction and processing, the installation (transport, site preparation and grid connection), the operation and maintenance, the system decommissioning, the recycling and/or final disposal of the components. Unlike the environmental LCA studies, most of the reviewed LCC studies consider the full range of costs for the assessment, including final disposal and end of life operations. Only a few studies excluded these from their system boundaries (Karunathilake et al., 2018; Tourkolias & Mirasgedis, 2011). The energy costs related to additional backup and storage technologies to cover the production uncertainty inherent to intermittent RES are generally excluded from the calculation of LCC.

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For the identified problematic tender categories (special RES services and technologies), it has been recommended to leave out of the scope the Use phase for some of them. However, another important life-cycle stage may rise some difficulties that need further consideration: dismantling of RES Technologies at the end of their service lifetime. The EoL stages will be discussed with other project partners and decided upon for the next deliverable.

Guideline Indication

According to the Goal&Scope definition, in this study two different approaches are chosen: the first one with a product and production process approach instead of the second one with a comprehensive system approach. Therefore, the scenario to be considered in the "Product Approach" is a *cradle to gate* one, with the following stages: raw materials extraction, components manufacture, product assembly, transports, energy delivery and waste management linked to the production stage. In the "System Approach", transport to the use site, site preparation and installation, operation activities, maintenance and end of life stages will be also included. Whereas for the EoL stages this will be handled and decided at later stages.

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4.1.4. Functional Unit

The functional unit (FU) measures the functional performances of the product, system or service under assessment. It is defined with the aim to have a unit to which reporting the outcomes of the Life Cycle Sustainability Assessment and to allow the comparison among the results of the evaluation of alternative products that perform the same function. All the FU considered for each RES Technology of the LCSA tool are shown in the **Technical input data tables by RES Technology**.

As previously described in paragraph 4.1.2, the sustainability assessment will be conducted on the basis of two different approaches, the "Product" one and the "System" one. They consider different methodological settings due to the necessity of evaluating a single RES product, adopting the "Product Approach" with a *cradle to gate* scenario, or a wide spectrum of RES Technology solutions to be compared in a specific context, using the "System Approach" with a *cradle to grave* scenario. Therefore, it is necessary to define two different functional units (FU) for the two options.

In the reviewed papers, the sustainability assessments of the single products or specific technology solutions are carried out by setting the nominal power (1 kW of power generation capacity) as functional unit to compare the results with other technologies of the same power class. On the contrary, the most common FU in the studies that compare the environmental performance of RES technologies in specific contexts (i.e. Italian scenario in the period 2020-2030), is the power delivered to the grid (1 kWh of produced power in a specific time scenario). In this way a reasonable comparison among RES Technologies is facilitated and the comparison among RES Technologies and fossil fuels is also enabled.

Functional Unit in the review

Indeed, according to the analysed papers, it has been observed that most of them use 1 kWh (or related units of different magnitude, like 1 MWh or 1 GWh) as FU to calculate and present the assessed impacts (Amponsah et al., 2014; Arvesen & Hertwich, 2012; Asdrubali et al., 2015; Atilgan & Azapagic, 2016; Basosi et al., 2018; De Wild-Scholten, 2013; Desideri et al., 2012; Dolan & Heath, 2012; Evans et al., 2009; Fthenakis & Kim, 2011; García-Gusano et al., 2017; Garcia et al., 2014; Gerbinet et al., 2014; Hadian & Madani, 2015; Hou et al., 2016; Kaldellis & Apostolou, 2017; Kim et al., 2014; Kouloumpis et al., 2015; Laleman et al., 2011; Li et al., 2019; Nugent & Sovacool, 2014; Parida et al., 2011; Raadal et al., 2011; Santoyo-Castelazo & Azapagic, 2014; Sumper et al., 2011; Turconi et al., 2013; Varun, Bhat, et al., 2009; Varun et al., 2012; Varun, Prakash, et al., 2009; Wong et al., 2016; Zhong et al., 2011). The functional unit is defined differently in the remaining 30% of cases, as explained below.

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T. Brown et. al., 2012 consider a revised operational definition of Emergy Yield Ratio for the evaluation of the technological processes that is merged with the LCA method. So the selected FU “seJ/J” is based on the Emergy Value unit of the electricity generated by the ground-mounted CdTe photovoltaic system compared to the Oil-fired power plant. Since this paper focuses on Emergy in addition to LCA, we decided to exclude it from the references relevant for the present study.

In Petrillo et al., 2016 the FU is the “operation of the power supply for a calendar year”. This choice is made because they consider a novel technology of a compressed air energy storage system coupled to an electrolyser that produces hydrogen. The hydrogen is subsequently stored in a metal hydride tank and utilized in a fuel-cell combined with photovoltaic panels for a small-scale stand-alone power plant useful for a radio base station for mobile telecommunications. This system is out of the scope of the present study.

In (Shaddel & Shokouhian, 2014) the MJ/year is used as FU for a case study in which a solar thermal collector is adopted as auxiliary energy source in dwelling buildings. This RES system is designed with the purpose to preheat water for domestic hot water and provide space heating. This technology will be considered in the XPRESS project but the methodological choices of the Shaddel et al. case study makes their outcomes not comparable with other research.

In some other studies the FU has not been identified because they evaluate other aspects than the environmental impacts, i.e. general sustainability criteria for the renewable energies.

Haddad et al., 2017 describes a multi-criteria approach to rank RES Technology solutions (like solar, wind, hydropower etc.) to identify the best option for the electricity production by 2030. In the study the Analytical Hierarchy Process method is chosen, taking experts' feedback and opinions to evaluate different aspects (technical, environmental, social, economic) of the analysed RES with the aim of ranking them and identifying the best option. The findings show the importance of considering environmental, technical and socio-economic aspects.

(Ellabban et al., 2014) is an up-to-date and detailed status of the major renewable energy sources in the world, with a focus on the power electronic converters and the integration of RES into the smart grid system.

(Hussain et al., 2017) provide a comprehensive review of five emerging renewable technologies (i.e. ocean energy, cellulosic ethanol, concentrated solar power, artificial photosynthesis and enhanced geothermal) to give an insight of the recent developments and their potential, drawbacks and challenges.

(Koroneos & Nanaki, 2012) LCA study quantifies the environmental benefits of the installation of a Solar Water Heating System with electricity as auxiliary for domestic use in the city of Thessaloniki (Greece). In this specific case study, the functional unit is set at 1 MW of hot water.

Guideline indication

According to the "System Approach" the FU should be set as "1 unit of energy produced by the analysed technology (1 kWh of energy)" in the given context. On the basis of the literature review,

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all the studies that compare different RES Technologies (across them or versus a fossil fuel system) chose this functional unit.

According to the "Product Approach" the FU should be set as "1 unit of nominal power of the analysed technology (1 kW of power)". In any case the installed power capacity is a useful indicator for the choice of the best single technology into the same class.

4.2. Life Cycle Inventory

According to the ISO 14040:2006 and ISO 14044:2006 the Life Cycle Inventory (LCI) is an essential step of the Life-cycle methodology that involves the creation of an inventory of the total input and outputs of the selected system. The inventory flows have to include raw materials, energy and water consumptions, emissions to air, land and water. It has to be performed for all the products, processes and activities within the system boundaries for the selected scenario (*gate to gate*, *cradle to gate* or *cradle to grave*). Furthermore all the qualitative and quantitative data must be related to the FU defined in the goal&scope.

The inventory describes through qualitative and quantitative data the relationship between the biosphere and the so called technosphere, that is the human-made world. The goal of a life-cycle analysis is to describe and measure all the energy and material flows that are generated between the two systems, with the final aim to reduce the consumptions and improve the recycling processes.

The LCI has to describe in a detailed and realistic way the energy and materials flows involved in the product/process/activity under assessment, therefore it has to be consistent with the general methodological settings, such as goal&scope of the evaluation, functional unit, system boundaries, life-cycle scenario. The LCI is the basis for calculating the environmental and socio-economic impacts of the product/process/activity through the Life Cycle Impact Assessment.

4.2.1. Data sources

Considering the two selected approaches, "System Approach" and "Product Approach" as described in "Goal and Scope", the sources of the data to conduct the analysis have to change accordingly to the selected strategy. The "System Approach" implies a wider vision and a broader life-cycle scenario therefore the data have to describe the point of view of the Public Authorities and the communities. The data will be collected from the Public Authorities selected and involved

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in the XPRESS project to have direct information about the RES Technologies they purchased or planned to be purchased, the characteristics of their energy systems, the economic profile and the social issues. The information about the national energy mix of each country, to compare the actual scenario with a future scenario based on RES, will be gathered from European Commission and EU Energy Agency documents, from publications of the National Energy Agencies, life-cycle certified databases (like Ecoinvent and Social Hotspot Database) and LCA-practitioner tools. Through the "System Approach", the geographical setting of the data will result in a technologies suitability assessment, according to the specific characteristics of each Country.

In the "Product Approach", the information about the specific RES Technologies devices will be collected from producers and assemblers; they will be identified through the TED platform (WP2) and will be involved in the assessment to obtain the information for the Life Cycle Inventory through a survey or interviews.

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4.2.2. Data quality

To ensure the best data quality and to reduce the uncertainty of the collection, a classification of data, based on the following criteria, will be considered.

The first level of the collection will be performed through the scientific institutions that could provide a validation of the sources and, at the same time, the primary data provided by the producers. As second level, the most suitable databases (like Ecoinvent) for the purpose will be selected; furthermore, as third level several scientific literature sources from selected journals or specific case studies and punctual datasets will be acquired.

All the data will be consistent from the technological, geographical and time point of view, with a strong relation between data and actual context.

To meet the objectives of this project, the XPRESS Countries will be considered beforehand, in the second place the European context and lastly the extra-EU data.

4.2.3. Environmental, Economic and Social datasets

In order to perform life-cycle analysis (Life Cycle Assessment, Life Cycle Costing or Social Life Cycle Assessment) is mandatory to have inventory data for the complete supply chains. Due to the amount of data needed in order to be able to perform a life-cycle study of a full supply chain, it is quite impossible to collect and organize the data related to the complete background system based only on primary data. For this reason, some background LCI database are available to complete the analysis of the processes beyond the control of the person/organisation which commissions or conducts the evaluation. Therefore, the most consolidated and up-to-date of the available datasets will be taken into account, like Ecoinvent, ELCD, LCDN and Thinkstep for the environmental aspects and SHDB for the socio-economic aspects. The costs evaluation does not require a specific life-cycle dataset but appropriate financial data will be collected.

Ecoinvent

The ecoinvent database is one of the most used LCI database which offers fully interlinked unit process supply chains for all products present in the database. Datasets cover all relevant environmental flows, such as resource extractions, land use and emissions, as well as all material and energy inputs and products of an activity. By offering data on the unit process level, the ecoinvent database ensures transparency over the whole supply chain.

The largest part of ecoinvent datasets is generated in data collection projects dedicated to specific economic sectors and countries with the collaboration of external partners such as research institutes, industries, consultancies etc. or internally by small LCA experts. The primary data are provided from the interviews or field visits and the secondary data are sourced from publicly available statistics, peer reviews scientific literature, company reports and so on. In any case all datasets are reviewed to ensure the best possible quality and transparency before publishing.

ELCD (European Reference Life Cycle Data System)

Developed by the Joint Research Center (JRC) and the European Platform on Life Cycle Assessment (EPLCA) with the aim to increase the availability of quality-assured life-cycle data, methods and assessments. The EPLCA has developed both the ELCD database and the International reference Life Cycle Data System (ILCD) Handbook. All datasets are carefully selected, of high quality and in line with ISO 14040 and 14044. The ELCD database emphasizes consistency and quality the requirements for data follow the guidelines from the ILCD handbook.

The last version of ELCD database contains more than 500 datasets with data from industries such as the chemical and metal industry. It also includes data on energy production, transport

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and end-of-life processes. The datasets are provided and approved by their respective industry associations.

This, together with the ILCD Data Network IT infrastructure, will allow to set-up an ELCD node as part of the ILCD Data Network. The ILCD Data Network is a web-based infrastructure allowing convenient online access to consistent and quality-assured life cycle inventory (LCI) data sets from various providers, globally. Datasets quality within the ILCD DN is ensured by the development of the ILCD Entry-Level requirements.

Life Cycle Data Network

The Life Cycle Data Network (LCDN) was launched in Brussels on 6th February 2014 by the Director General of DG JRC, and the Deputy Director General of DG Environment.

The LCDN aims to provide a globally usable infrastructure for the publication of quality assured LCA dataset (i.e. LCI datasets and LCIA method datasets) from different organizations (e.g. industry, national LCA projects, research groups, and consultants).

Originally meant to host data compliant with ILCD entry level requirements, since April 2018 a new registry has been added, to host and share data packages in line with the Product and Organisation Environmental Footprint (PEF and OEF) framework (see the dedicated website of DG ENV for further details). The Network is a non-centralised web-based infrastructure composed by Nodes, and it also called Registry.

All datasets registered and published are compliant with quality requirements aimed at guarantee datasets quality and coherence in terms of Methodology, Documentation, and Nomenclature, for the two compliance systems allowed (ILCD entry level and PEF/OEF).

Thinkstep free dataset

Free Global Environmental Life Cycle Inventory (LCI) Data for Energy and Transportation, a common, independently reviewed energy and transport data foundation based on audited workflows from thinkstep’s databases.

The data describes environmental burdens, such as emission factors or consumption of resources from different types of energy generation and transport systems. Covered by the data

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are country-specific electricity grid mixes, country-specific fuel import mixes as well as data sets on the generation of steam and thermal energy from different fuels for more than 55 countries. In addition, LCI data representing the most important refinery products are provided for 10 countries.

4.3. Life Cycle Impact Assessment Methods and selected Impact Categories and Indicators

The Life Cycle Impact Assessment (LCIA) phase comes right after the Life Cycle Inventory (previous 4.2 paragraph). This phase is aimed at calculating the potential environmental impacts from the inventorised life-cycle resources and emissions. The selection of the impact categories, the category indicators and the characterization factors is done according to the stated goal of this WP4 (1.1). For the impact calculation, the categorized LCI flows are characterized using one of many possible LCIA methodologies (i.e. GHG emissions along the life-cycle are converted into GWP impacts [kg CO_2-eq units]). The LCIA methods and the impact categories will be described in the following sections.

Other optional LCIA elements –normalization, grouping, and weighting– may be conducted depending on the goal and scope of the LCA study. In normalization, the results of the impact categories from the study are usually compared with the total impacts in the region of interest, while grouping consists of sorting and possibly ranking the selected impact categories. Weighting is generally skipped because it implies value-judgements over the importance of each impact category. This is why ISO 14044 advises against weighting, stating that "weighting, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public". For WP4, however, a weighting method shall be incorporated to help rank RES Technologies through a Multiple-criteria Decision Making Method (see section 71) and assist the stakeholders in the decision-making process, since not only environmental, but also socio-economic impacts and energetic performance, will be considered. The stated preferences, which shall be collected by CIRCE and the WP2, will be used to select a weighting method and the weighting factors themselves. This is covered in more detail in sections 4.3.4 and Multiple Criteria Decision-Making methods.

A key purpose of performing life-cycle interpretation is to determine the level of confidence in the final results and communicate them in a fair, complete and accurate manner. Thus, after the

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impact assessment, the results shall be interpreted to identify the best alternative according to the case and the stated preferences of stakeholders, drawing the limitations of the approach and method pursued. During the interpretation of results, the identification of significant issues or hot-spots will be carried out. An important step of the interpretation is the assessment of the accuracy of the results, by which the practitioner shall ensure that the goal of the study is met. This is accomplished by identifying the data elements that contribute significantly to each impact category, evaluating the sensitivity of results to these significant data elements, to the weighting and ranking methods and overall by assessing the completeness and consistency of the study. Finally, the conclusions, limitations and recommendations of the study can be presented.

This section has been subdivided in environmental (4.3.1), energy (4.3.2), economic (4.3.3) and social (4.3.4) subsections where the selection of methods, impact categories and indicators is presented.

4.3.1. Environmental LCIA methods, impact categories and indicators

For the present deliverable D4.1, the Impact Assessment methodology of ILCD 2011 (Midpoint) has been selected as a guideline indication of the LCIA phase. Nevertheless, to simplify the decision-making process without compromising the accuracy and meaningfulness of the environmental assessment part, a handful of impact categories have been identified as key and representative for a tailored LCSA framework for RES Technologies. Therefore, in order to create a practical evaluation tool that can merge Economic and Social indicators to obtain a full LCSA of the RES Technologies, based on the literature review (Turconi et al., 2013; Arvesen et al., 2012; Cellura et al., 2019; Kouloumpis et al., 2015; Asdrubali et al., 2014; Garcia et al., 2014; Santoyo-Castelazo et al., 2014) and according to Garcia-Gusano et al., 2017, Atilgan et al., 2016 and Hadiana et al., 2014, the following impact categories have been selected for the framework:

- **Carbon Footprint** (GWP_{100} method, (Myhre et al., 2013))
- **Land Use Footprint** (LU occupation, differentiating among competing and non-competing LU with food production - to be developed)
- **Water Footprint** (Water scarcity method, AWARE v1.02, (Boulay et al., 2018))
- **Mineral Footprint** (Mineral, Fossil and Renewable resource Depletion, (Oers et al., 2006))

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-     Acidification (Accumulated Exceedance, (Seppälä & Posch, 2006))

Eutrophication, Ozone Depletion, Human Toxicity and Photochemical Smog impact categories have been excluded because the LCSA framework will focus on the assessment of RES Technologies alone. These impacts are linked to the life-cycle impacts of electricity production from fossil resources (Kouloumpis et al., 2015). Bioenergy systems can largely contribute to eutrophication, climate change and biodiversity loss, but these RE systems are out of the scope. Some of these would be relevant indicators to be included if the tenders for public services procurement in the future would consider not only electricity provision but also heating. In such cases, bioenergy and waste valorisation technologies would come into play and so the need to include some of the excluded indicators (i.e. Eutrophication, Photochemical Smog). Genetic diversity loss is also of great concern, as shown in Planetary Boudaries Framework (Figure 2) (Steffen et al., 2015). This impact category will be covered by the Land Use Footprint indicator as shown above. The only RES that can contribute to biodiversity lost are those that can induce an iLUC effect. Excluding agricultural first-generation bioenergy, the RE services and technologies which create iLUC are all those which take agricultural land out of production: solar photovoltaic (PV) and concentrated solar power (CSP).

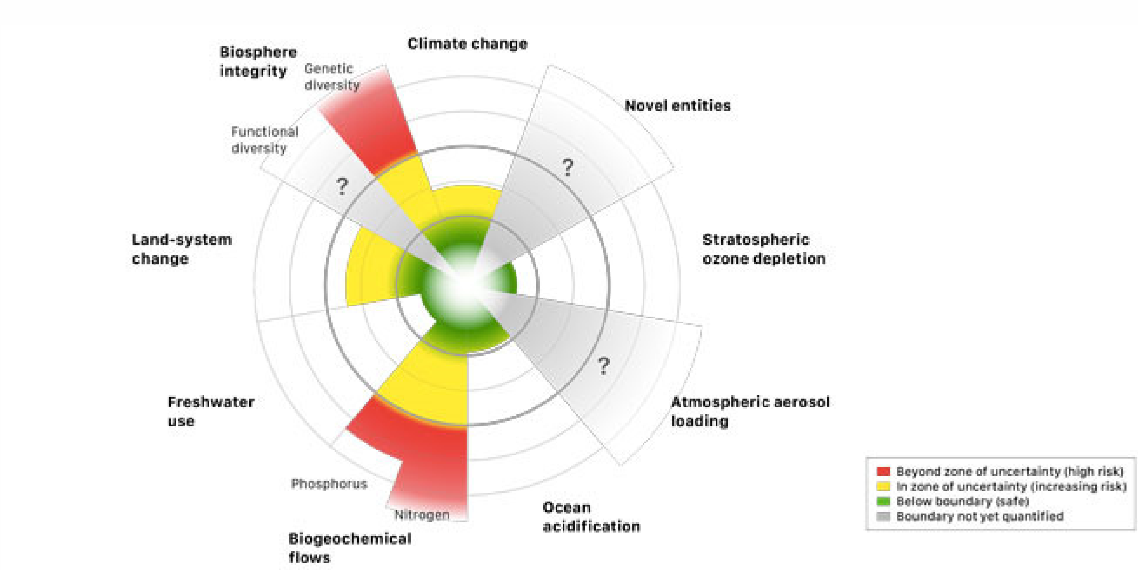

Figure 2 - Planetary boundaries framework

We focus on midpoint-level methods due to the fact that extending the LCA to the Endpoint level would introduce an additional grade of uncertainty in the system. In such broad and complex

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product system assessments, the inherent uncertainty of the system is already considerable, present in the input data (use of generic or secondary and proxy data) and the limitations of the LCIA methods utilized. Since the proposed LCSA framework will include a further aggregation step to evaluate economic, energetic and social indicators to rank the best RES Technology options, it was decided to stop at the midpoint-level assessment of the LCA methodology.

Guideline indication

For the assessment of environmental impacts, and based on the scope of the LCSA framework, the selected indicators are: **Carbon Footprint** (GWP method)**, Land Use Footprint** (land occupation, differentiating by competing or non-competing with food production[1])**, Water Footprint** (AWARE method)**, Mineral Footprint** (ILCD method) and **Acidification** (ILCD method).

Technical input data tables by RES Technology

[1] This will be a methodological elaboration to account for the induced iLUC (comprising further GWP and a Biodiversity indicator), which will add to the existing life-cycle Ecoinvent database.

[1]CED = Cumulated Energy Demand of the device or RES system for its production
[2] Future revenues and costs annualized with a 1-4% discount rate to account for the predicted depreciation of money (to be taken from International Monetary Fund or European Central Bank: 20-year term expected growth)

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The following table that gathers the output (final results) data summary:

Table 17. Output data from the LCSA tool (final results from WP4)

Impact Category	Indicator	Impact Assessment Method	Unit
Global Warming/ Climate Change	Carbon Footprint	GWP_{100} (Myhre et al. 2013)	$kgCO_2$-eq
Water Use/ Scarcity	Water Footprint	AWARE (Boulay eta al. 2018)	m^3-eq?
Land system change / Biosphere integrity	Land Use Footprint	Top-down biophysical (XPRESS)	-
Abiotic, non-renewable resource depletion	Mineral Footprint	(ILCD 2011) van Oers et al. 2006	Sb-eq?
Acidification	pH Footprint	Accumulated Exceedance (ILCD 2011)	kgSO2-eq
[energetic performance]	Energy Payback Time	PT = CED[1]/Annual estimated production	years
[economic	Payback Time	PT = Investment/Annual estimated revenue	years
performance]	Levelized costs	Life Cycle Costing[2]	$€_{2020}$
Local Added Value	Local Added Value	Zimdars et al. 2018	€
Total Added Value	Total Added Value	Zimdars et al. 2018	€
Fair Minimum Wage	Fair Minimum Wage	De Croes 2016	€
Human Health risks	Human Health risks	QALY/DALY	years

Input Data for LCSA – Output Data from Surveys

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The following technical tables are framed in order to carry out the LCSA of RES Technologies, with focus on environmental and social aspects, since the economic ones are mainly addressed in other WPs. That is, these tables gather the necessary input data for the LCSA tool which will be developed to assist European PA in their decision-making process for GPP of RES technologies/installations/services, by covering key environmental and social aspects of such items and/or related services.

The "Data Input" column is the required information that public authorities shall introduce in the LCSA input survey to receive a first-order, RES Technology and type-specific assessment of key environmental and social aspects.

The FU for each technology (coloured in light green) is a fixed parameter by the survey, based on which the LCSA will be carried out (it cannot be modified). The white cells are the ones that require specific user-input. The technology parameter will be a drop-down menu or similar, which will allow public institutions to select the specific RES Technology type to be assessed. The end of life (EoL) treatment data (coloured light orange) represents the shared responsibility between SMEs and PA. It is usually difficult to model, given the inherent uncertainty of events far in the future, and for that reason several possible EoL scenarios will be implemented. These can be country-specific and company-, product- or design-dependent, but will be classified in three main categories: **recycling** (for the recyclable parts), **disposal** (for non-recyclable, hazardous waste), **incineration** (for the rest). The case-specific EoL scenarios shall be defined after the second round of the data gathering process together with the selected SMEs. The public authorities may also play a role in defining the most plausible EoL treatment. These have part of the responsibility in the definition of EoL treatment scenarios too, since they are the owners of the purchased RES Technologies/services. Their shared responsibility lays on the fact that the public administration will still exist at the EoL of the technology, while the existence of a SME in the future is not always certain. The purple-coloured row refers to the SLCA part (see section 4.3.4).

White cells represent user input data (country- and case-specific), while yellow cells will be fixed, technology-dependent data (target data for SME survey). These data (yellow cells) will not be visible to the end-users (PA) but are needed to build the LCA models.

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Core RES technologies considered

Solar PV

SOLAR PV		
Parameter	**Data Input**	**Unit**
FU	1	kWh
Commercial technology sub-categories	Polycrystalline	
	Bifacial	
Installation country		kWh/m²
➔ Region		kWh/m²
Installation capacity		kWp
Installation site	Agricultural?	Yes/No[1]
Sun tracking system?		Yes/No
Installation area		m²
Service lifetime		Years
Efficiency		%
O & M		€/years
Supplier/Component origin		China
EoL treatment		

Table 18 - Photovoltaic Systems technical table

[1] If Yes then iLUC factor (land use footprint method will be developed)

Concentrated Solar Power

SOLAR CSP		
Parameter	**Data Input**	**Unit**
FU	1	kWh
Commercial technology sub-categories	Parabolic trough	
	Tower: molten salt	
	Tower: steam	
Installation country		kWh/m²
➔ Region		kWh/m²
Installation capacity		kWp
Installation site	Agricultural	Yes/No[1]
Installation area		m²
Service lifetime		Years
Efficiency		%
O & M		€/years
Supplier/Component origin		…?
Off-sun production autonomy		kWh
EoL treatment		

Table 19- CSP technical table

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Wind energy

WIND		
Parameter	**Data Input**	**Unit**
FU	1	kWh
Commercial technology sub-categories	Offshore Onshore Rooftop micro?	
Installation country ➔ Region Installation capacity		Load Factor kWh/kWp kWp
..max. budget?		
Service lifetime Efficiency O & M Supplier/Component origin Off-sun production autonomy EoL treatment		Years % €/years …? kWh

Table 20 - Wind turbines technical table

Hydropower

HYDROPOWER (micro)		
Parameter	**Data Input**	**Unit**
FU	1	kWh
Efficiency (turbine) *Technology*	 Micro-dam River run-off	% -
Service lifetime O & M		Years €/years
Supplier/Component origin		country
EoL treatment		

Table 21 - Hydropower technical table

Potentially RES technologies considered

The Use phase for these types of technologies is excluded from the Life Cycle Sustainability Assessments.

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Electric Vehicles

EV (Passenger/Cargo)		
Parameter	**Data Input**	**Unit**
FU_c	1	t.km
FU_p	1	person.km
Efficiency		%
		kWh/FU
Autonomy range		km
Technology EVp		
	e-kick-scooter	
	e-scooter/bike	
	e-car/van	
	e-bus	
Technology EVc		
	e-van	
Service lifetime		Years
O & M		€/years
Supplier/Component origin		country
EoL treatment		

Table 22 - EV technical table

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Heat Pumps

HEAT PUMPS		
Parameter	**Data Input**	**Unit**
FU	1	kWh_th
Efficiency (COP)		%
Technology		
	Air-ground	
	Air-Air	
	Air-Water	
	…	
Service lifetime		Years
O & M		€/years
Supplier/Component origin		country
EoL treatment		

Table 23 - Heat pumps technical table

Potentially RES technologies under consideration

Inclusion under consideration.

Biogas plants

BIOGAS		
Parameter	**Data Input**	**Unit**
FU	1	kWh_th
Efficiency		%
Biomass type		
	Distance (source to gate)	Km
	Virgin	
	Residual	
Service lifetime		Years
O & M		€/years
EoL treatment		

Table 24 – Biogas plants technical table

District heating, cogeneration and municipal waste incineration plants

MUNICIPAL WASTE INCINERATION		
Parameter	**Data Input**	**Unit**
FU	1	kWh_th
Efficiency		%
Biomass type		
	Distance (source to gate)	Km
	Virgin	
	Residual	
Service lifetime		Years
O & M		€/years
EoL treatment		

Table 25. DH and CHP plants

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Geothermal, Tidal and other minor RES Technologies

Little relevance today and likely marginal in future too.

Geothermal systems

GEOTHERMAL		
Parameter	**Data Input**	**Unit**
FU	1	kWh
Efficiency		kWh/site %
Technology	…	
Service lifetime		Years
O & M		€/years
Supplier/Component origin		country
EoL treatment		

Table 26 - Geothermal Systems technical table

Solar collectors (direct solar heating systems)

SOLAR HEATING SYSTEMS		
Parameter	**Data Input**	**Unit**
FU	1	kWh_th
Efficiency		kWh/m2
Installation		
Technology	Flat Cylindrical Tubular	
Service lifetime		Years
O & M		€/years
Supplier/Component origin		country
EoL treatment		

Table 27. Solar collectors table

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XPRESS

RES Technologies excluded

Due to the multiple difficulties involved in their modelling for a LCSA tool with such a broad application perspective.

Bioenergy Systems

BIOENERGY SYSTEMS		
Parameter	**Data Input**	**Unit**
FU	1	kWh_th
Efficiency		%
Biomass supply		
	Distance (source to gate)	Km
	Virgin	
	Residual	
Forest Management		
	Intensive	
	Sustainable (i.e. FSC)	
Service lifetime		Years
O & M		€/years
EoL treatment		

Table 28 - Bioenergy heating systems technical table

4.3.2. Energy indicators

Some other indicators were identified: they are not directly environmental nor economic or social indicators, but are relate to the energetic performance of RES Technologies. In addition to the environmental impact categories and indicators, the energy-related metrics are profusely used in the reviewed papers. The observed metrics include, but are not limited to, Cumulative or Primary Energy Demand, Net Energy Use or Energy Return on Energy Invested Ratio. However, the most utilized energy indicator in the reviewed papers is the **Energy Payback Time** (Varun et al., 2009; Fthenakis et al., 2011; Laleman et al., 2011; Desideri et al., 2012; deWild et al., 2013; Gerbinet et al., 2014; Wong et al., 2016; Paridaa et al., 2011; Kaldellis et al., 2017), which is the period needed by the assessed technology to produce the same amount of energy that was invested in its production process.

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Other energy metrics that were also found in the literature review are Emergy (Ingwersen, 2011; Kamp & Østergård, 2013; Ulgiati et al., 2006) and Exergy (Dewulf et al., 2005; Hau & Bakshi, 2004), as well as the mentioned Cumulative Energy Demand (Arvesen et al., 2012; Cellura et al., 2019; Girardi et al., 2019; Asdrubali et al., 2014; Garcia et al., 2014, Sumper et al. 2011) and Energy Return on Energy Invested Ratio (Kubiszewski et al., 2010; Liu, 2014; Marszal et al., 2012; Raugei & Leccisi, 2016; Strantzali & Aravossis, 2016). The first two are concepts similar to energy but they also incorporate additional information. Emergy represents the total *embodied solar energy* in the products, giving an indication of the renewability degree of it, while exergy represents the *quality* of the energy to produce effective work. Despite the interesting contribution and supplementary and complementary information they can provide, they are beyond the scope of this project due to the difficulty to implement them in a practical European-scale tool.

Guideline indication

For the assessment of the energy performance of RES Technologies only one indicator has been selected, the **Energy Payback Time**.

4.3.3. Life Cycle Costing and Economic indicators

The review of the last 10 years literature on RES Technologies gives an overview of a wide range of methods and indicators that aim to measure sustainability in its economic dimension too. Economic aspects have always had a privileged position in the list of decision-makers' priorities. However, their integration with environmental assessments does not take place according to a single method, but through different techniques and approaches.

Brahim Haddad et. al., 2017 applied the Analytical Hierarchy Process for the construction of a weighting system based on expert opinion. With this method they provide a ranking for the most suitable RES Technologies to achieve the objective of the Algeria program on renewable energy and energy efficiency of deriving 40% of electricity production from renewable energy sources by 2030. In this case, the selected economic indicators were Investment cost, Operation and Maintenance (O&M) costs, Life Service and Payback Period.

A similar application of the AHP method was carried out by (Al Garni et al., 2016) in order to compare 5 different technologies of energy production from renewable energy sources and

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develop an energy mix hypothesis for Saudi Arabia. In this context the selected indicators were: Capital costs, National economic development, O&M costs and Energy cost.

In 5% of the reviewed studies, the input-output analysis is used to investigate the effects on employment of European strategies for the increase of energy produced from renewable sources (Henriques et al., 2016). In Henriques, the focus is not on indicators that measure impacts, but on interconnections between the different sectors of the Portuguese economic system that originate effects on employment.

About 15% of the reviewed studies analyze the subjective and behavioural dimension together with the monetization of direct and indirect costs. (Bigerna & Polinori, 2014; Dagher & Harajli, 2015) investigate the individual Willingness to Pay (WTP) for renewable energy, while (Kaenzig & Wüstenhagen, 2010) analyzes the influence of LCC information on consumers' decisions to spend on eco-innovation and renewables.

In the case studies analyzed by Bigerna et al., 2014, the WTP for a greater development of green electricity is estimated through surveys delivered to Italian households. Dagher et al., 2015 submits to the interviewees a list of four possible scenarios for the integration of renewable energy sources in the Lebanese energy mix. Evans et al., 2009 uses the Price of electricity generation as an indicator of the economic sustainability to rank four renewable energy sources: photovoltaic, wind, hydropower and geothermal. A similar study was conducted by Varun et al., 2009, with the aim to compare different renewable energy production systems using a single figure that connects the price of electricity generation with other environmental impact indicators.

Guideline indication

As for the economy aspects, the most adopted economic indicators in the analysed papers are the **Payback Time** (Chong et al., 2011; Liu, 2014; Strantzali & Aravossis, 2016) necessary by the RES Technology to repay the investment and **Levelised LCC** (Bigerna & Polinori, 2014; Dagher & Harajli, 2015; Dale, 2013; Dombi et al., 2014; Haddad et al., 2017; Hadian & Madani, 2015; Stigka et al., 2014; Valente et al., 2011). The Levelised LCC include "all the costs that will be incurred during the whole life-cycle of a product/service by different stakeholders" (section 2.3), implying the necessary currency conversion rates, the price adjustment conversions for the initial

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investments and first life-cycle stages (raw material extraction, processing, component production, product assembly, etc.), as well as the annualization of future costs/savings (O&M, disposal, etc.) by means of a discount rate. The general costs can be termed as:

- **Production**: materials/components acquisition, installation, running costs (energy consumption), fixed costs (rent, investments…), taxes and tax relief, margin, labour, indirect management costs.
- **O&M**: use stage costs related to operation (consumption) and maintenance (spare parts, replacements, labour).
- **End of Life**: costs related to final disposal, disassembling, recycling, safe disposal of hazardous materials, etc.

4.3.4. Social impact categories and indicators

The field of Social Life Cycle Assessment (SLCA) has experienced increased attention from the scientific community and LCA practitioners in the last years. Due to its high value-laden nature and intrinsic modelling difficulties, there is no (and unlikely will be) a consensus around a single methodology, neither around a reduced set of impact categories nor indicators (as it happens in common LCA), from the myriad of new methods, indicators and approaches that have emerged in this quickly evolving field of LCA. The weighting, grouping and aggregation of these (within a SLCA study or a broader LCSA framework), is generally done through different weighting methods available and one of the diverse multi-criteria decision-making (MCDM) existing methods (see below).

For the XPRESS project and the current deliverable D4.1, we acknowledge that the final selection of the:

- Weighting method
- MCDM method
- SLCA impact categories, social themes and indicators

will require a discussion among the XPRESS relevant partners and probably the involvement of public and private stakeholders as well. Surely, a more appropriate and effective choice can be made downstream of the selection of the RES Technologies/devices/products under assessment and the SMEs/PAs supporting the activity.

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The following parameters are now suggested as interim SLCA indicators, selected on the basis of our experience and the conducted review:

Indicator	Definition	Stakeholders/ Region included	Pros-Cons	Method/ Reference
Working hours	Amount of hours worked per monetary output (activity variable) Ratio of working hours to global (impact)	SH: Workers Region: Developing Countries (raw material, electrical/electronic components, production phases)	-Major stakeholders are excluded -Interpretation? +Existing Databases	(Benoit-Norris et al., 2012) SHDB and EXIOBASE databases
Added Value	Added value of the product system (€/FU)	SH: all Region: all supply chain	-Only positive impacts (no indication of i.e. inequality)	(Zimdars et al., 2018)
Job generation or Local Added Value	Local jobs generated by the RES Technology	SH: Workers, Local Community, Society Region: local (EU)	+significant goal for the EU Commission	Zimdars et al. 2018
Human health	Increased damage on human health (DALY, QALY) or related risk (%)	Workers, Society, Community Region: all supply chain	+linked also to environmental assessment	to be discussed and chosen together with other partners (QALY or DALY)
Fair minimum wage	Fair minimum wage based on ILO principles, relative to a country benchmark	SH: Workers, Community, Society, Value Chain actors Region: non-EU /developing countries	+implies a group of conditions/targets under which several additional aspects are covered	(Croes & Vermeulen, 2016)

Table 29 - SLCA indicators and related methods

This first approach would require agreeing on a reduced set of key social indicators (as preliminarily suggested here) and incorporating them to the LCSA framework, which also includes 5 environmental indicators (4.3.1), 1 energy indicator (4.3.2) and 2 economic indicators (4.3.3).

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A second possible approach, to be discussed with the UoY and CIRCE partners, is to address a whole existing set of social indicators, e.g. as deployed by the social hotspot database (SHDB: (https://www.socialhotspot.org/), which includes more than 700 indicators grouped in 16 social themes and re-grouped in 5 social categories (Takeda et al., 2019 present a case-study application). The whole set of indicators can be taken as deployed by the SHDB (which includes its impacts across the supply chain of processes and products), and agree on a subset of those, as well as the weighting method. This choice will involve a relevant complexity in the assessment and a higher uncertainty after the grouping and weighting.

Multiple Criteria Decision-Making methods

The introduction of this family of methods is necessary in LCSA, because the scope of the impacts covered is expanded beyond the basic climate change and energy indicators to include important socio-economic aspects, in terms of Life Cycle Costing and Social Life Cycle Assessment. Those studies that went beyond the classic LCA, adopt different MCDM methods. MCDM are useful mathematical tools that incorporate the preferences and value choices of the involved stakeholders and/or decision-makers to identify the most relevant options according to their stated preferences (Kalbar & Das, 2020; Wang et al., 2009). Multi-attribute decision making (MADM) methods are those associated with decision-making problems involving a finite number of alternatives, which is our case. Appropriate weighting and MCDM method selection is non-trivial and could in itself be a multi-criteria decision-making problem (Wang et al., 2009).

A comprehensive study will be conducted by CIRCE among the sector and main stakeholders involved, in order to identify and prioritise social impact categories, subcategories and corresponding indicators to be assessed (i.e. materiality analysis). The indicators will be grouped into specific topics. With regard to Social Life Cycle Inventory, quantitative, semi-quantitative and qualitative data will be collected in the XPRESS Survey (WP2) in order to cover social dimensions in terms of the social impact categories, subcategories and indicators selected. The presence in the XPRESS of companies and research institutes guarantees the contribution of various stakeholders and different points of view to conduct the social analysis of the proposed processes. Finally, the potential positive and/or negative social impacts on related stakeholders within life-cycle stages will be evaluated with a multi-criteria approach and scoring system for

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decision-making. The comparison is contemporary performed at indicator level, at the topic level, and at the end by an aggregated Sustainability Performance Index.

Other possibilities include outranking methods, which provide partial/complete rankings (ELECTRE family, PROMETHEE) and distance-based methods (compensatory, compromising methods like TOPSIS) which can be both useful for the goal of this framework (Kalbar & Das, 2012). The TOPSIS method chooses the alternative that is nearest to the formulated ideal solution and farthest from the formulated non-ideal solution. The ideal and non-ideal solutions are defined based on the type of attribute (cost or benefit type) and can thus handle multidimensional problems (Kalbar et al., 2015).

Equal weighted sum method is the most commonly used approach in sustainable energy systems (Pohekar & Ramachandran, 2004; Wang et al., 2009), also referred to as multi-attribute value theory (Atilgan & Azapagic, 2016), as it has been observed in several multi-criteria studies (Dombi et al., 2014; Fan et al., 2018; Santoyo-Castelazo & Azapagic, 2014; Takeda et al., 2019; Traverso et al., 2012).

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4.4. Sensitivity Analysis

The conduction of a life-cycle analysis on complex products and systems certainly involves numerous assumptions. Firstly, the XPRESS project aims to compare multiple RES Technologies among them and this requires that all the solutions have to be analyzed according to a common methodological structure and on the basis of the same level of the quality of the input data. Since the input data are gathered from several subjects from various geographic locations, a set of assumptions needs to be put in place. In the same way, many assumptions are necessary because of the intent to define an average scenario at European level.

A second goal of the XPRESS project is to analyse the environmental, economic and social variations resulting from the improvement of the RES Technologies over the next decades, according to a set of forecast scenarios.

The introduction of multiple assumptions causes a high level of uncertainty in the assessment outcomes; therefore, a sensitivity analysis is needed to establish the consistency of the results of the LCSA.

The main reference for the sensitivity analysis is provided by the ISO 14044 standard. It identifies the variation of the system boundaries, in order to include/exclude the input and output flows other than those included in the initial assessment, as the methods to verify the consistency of the study. When a sensitivity analysis is carried out, some parameters are varied to understand the effects generated on the final results.

An exemplary and non-exhaustive list of the elements to be submitted to the sensitivity analysis includes:

- the amount of energy produced during the useful life of the product
- the amount of energy absorbed during the production process and maintenance of the power plant
- the Reference Service Life of the products
- the purchase and operative costs
- the discounting rates of the future costs
- the evolution in the use of RES Technologies in the near future.

The sensitivity analysis will be conducted in accordance with ISO 14044.

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5. Conclusions

This deliverable was prepared with the aim to setup the general framework for the whole sustainability assessment of RES Technologies in the European context. The evaluation will be conducted in a life-cycle perspective, adopting two complementary approaches: the "Product Approach" and the "System Approach". The first one is useful to describe the sustainability profile of products, from the point of view of the producers and taking into account the implications of the production process, in a life scenario from cradle to gate. On the contrary, the latter is a good option for describing the effects of the RES Technology under assessment in its operational context and from the point of view of the Public Authorities. Therefore, the life scenario is extended from cradle to grave, with the goal to include into the system boundaries the operational and maintenance aspects of the technology up to the end of its life.

The sustainability evaluation adopts the life-cycle methodology with a contextual analysis on the environmental, economic and social aspects. More specifically, a Life Cycle Sustainability Assessment will be conducted to describe the RES Technologies available on the European market and purchased by the European Public Authorities. It will be composed by Life Cycle Assessment for the environmental aspects, Life Cycle Costs for the economic issues and Social Life Cycle Assessment for the social matters. The final outcomes will be composed and weighed with a Multiple Criteria Decision-Making method to produce a scoring of the various available technologies.

The RES Technologies under assessment will be: photovoltaic systems (PV), concentrated solar power systems (CSP), solar thermal collector systems, wind turbines, hydropower, electrical vehicles, bioenergy heating systems, heat pumps, district heating systems, geothermal systems. The outcomes of the research will be described using 5 environmental indicators (section 4.3.1), 1 energy indicator (section 4.3.2), 2 economic indicators (section 4.3.3) and 5 social indicators to be confirmed (section 4.3.4). The main environmental categories under consideration will be: Carbon Footprint, Land Use Footprint, Water Footprint, Mineral Footprint and Acidification. The main energy category will be: Energy Payback Time. The main economic categories will be: Payback Time and Levelised LCC, which includes production costs, operation & maintenance costs and End of Life costs. The main social categories will be: working hours, Added Value, Job

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generation or Local Added Value, Human health and Fair minimum wage. Finally, a Multiple Criteria Decision-Making method will be adopted to weigh and aggregate all the indicators with the goal of classifying the RES Technologies on the basis of their sustainability level and provide the Public Authorities with a decision-making tool.

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