*Smart system of renewable energy storage based on **IN**tegrated E**V**s and b**A**tteries to empower mobile, **D**istributed and centralised **E**nergy storage in the distribution grid*

Deliverable nº:	**D3.4**
Deliverable name:	**Draft Life Cycle Assessment**
Version:	**1.0**
Release date:	**11/12/2018**
Dissemination level:	**Public**
Status:	**Submitted**
Author:	**UPC – Íngrid Munné Collado, Fabio Maria Aprà**

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 731148.

Document history:

Version	Date of issue	Content and changes	Edited by
0.1	24/10/2018	First draft version	Íngrid Munné Collado Fabio Aprà
0.2	24/11/2018	Second draft version	Íngrid Munné Collado Marja Myllysilta
0.3	26/11/2018	Third draft version. Suggested changes from the german pilot-site responsible person have been included.	Íngrid Munné Collado Fabio Aprà
0.4	05/12/2018	Peer-reviewed by Bernt Bremdal. Suggested changes have been included	Bernt Bremdal Ingrid Munné Collado Fabio Aprà
0.5	10/12/2018	Suggested changes from Ramon Gallart (Estabanell), Patrick Rademakers (Elaad) and Michel Bayings (GreenFlux) have been included	Ingrid Munné Collado Fabio Aprà
1.0	11/12/2018	Peer-reviewed by Dimitar Stanev (Albena). Suggested changes from Jefta van Hees (GreenFlux) have been included	Dimitar Stanev Íngrid Munné Collado

Peer reviewed by:

Partner	Reviewer
SmartIN	Bernt Bremdal
Albena	Dimitar Stanev

Deliverable beneficiaries:

WP / Task
WP2, WP3, WP6, WP10

Table of contents

Executive summary **6**

1. Introduction **7**

2. Life Cycle Assessment Concept **8**

2.1 Definition 8

3 Life Cycle Assessment Methodology **9**

3.1 Standardized references 9

3.2 Screening LCA of INVADE 10

3.3 Steps 10

3.3.1 Goal & Scope 11

3.3.2 Life Cycle Inventory (LCI) 15

3.3.3 Life Cycle Impact Assessment (LCIA) 16

3.3.4 Interpretation 19

3.4 Tools 19

4 Life Cycle Inventory (LCI) **20**

4.1 LCI in the INVADE Project 20

4.2 Pilot sites 22

4.2.1 Norwegian Pilot Site 23

4.2.2 Dutch Pilot Site 25

4.2.3 Bulgarian Pilot Site 27

4.2.4 Spanish/Catalan Pilot Site 28

4.2.5 German Pilot Site 29

4.2.6 Use cases in INVADE project 31

5 Pilot sites technologies **34**

5.1 PV Panels 34
5.2 Batteries 36
5.3 Flexible Loads & Local Controllers 39
5.4 EV chargers 40
5.5 Electricity grid mixes 42
5.5.1 The importance of the peak hours 42
5.5.2 Data collection and general methodology 42
5.5.3 Assumptions and system boundaries 46
5.5.4 Dutch electricity grid mix 47
5.5.5 Norwegian electricity grid mix 48
5.5.6 Bulgarian electricity grid mix 52
5.5.7 Spanish electricity grid mix 56
5.5.8 German electricity grid mix 61
6 Conclusions and further research needs 63
7 References....65
A. Appendix....67

Abbreviations and Acronyms

Acronym	Description
EOL	End Of Life
DER	Distributed Energy Resource
DSO	Distribution System Operator
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PSR	Pilot Site Responsible
PUC	Public Use Case
PV	Photovoltaic
ToU	Time-Of-Use
TSO	Transmission System Operator
V2G	Vehicle to Grid
WP	Work Package

Executive summary

This report contains the first version of the Life Cycle Assessment model that is one of the tasks under WP3: Exploitation. In this work package the previous deliverable, D3.3 addressed the expected impacts from the project and is concerned with aspects of sustainability within the framework of societal impact and social responsibility programs. The current task, T3.7, deals with the Life Cycle Assessment of the INVADE system. This task aims to assess the overall environmental impacts of the system, considering all pilot sites and all the technologies installed on each pilot site. The main result of this task will be the potential environmental impact assessment in terms of CO_2 emissions, compared with the current reference. By developing the Life Cycle Assessment model, recommendations can be extracted and applied on the exploitation strategy.

In this task, two deliverables are expected. This deliverable D3.4 provides the Screening LCA, detailing the methodology that is going to be implemented according to standardized references, the pilot sites assessed, the technologies that are going to be involved, as well as all the information regarding each pilot site. The second deliverable D3.5 will continue on this analysis and develop the final LCA model for each pilot site, considering the base scenario and the INVADE scenario. The final deliverable D3.5 can be an important input to the overall WP3 and hence, it can become an important component of the Total Society Impact (TSI) factor [1].

This deliverable documents the method developed to assess the potential environmental impacts of the INVADE Project. It contains a description of the ISO 14040 and the ISO 14044 methodologies that are applied to assess the potential environmental impacts. Secondly, it specifies the theoretical characteristics of the INVADE LCA according to the previously detailed methodologies. Third, the Life Cycle Inventory step is detailed, explaining the process where representatives of all the pilot sites have participated to define the technologies. Later, a specific analysis of each pilot site technology such as PV panels, Batteries, Local controllers, EV chargers and the electricity grid mix is detailed in Section 6. Finally, the document provides conclusions and further research needs, as well as the next steps to be done for the development of the second part of the task T3.7 and the deliverable D3.5.

This task is being performed by UPC with the support of VTT, which also has expertise in Life Cycle Assessment. VTT is collaborating in this WP since this task is directly related to WP6 in terms of potential environmental impacts assessment.

1. Introduction

Sustainability has become a major issue related to all processes, products and activities. Climate change is one of the major concerns in the human kind and by assessing the impacts of climate change, we may find new ways to improve our operations and mitigate the effects of human activities. Life Cycle Assessment can be used to analyse the potential environmental impacts of any process, product, system or service. Right now, while we are immersed in the peak integration of renewable energies alongside the grid (both transmission and distribution), several questions regarding the sustainability of these technologies have arisen. Hence, the development of LCA in this project is needed to analyse the environmental impacts of new technologies, besides the purpose of increasing the integration of DERs. As a result, the INVADE project has defined a task to analyse the potential environmental impacts of the overall INVADE system.

This document aims to provide the methodology according to standardized references as ISO 14040 and 14044 to assess the potential environmental impacts of the INVADE Project. This methodology will be applied in a later stage, and will be documented in the deliverable D3.5.

Under this system, all pilot sites in Germany, Bulgaria, Norway, the Netherlands and Spain are considered; as well as all the technologies that are implemented in each pilot site: PV Panels, EV chargers, Local controllers, Flexible Loads, distributed and centralized energy storage systems, and the electricity grid mixes. During the work performed for the development of the LCA, the communication with the pilot site responsible persons has been important to develop the models which serve as a basis for our analysis. In that sense, Section 3.3.2 details the Life Cycle Inventory form, that has been required to detail the pilot site purpose, the devices that are located in the pilot site, the scenarios to be considered, as well as the definition of the base line and the INVADE scenario. After detailing the LCI of each pilot site, each technology is analysed and then clustered if possible, between the different pilot sites. This facilitates the development of the task.

Finally, conclusions are detailed in Section 6, and the further research needs. Since this deliverable comprises the Screening LCA of the INVADE system, deliverable D3.5 will continue on the potential environmental impacts calculations, considering the methodology and the preliminary results detailed in this document.

2. Life Cycle Assessment Concept

2.1 Definition

LCA, or Life Cycle Assessment, is a tool that enables evaluating the potential environmental impacts of a product during its entire lifetime, starting from a series of inputs and outputs related to the product itself. The International Standardization Organization has specified the standards ISO 14040 and ISO 14044 [2] that provide framework for the LCA in this task .

There are many intended use applications for an LCA: comparison of specifics goods and services, monitoring environmental impacts of a product and even of an entire industry sector, greening the supply chain. As well, it is very useful as a policy information: it can help public institutions, industries and decision makers in general to let them choose the right pathway to develop a new project, regarding its environmental performances. As companies experience serious challenges regarding their relationship with the society overall and their customers LCA emerges as a prime instrument and reference in order to achieve societal and customer approval. The millennials constitute a market segment that is more societal oriented in several ways compared to the generation before. Large investment funds divest from companies that are a liability to the society and nature. Media pays acute attention to possible violations of proper conduct with respect to people's welfare and environmental threats. Most of the project partners promote a social responsibility with respect to sustainability. The principal question that needs an answer is whether such declarations of societal responsibility are truly genuine. This issue should then be followed up with the question on how INVADE can improve the overall sustainability aspect and the present CO2 footprint.

LCA is an effective tool also because it can perform a multi-media (air, water, waste, resources depletion, etc.) analysis and at the same time, the results cover multi-attributes (Global Warming Potential, Abiotic Depletion Potential, Acidification Potential, etc.) impacts.

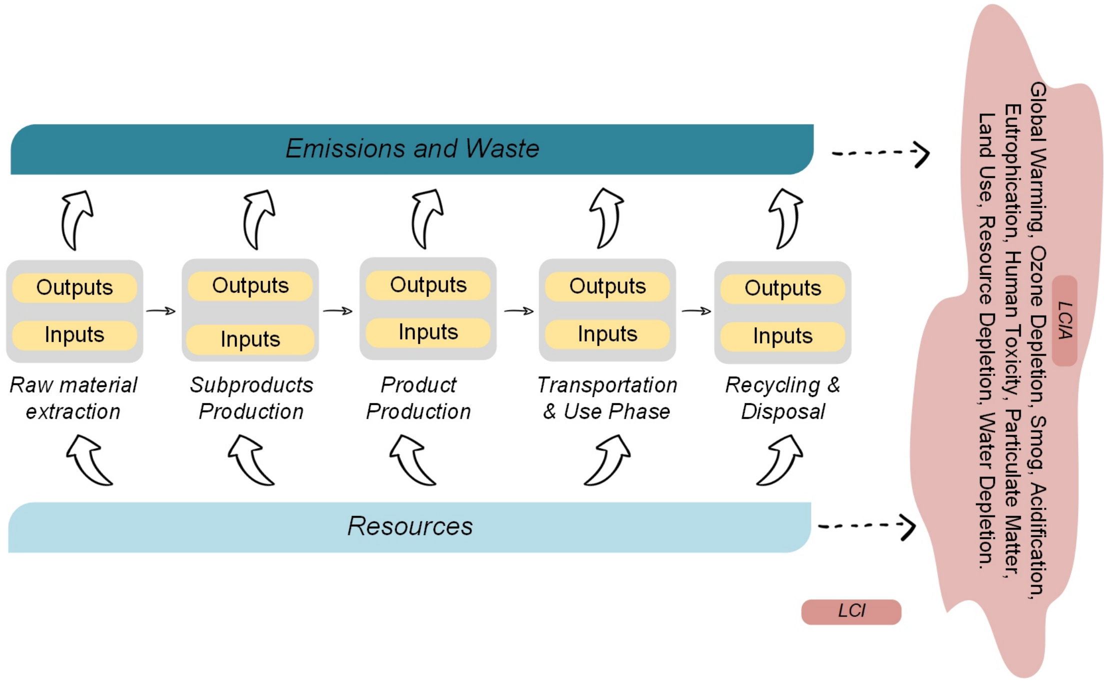


Figure 1 - Overview of a LCA process

3 Life Cycle Assessment Methodology

3.1 Standardized references

As already mentioned before, ISO 14040 and ISO 14044 are the two existing standardized references for the LCA procedure. The first one, ISO 14040, regards the principles and the framework of a LCA. The second one explains the requirements and the guidelines to perform a valuable LCA. The European Commission accepts these two references and it recognizes LCA as the best process currently available, to assess the potential impacts on the environment of a product/project [3]. More specific about Life Cycle Assessment and its performances can be found on the LCA European Platform [4]. Another interesting document is the ILCD Handbook [5] elaborated by the European Commission and the Joint Research Centre. This handbook is essentially a resume of the background analysis of existing methods, including the nomenclature and terminology used for LCA and it can be seen as a general guide, because it is based on ISO 14040 and 14044.

3.2 Screening LCA of INVADE

This document aims to provide the first calculation on the INVADE Life Cycle Assessment, also known as Screening LCA. LCA is considered an iterative process as it can be detected from Figure 2. The first iteration loop prefers to the Screening LCA approach in INVADE. It stands for defining the value chains and devices, calculation model and data collection. The data that is considered for this assessment are those that are available readily in literature and databases.

In the following sections, the screening LCA of the INVADE system is presented. Alongside these pages, the standardized references are detailed, as well as the definition of all the steps to perform the LCA of the INVADE system.

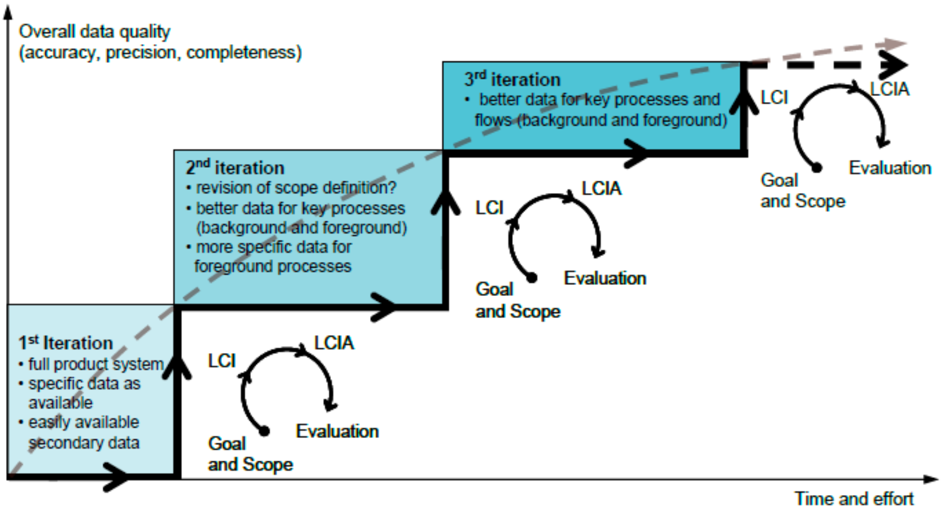


Figure 2 - Iterative nature of LCA.

3.3 Steps

The recommended structure to perform a Life Cycle Analysis is shown in Figure 3. According to ISO 14040 and ISO 14044, the four needed steps are **Goal and Scope definition**, **Life Cycle Inventory**, **Life Cycle Impact Assessment** and **Interpretation of the results**. The two-way arrows in the figure reflect that the LCA is an iterative process and it means that the steps can be re-performed during the process because of different reasons (recollection of data, goal and scope of the results, etc.).

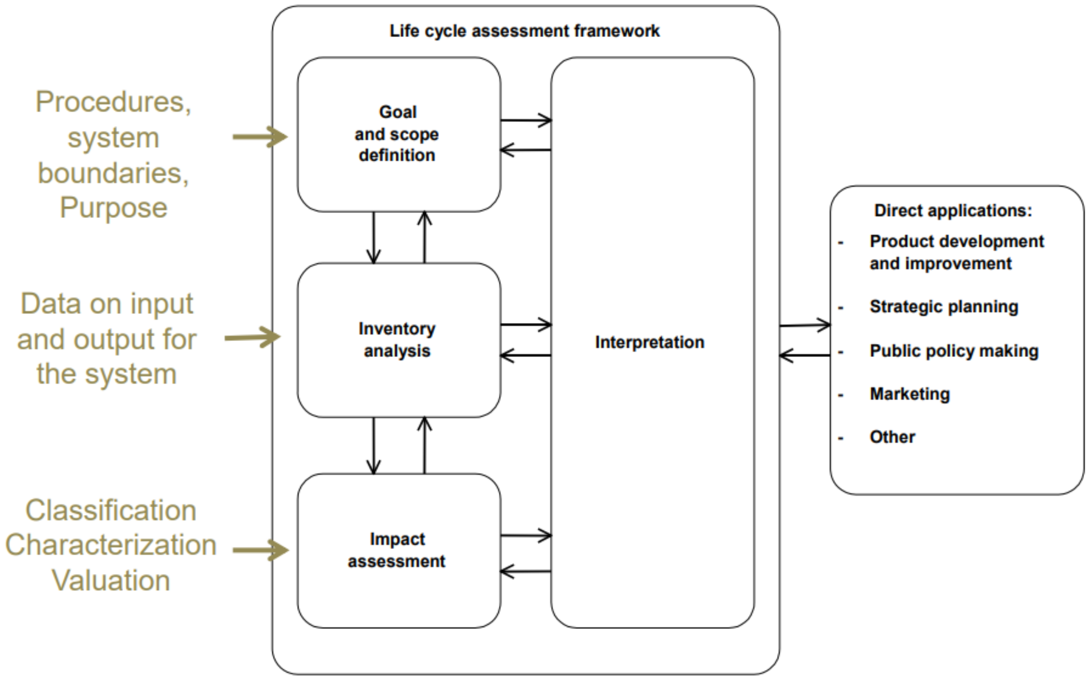


Figure 3 - *LCA steps according to ISO 14040 and ISO 14044*

3.3.1 Goal & Scope

The first step of a Life Cycle Analysis is to define the objectives. Goal and scope should be consistent related to the product/project and they have to be clearly defined. If the reader already knows the common categories of any screening LCA and their meanings, we suggest him/her to go directly to Table 1, where the INVADE screening LCA is presented. If something would be unclear, he/she can refer to sections 3.3.1.1 and 3.3.1.2

3.3.1.1 Goal

To define the goal of the LCA, different points have to be taken into consideration:

- *Intended application*: marketing, product improvement, product development, product evaluation, strategic planning, etc.
- *Purpose of the study*: is the study made for an internal analysis or to be published? Different purposes require different types of writing, more or less technical and comprehensive.
- *Intended audience*: Who will utilize the LCA results? It can be a stakeholder of the project, the public administration, engineers, customers, etc.

- *Comparative analysis*: If the LCA compares two different alternatives, it should be defined at the beginning of the report.

3.3.1.2 Scope

The scope of the study frames the system that will be analysed. In this step, the assumptions and the methodology of the process should be precisely defined. It is a priority in this stage, to let the reader having a clear comprehension on which are the relevant points of the study:

- *Function of the product:* refers to a basic description of how the product/system works.
- *Functional unit:* it is one of the most important definitions since the results are based on this. The unit is related to the product or system to be analysed and it has to give a good qualitative and quantitative description of the process. It is not always easy to evaluate, because the functions and the performances of the product cannot be easily described or isolated. The comparison between different systems is made on the basis of this equivalent function and a clearly quantitative measure is crucial for comparative LCAs (e.g. a 10 kWh battery for a plug-in hybrid electric vehicle capable of sustaining 3000 charge cycles).
- *Reference flow:* the reference flow is the measurement of product materials and components needed to fulfil the function, as it has been defined in the functional unit. The data used in the Life Cycle Assessment should be calculated referring to the reference flow.
- *Description of the system:* performing the description of the studied system allows the reader to better understand the specifics.
- *System Boundaries:* the system boundaries limit the LCA scope. To not let the analysis be too broad or too less specific, who performs a Life Cycle Assessment should set some boundaries to simplify the study case. There are several options to set up the system boundaries for a LCA. The most complete *Cradle to Grave*; the *Cradle to Gate* which takes into consideration just until the use process of the product; the *Gate to Grave* that includes the processes between the factory gate and the disposal of the product; the *Gate to Gate* which starts from the reception of raw material until the factory gate. In Figure 4 the first two examples are shown in a more direct way.

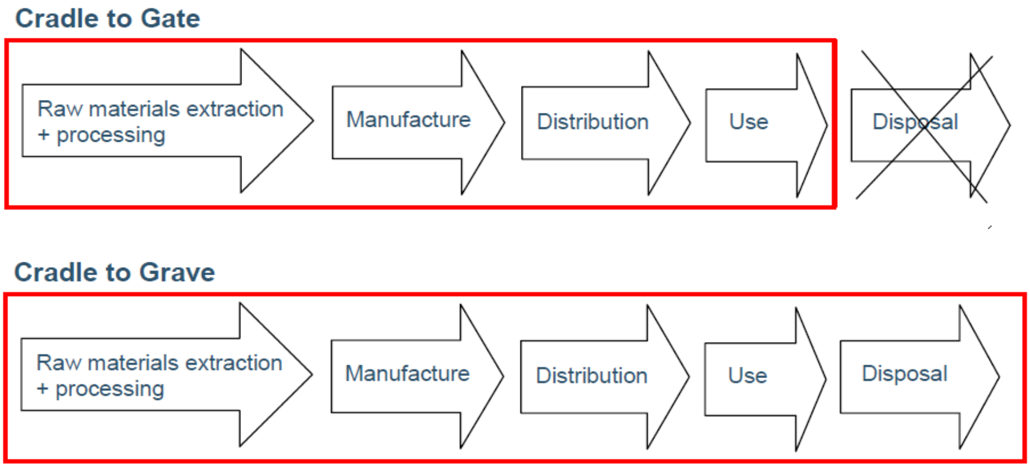


Figure 4 - Cradle to Gate and Cradle to Grave system boundaries examples

- *Allocation Procedures:* for example, in multi-output processes different by-products are manufactured, thus, it is needed to portion the inputs and outputs of the system in order to allocate the justified quantities (of material, energy, waste) to the different by-products. Finding the suitable allocation factor may be sometimes problematic, and there might be significant impact of these choices on the LCA results. Hence, according to ISO 14040 and ISO 14044 recommendations [2], allocation should be avoided whenever possible.
- *Impact categories and Impact assessment method:* the results of a Life Cycle Assessment are expressed with the help of the inventory results and the impact assessment method. The method includes typically different environmental impacts such as climate change. The impact categories include emission-specific characterization factors to express the potential environmental impact (e.g. regarding the Atmosphere: climate change, ozone depletion, smog formation; Hydrosphere: eutrophication, acidification; Biosphere: soil depletion, deforestation).
- Data requirements: it is needed to evaluate the quality of the data to further analyse. All the data requirements should be properly documented. The more detailed the data, the more relevant the LCA.

Table 1 defines each of the categories under the Goal and Scope step of the INVADE screening LCA, considering the points detailed previously. This table aims to provide the reader with the main assumptions and definitions of the analysis.

Table 1: INVADE Project screening LCA description

INVADE Project Screening LCA		
GOAL	**Intended application**	Product evaluation, by assessing the potential environmental impacts of the cloud-based market platform for flexibility services in each pilot site.
	Purpose of the study	Provide the pilot operators and their value chain partners environmental information such as climate change impacts on their own energy system and devices. Identify and suggest a set of environmental indicators to be included into INVADE cloud-based platform.
	Intended audience	This analysis is going to be public. The target audiences of this assessment are the consortia partners, the pilot sites responsible persons, and the European Commission.
	Comparative analysis	Two different scenarios are considered for each pilot site: baseline and INVADE scenario. No comparison between pilots or different products (e.g. batteries) are intended.
SCOPE	**Function of the system**	The pilot systems consider energy production, distribution, and consumption. Each pilot site has a main purpose to implement the INVADE cloud-based platform for flexibility services, depending on the flexibility customer, according to deliverable D4.3: - Congestion management (DSO) - Voltage/ Reactive Power control (DSO) - Controlled islanding (DSO) - Day-ahead portfolio optimization (BRP) - Intraday portfolio optimization (BRP) - Self-balancing portfolio optimization (BRP) - ToU optimization (Prosumer) - kW_{max} control (Prosumer) - Self-balancing (Prosumer) - Controlled islanding (Prosumer)
	Functional unit	1 kWh

	Reference flow	Energy flow (kWh), of electrical energy. It refers to energy provided by the pilots on a specified time period and it will be specified for each pilot in the next phase of the project.
	Description of the system	The INVADE pilot systems are based on DERs such as PV panels, Centralized Energy Storage (CES), Distributed Energy Storage (DES), Space heaters and water boilers as flexible loads and controlled by Local Controllers, One-way EV Chargers, bidirectional EV chargers
	System boundaries	Screening LCA focuses on devices/energy products from the cradle to gate, i.e. no usage and disposal is included under the screening LCA. Later stages will consider the usage phase of the devices during the pilot tests. Regarding the batteries, cradle to grave will be considered.
	Allocation procedures	Allocation methods are integrated into the life cycle inventory database datasets as mainly secondary data is used. For ecoinvent data, the “cut-off” system model has been chosen.
	Impact Assessment Method	CML 2015. Impact category to be assessed: GWP [kg $CO_{2\ eq}$/ kWh]. Also known as Carbon footprint.
	Data requirements	Primary data used from information provided by the pilot site responsible and from direct communication with manufacturers. Secondary data used from Literature and LCA specific Databases: GaBi and ecoinvent.

3.3.2 Life Cycle Inventory (LCI)

The main objective of this stage is to compile an inventory of energy and material inputs and environmental outputs across the whole lifetime, referred on the goal & scope phase.

Data collection is the basis of the Inventory Analysis. This is one of the most time-consuming parts when performing a LCA. It demands a detailed knowledge of the processes included inside the system boundaries.

The references ISO 14040 and 14044 [2] suggest certain criteria for the data collection in order to perform a valuable LCA:

- *Data quality*: data should be able to satisfy stated requirements.

- *Data acquisition*: measured, calculated or estimated? Primary data (measured) or secondary data (calculated, taken out from literature and database)?

- *Time-reference*: when was the data obtained and until when it is supposed to be valid?

- *Geographical reference*: from where the data was obtained (Country or Region)?

- *Technology coverage*: define specific single technology or technologies mix.

- *Uncertainty of the information*: define assumptions and limitations of the model.

An example of the general structure of the LCI phase is shown in Figure **5**.

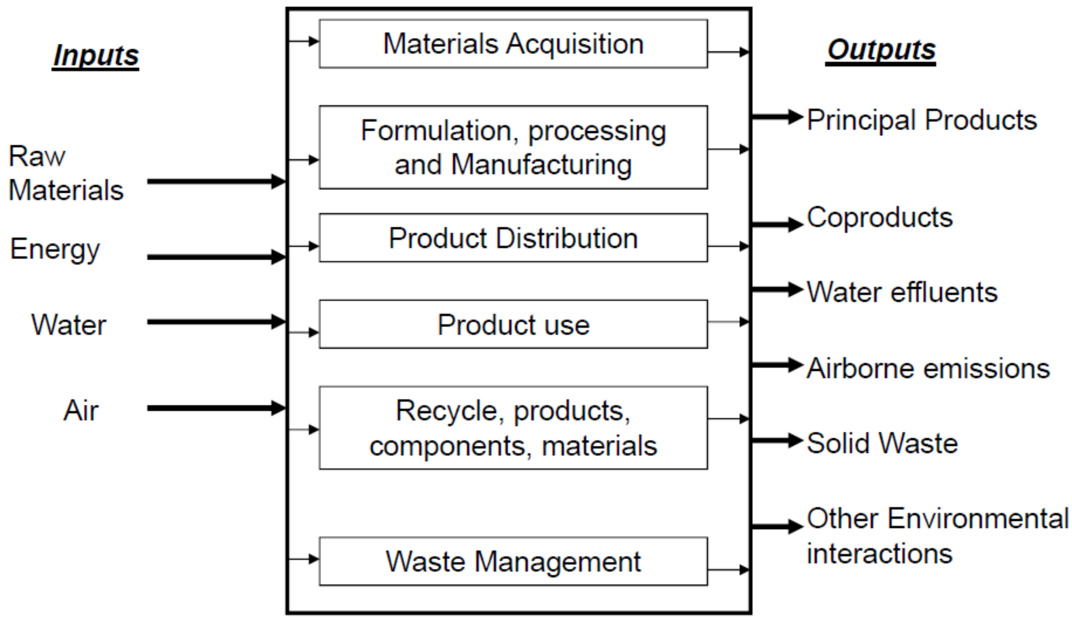


Figure 5 - inputs/outputs analysis for LCI

3.3.3 Life Cycle Impact Assessment (LCIA)

Emissions, used raw materials, and energy demand quantified in "Inventory Analysis" are translated into the related environmental impacts. This is carried out within the following mandatory steps: *Selection of impact categories*, *Classification* and *Characterisation* [2].

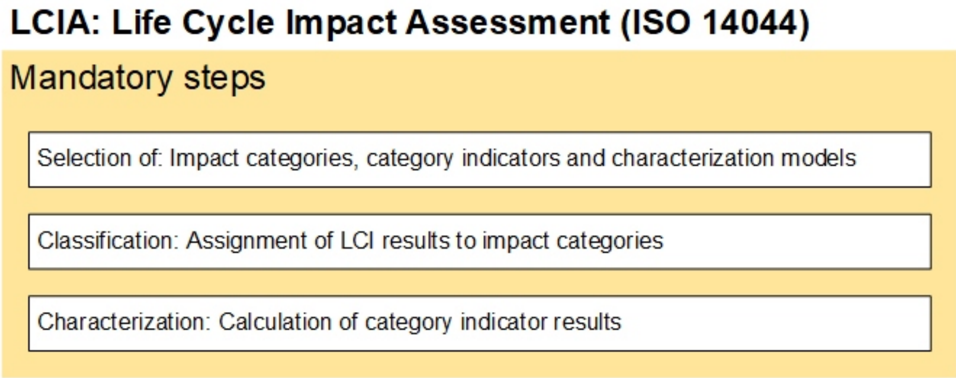


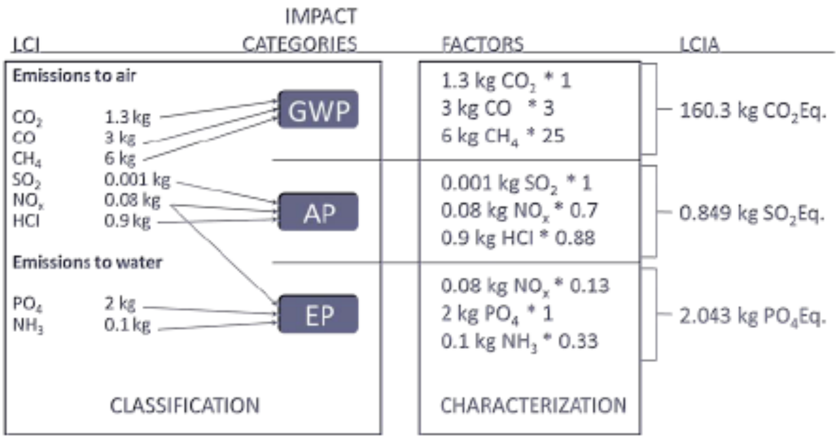
Figure 6 - LCIA mandatory steps according to ISO 14044

It is possible to set up the right environmental impact categories, by knowing the analysed system (*Selection*). From the impact categories, the environmental indicators should be extracted to analyse the effective environmental impacts of the product/project. These indicators have to be linked to the elementary flows of the system (*Classification*).

The next mandatory step (*Characterization*) involves the quantification of the impact of interest relative to a reference substance (e.g. Global Warming Potential (GWP): measure for Global Warming in terms of radiative forcing of a mass-unit [kg CO_2-eq]).

Finally, the environmental indicator results are calculated, summing up all the indicator results from the different stages of the product's lifetime, resulting to be total effective environmental impact for each indicator. An example of the general structure of the LCIA phase is shown in Figure 7.

.



3.3.3.1 Definitions

Impact category: class that represents environmental issues of concern to which Life Cycle Inventory analysis may be assigned (ISO 14044) [6].

The most common impact categories include Global Warming, Acidification, Eutrophication, Stratospheric Ozone depletion, Smog creation, Toxicity, Resource depletion, Water depletion, Land use and transformation, Primary energy demand, Particulate matter and Ionizing radiation.

Characterization model: This is the model that calculates the environmental impacts by describing the relationship between the LCI results and category indicators [6]. There are several characterization models available to assess the potential environmental impacts of a certain system. The most commonly used are named CML, TRACI and ReCiPe. In order not to be redundant and to give the reader a clearer vision of what a characterization model is, only the first one (which is the one we look at for INVADE) will be described.

- CML Impact Method

CML is a problem-oriented LCA method developed by the Institute of Environmental Sciences of the University of Leiden. It aims to offer the best practices for midpoint indicators (environmental problems) and to operationalize the ISO 14040 series of standards. It uses the European impact assessment models and it is considered the most complete methodology. The first model was released in 1996. In 2001, CML developed their main methodology update. Since then, they have implemented some updates on different substances.

3.3.3.2 Selection of impact categories

The impact categories are classes of interest that represent issues of concern to which the life cycle inventory analysis may be assigned (ISO 14044) [6]. There are different impact categories that can be taken into account during the LCIA process, but they should be decided in advance and be consistent with the goal of the study.

For this deliverable, just the Global Warming Potential results have been taken into account because it is certainly the most important indicator related to Climate Change and the one for which there are the biggest amount of data. Further reports will include all the different indicators that are consistent with the scope of the project. For further information, there is a detailed table on impact categories according to CML 2015 in Appendix A.

3.3.4 Interpretation

This stage is the last one and the most interesting one of the whole Life Cycle Assessment. Changes are possible, because of the iterative procedure that affects the LCA. The interpretation of the results is needed to assess the real and effective environmental impact of the product or project that has been studied. Then, the results can be compared with the existing literature, to observe if they are aligned with the goal and scope of the project. At this stage it is possible to understand if the right data and assumptions were taken into consideration, realizing which are the weaknesses and the limitations of the assessment.

Hence, the LCA interpretation should include:

- Identification of the significant issues based on the results of the LCI and LCIA phases of Life Cycle Assessment.
- A final evaluation of the system, which should consider all the main points present in the process.
- Conclusions, limitations and recommendations.

Furthermore, to assure that the LCA has been developed in a valuable way, the ISO 14044 suggests using three additional steps to estimate the quality of the report:

- *Completeness Check*: ensures that all relevant information and data needed for the interpretation are available and complete. [2]
- *Sensitivity analysis*: evaluates the accuracy of the results, by assessing their affection by uncertainties in the model's data.
- *Consistency check*: concludes whether the assumptions, data and methodology used are consistent with the goal and scope of the project. [2]

3.4 Tools

In order to carry out Life Cycle Assessment efficiently, software tools need to be used. LCA software tools allow the user to develop a model for a specific product or system. The software tools also typically have a library of secondary databases. The user just has to collect all the inputs (related to energy, mass, etc.) and outputs (energy, mass, emissions, waste), and then the software evaluates the potential environmental impacts, according to several life cycle impact methodologies available on its database.

In the screening LCA phase two different software tools GaBi and SULCA have been used. GaBi Software is developed by the German company PE International, thinkstep. This software contains a modular and parameterized architecture. Anyway, the user can also add external data types like economic costs or social impacts information.

4 Life Cycle Inventory (LCI)

4.1 LCI in the INVADE Project

Collaboration with the pilot site responsible has helped to clarify the pilot site structure, the elements placed for the INVADE project development, and to define in each case the baseline scenario and the INVADE scenario. More average data and models have been defined for Norwegian and Dutch pilots, which were more complex than the rest of the pilots. At least one meeting with each pilot site responsible was carried out to help the understanding process of the pilot site and the INVADE LCA. An LCI questionnaire was sent to be filled in by each pilot site responsible to have an overall view of the devices that are placed on each pilot site. Figure 7 shows the general LCI questionnaire that has been sent to each owner. The responsible person has been encouraged to fill in the form after the initial telco meeting. Also, in this questionnaire the baseline scenario and the INVADE scenario have been possible to define. Some pilot sites will be assessed entirely, as is the case of Bulgaria and Spain. On the other hand, for every single technology (e.g. PV panels), a model will be developed, taking into account all the different characteristics of the installed technologies (e.g. manufacturer, cell type, rated power). Doing so, we will obtain an average model of every single technology involved in the project. This is done instead of developing an LCA model of each specific technology installed at each household, that is currently out of the scope of the project. This will be done for decentralized use cases such as Norway, the Netherlands, and Germany. Decentralizing means using a variety of small, grid connected devices instead of a single bigger centralized energy storage.

Section 4.2.6 details both the complete pilot-site devices installed as well as the initial modelling approach.

QUESTIONNAIRE FOR INVADE LIFE CYCLE ASSESSMENT (LCA)

UPC - 14.05.2018

1. DOCUMENTATION

Pilot Site Name	
Country	
Contact person	
E-mail	
Date	

Leave empty rows if no data is required

2. PILOT SITE INFORMATION*(Add rows if needed)*

			Units (change and highlight if needed)
	Customers		no.
PV	Units		no.
	Manufacturer		
	Model		-
	Cell type		Monocrystalline/Polycrystalline
	Peak Power		kWp/unit
	Area		m2
	number of cells		no.
Storage (new)	Manufacturer		-
	Model		-
	Units		no.
	Energy		kWh
Storage (2nd Life)	Manufacturer		-
	Model		-
	Units		no.
	Energy		kWh
EV Charger	Manufacturer		-
	Model		-
	AC Rated Power		kW
EV Charger (Bidirectional)	Manufacturer		-
	Model		-
	DC Rated Power		kW
Flexible Loads	Water Boilers		units
	Peak Power		kW /unit
	Space Heaters		units
	Peak Power		kW /unit

Figure 7 - Life Cycle Inventory questionnaire

4.2 Pilot sites

The INVADE Project is based on 5 pilot-sites located in five countries: Norway, the Netherlands, Bulgaria, Spain and Germany. All the pilot-sites are implemented so as to develop different use cases to prove the cloud-based flexibility management platform to provide and use flexibility services for several purposes such as congestion management, load shifting, and voltage/reactive power control, for instance. Alongside this Section the main specs of each pilot site are presented, based on the information provided from direct communication with the pilot site responsible, and also from deliverable D10.1 that contains the Pilot Specifications. The defined pilots are defined in such way that can be easily expanded to a greater number of users, without requiring substantial changes in their system. In the following subsection two figures per pilot-site are presented, to represent the two scenarios considered for each pilot site. The approach for each pilot site is, as defined previously, from cradle to gate.

In general terms, the devices that are included in the pilot sites are of different nature, such as flexible loads, EVs, EV chargers, energy storage, PV panels and the main energy supply for the pilot to run. Figure 8 shows the general scheme of the Pilot-Site LCA.

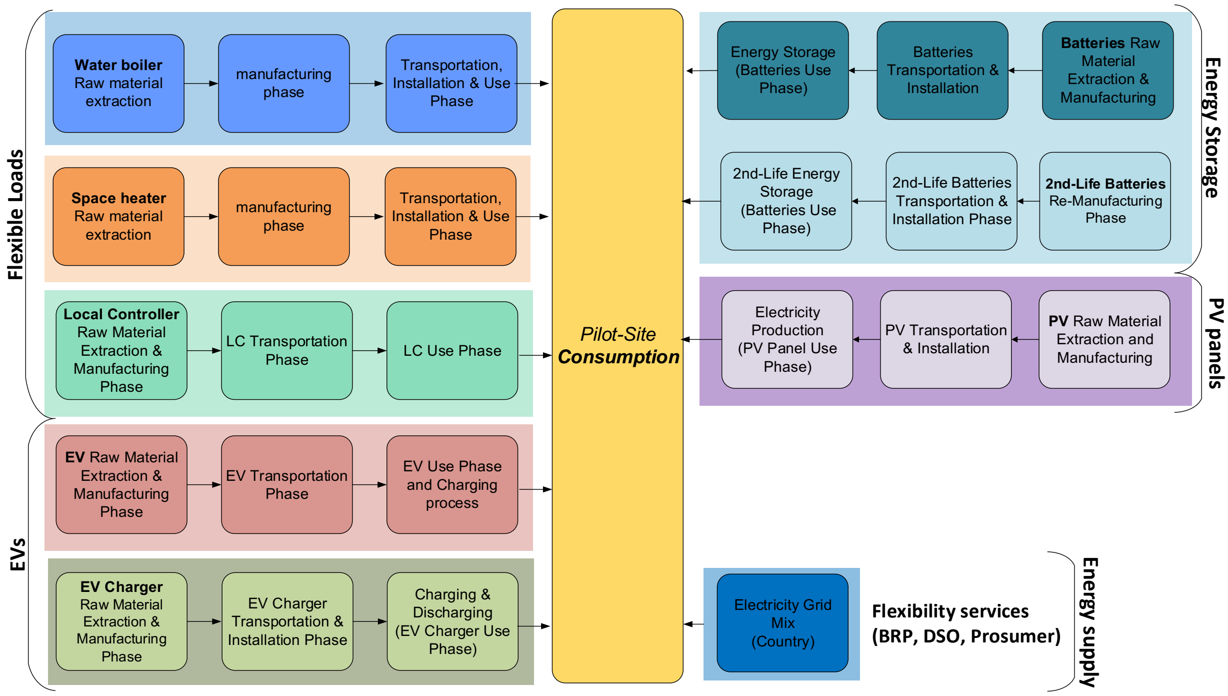


Figure 8: General scheme of the devices considered in the INVADE LCA.

4.2.1 Norwegian Pilot Site

The Norwegian Pilot Site is located in Lyse, in the Stavanger area. The pilot-site is based on households, Lyse headquarters, and housing cooperatives. The main aim of the pilot-site is to demonstrate the ability of the INVADE Platform to co-operate with an already existing Home Energy Management System (HEMS). There are different categories to describe all the different households, as stated in deliverable D10.1. According to these categories and the meetings developed, an average household model with the most installed devices in each household, and two different scenarios have been decided to assess the potential environmental impact of the INVADE platform in Norway.

Figure 9 details the baseline scenario of the Norwegian pilot site, containing a water boiler, a space heater and an EV. This is meant as a comparative reference for the INVADE set-up that is going to be tested. The energy supplied to the average household consumption is provided by the Norwegian electricity grid mix. Figure 10 represents the INVADE scenario and, in this case, the pilot site contains PV panels, new Distributed Energy Storage (DES), second-life DES, a local controller to control the water boiler flexible load, and an EV charger. In this case, the electricity supply is based both on the electricity grid mix, but also on the electricity supplied by the PV panels. By using the HEMS and the local controllers, three types of flexibility services are provided: ToU optimization by load shifting from high-prices to low-prices intervals, kW_{Max} control by means of peak-shaving and self-balancing by means of self-production and storage.

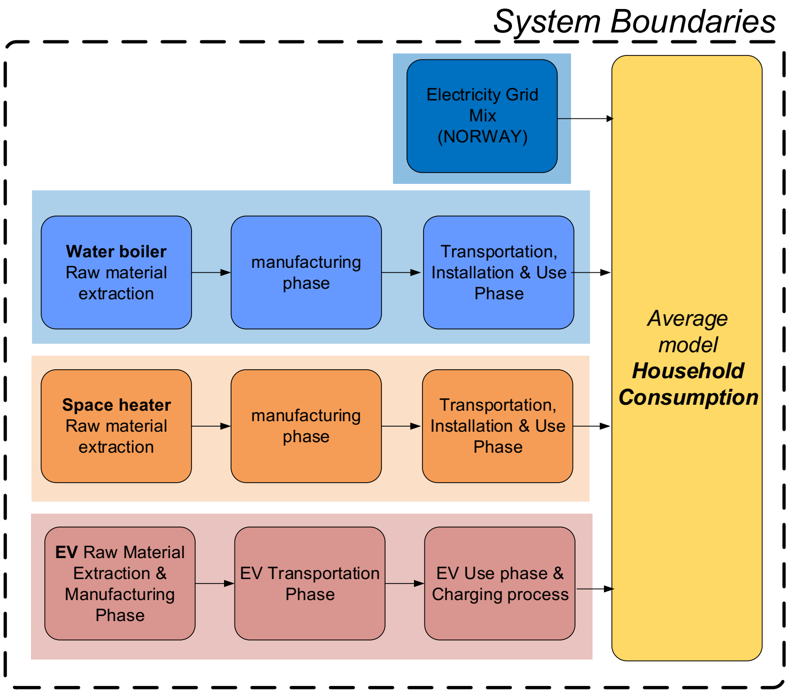


Figure 9: Norwegian Pilot-Site Baseline system boundaries.

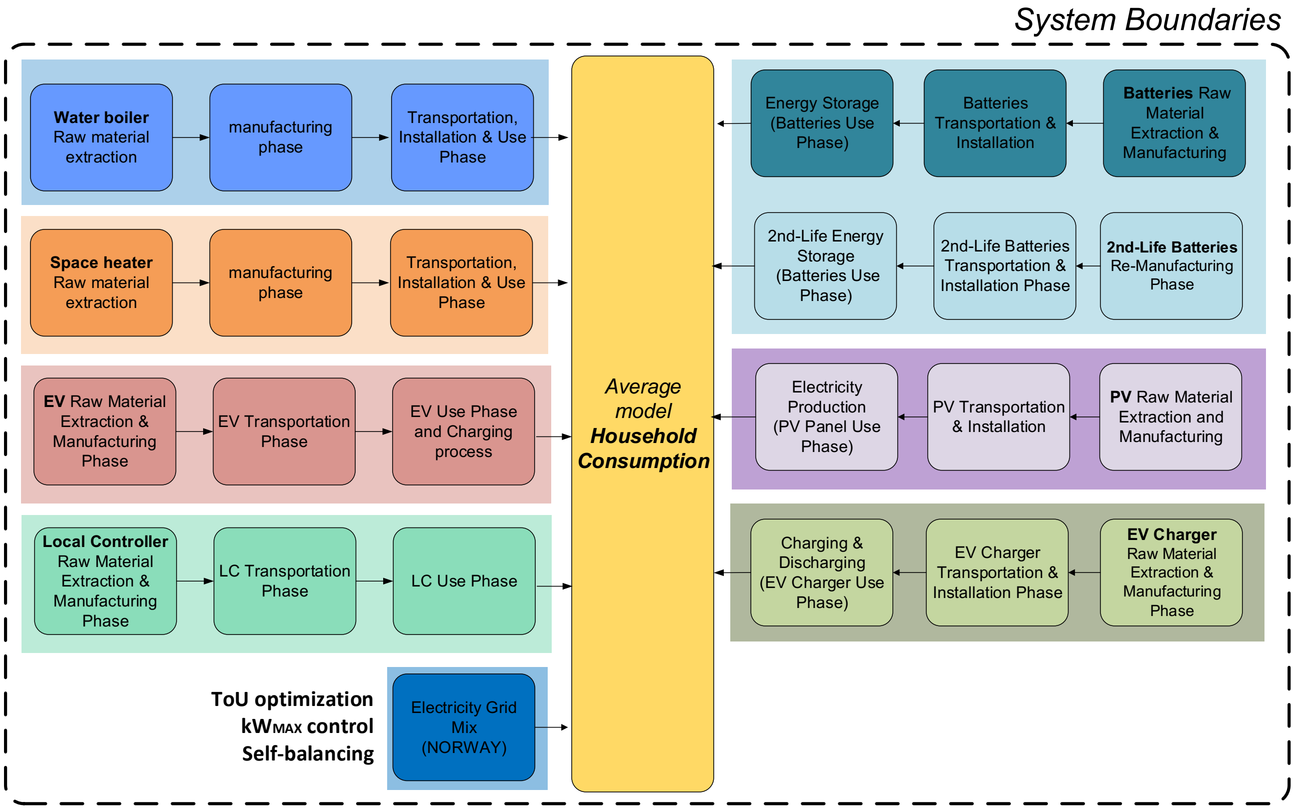


Figure 10: Norwegian Pilot-Site INVADE system boundaries.

4.2.2 Dutch Pilot Site

The pilot-sites located in the Netherlands aim to analyse the impact of a large-scale implementation of EVs charging on the electricity network. Furthermore, another objective is to charge EVs by means of renewable energy in most cases. There are 4 sub-pilot cases based on the technologies implemented and the end-users involved. For the LCA development, two sub-pilot cases have been chosen, because most of the components in cases SUB-1 and SUB-2 have been already decided and defined. SUB-3 and SUB-4 where not completely defined at that point and SUB-1 and SUB-1 have been chosen as representative Dutch pilot-site cases. Hence, the two sub-cases considered under the LCA task are the following ones: SUB-1: Small scale home sub-pilot with several homes and known private users.

- SUB-2: Large scale offices and parking lots sub-pilots.

In this case, the entire sub-pilot cases are going to be developed. Figure 11 details the baseline scenario, where there are already EVs on the streets and EV chargers installed. . The energy consumption comes from the main electricity grid mix in the Netherlands.

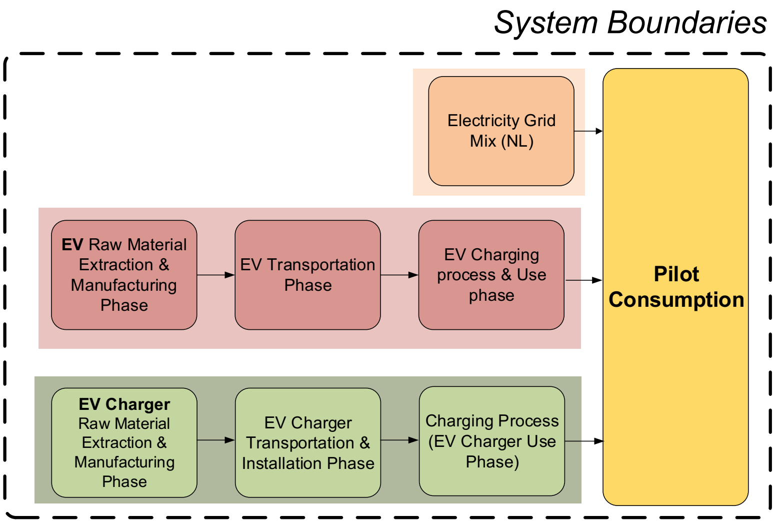


Figure 11: Dutch Pilot-Site Baseline system boundaries.

Figure 12 details the system boundaries for the INVADE scenario, where the EV smart charging controller and the Greenflux Cloud Platform have been installed to control the EV charging process to achieve the pilot-site objectives: congestion management and voltage control alongside the distribution network; ToU optimization and self-balancing by using renewable energy as PV panels.

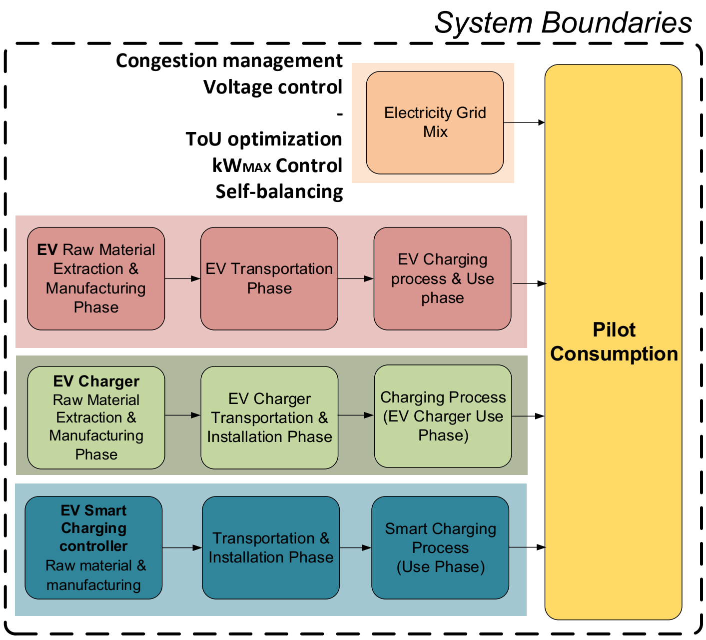


Figure 12: Dutch Pilot-Site INVADE Scenario system boundaries.

4.2.3 Bulgarian Pilot Site

The Bulgarian Pilot Site is located in Albena, at the hotel Flamingo Grand. This pilot site has installed a centralised energy storage unit (CES), together with PV panels to increase the share of renewable energy used. The hotel also wants to take advantage of the two water boilers by controlling them to provide flexibility services. In this pilot-site, the LCA model will include all the elements installed in there.

Figure 13 represents the baseline system boundaries for the Bulgarian pilot-site. There, the model contains the hotel consumption that is supplied from the main electricity grid and the two water boilers that are already installed there.

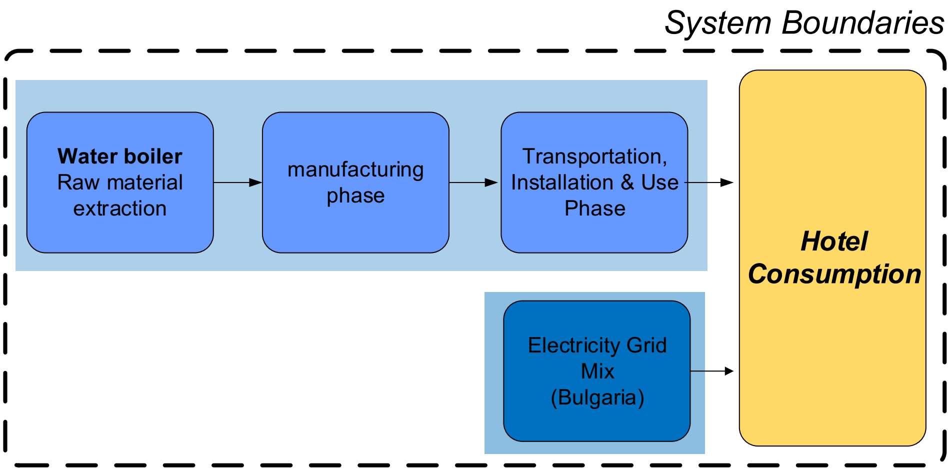


Figure 13: Bulgarian Pilot-Site Baseline system boundaries.

When the INVADE platform is developed, the implementation of DERs and flexible loads control is set, and so the system boundaries change. Figure 14 depicts the system boundaries for the Bulgarian pilot-site under the INVADE scenario. In this case, the water boilers are being controlled by means of a local controller to provide flexibility services. PV panels are installed together with a first-life centralised energy storage unit to increase the use share of renewables. By doing this, they can provide a total of 3 types of flexibility services. From the BRP point of view: self-balancing portfolio optimization; and from the prosumer perspective, kW_{MAX} control and self-balancing.

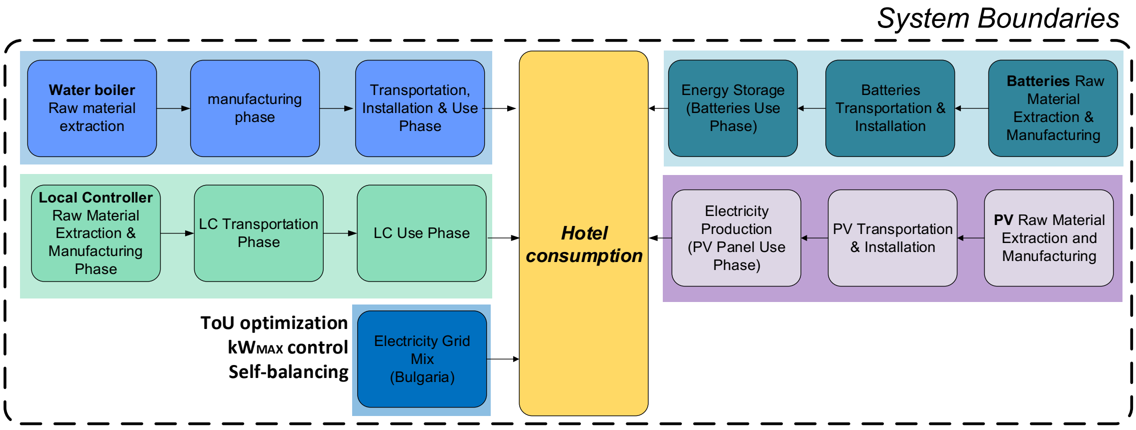


Figure 14: Bulgarian Pilot-Site INVADE Scenario system boundaries

4.2.4 Spanish/Catalan Pilot Site

The pilot-site is located in Granollers, Catalonia. It is focused on the integration of Centralised Energy Storage (CES) in the LV grid to prevent and mitigate congestions in the MV distribution network and the power transformer located there. This CES unit is going to provide flexibility services to this purpose, by means of the INVADE platform. There are two main objectives in this pilot-site (DSO side) and balancing (BRP side). First, to continuously supply electricity to a critical building and ensure their functionalities. Secondly, to develop congestion management activities to ensure a correct operation of the pilot site network.

Figure 15 shows the Pilot-Site system boundaries under a baseline scenario. In this case, the pilot consumption is supplied by means of the Estabanell distribution network.

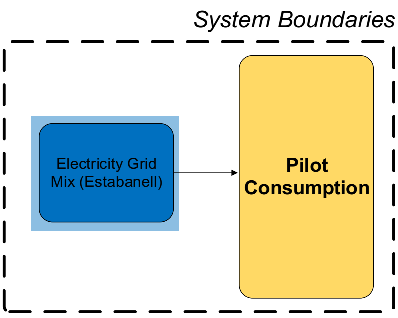


Figure 15: Spanish Pilot-Site system boundaries

Under the INVADE scenario, Figure 16 shows the system boundaries of this pilot-site. Here, the CES unit is installed together by a power electronics device (PED) to integrate the CES to the LV distribution network. By implementing the INVADE platform, the CES and the PED, four flexibility services can be provided. From the BRP perspective, the self-balancing portfolio optimization can be implemented and reduce and/or avoid deviation penalties. In terms of the DSO, congestion management, voltage and reactive control and controlled islanding actions can be performed.

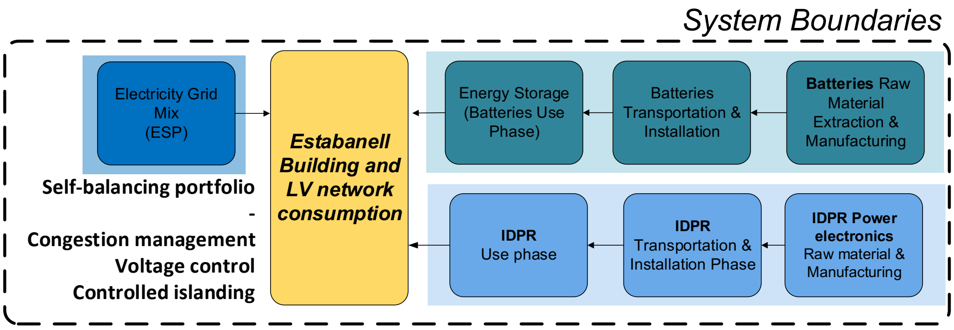


Figure 16: Spanish Pilot-Site INVADE Scenario system boundaries

4.2.5 German Pilot Site

The German Pilot Site is located in the area of Freiburg and is based on a hybrid approach. The Centralised Energy Storage (CES) is installed in the domain of the distribution grid, the Distributed Energy Storages (DES) are located in private households.

The selected spot for the CES is located in a remote area in the region of Freiburgalong with a weak feeder including four PV plants at the end of the feeder. The CES can provide flexibility to the distribution grid for voltage and reactive power control. Additionally, the DSO can use the flexibility of the battery for peak-shaving in the distribution grid. DES are always combined with PV panels on the roof of each house with the focus to increase the self-consumption of the households. The aim within the INVADE project and for all DES pilot sites is to test additional flexibility potential from households for peak-shaving in the distribution grid.

The entire inventory will be assessed for the CES pilot site, including all four PV-plants and the redox-flow battery. In case of the DES pilot sites an average model will be implemented. Three exemplary households are taken as a reference to conduct the analysis.

Figure 17 defines the baseline scenario and its system boundaries. All test sites are already equipped with PV plants on a household level. Numbers for the electricity mix are not taken from the average electricity grid mix in Germany but from the local electricity grid mix badenova is offering its customers. All storage devices in the households are already installed.

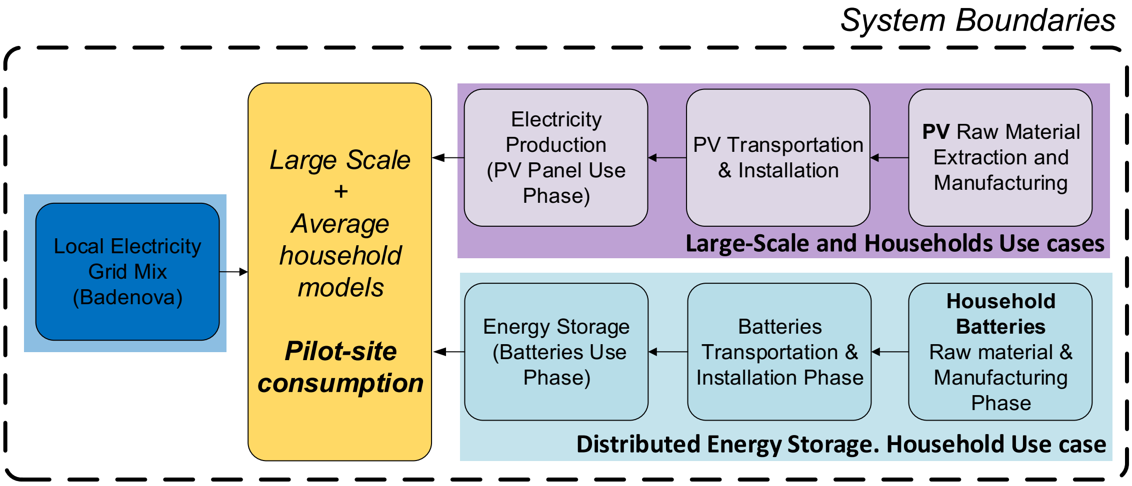


Figure 17: German Pilot-Site Baseline system boundaries.

Within the INVADE scenario, the CES provides flexibility services for congestion management, voltage and reactive power control and for peak-shaving purposes by the DSO. The already existing home management systems are still increasing self-sufficiency but provide additional flexibility to the DSO for peak-shaving purposes. Figure 18 details the system boundaries of the pilot site considering both sub-pilots.

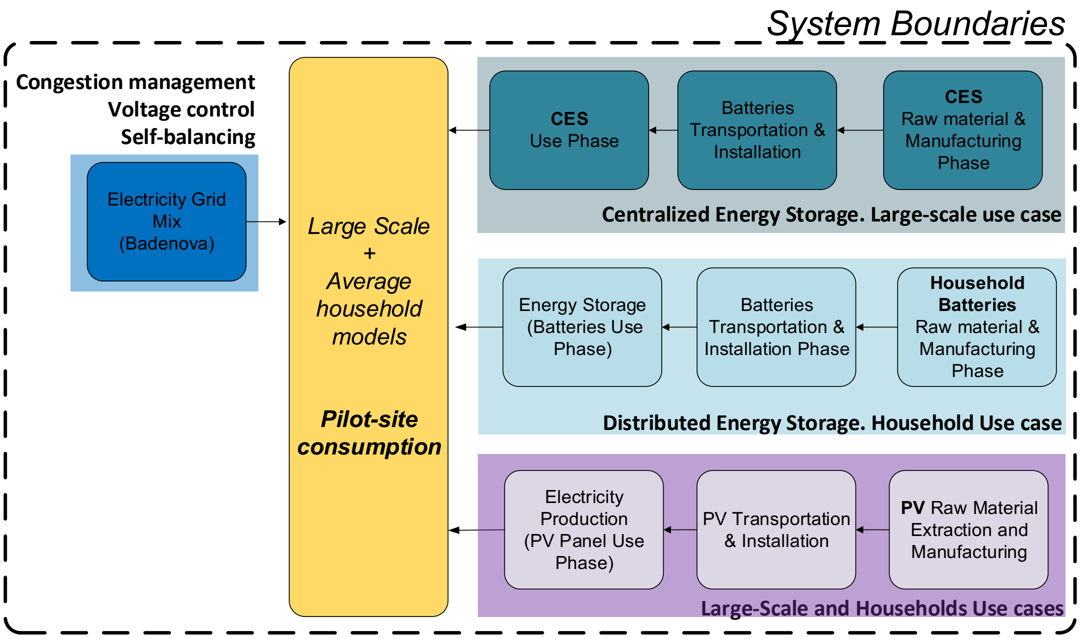


Figure 18: German Pilot-Site INVADE Scenario system boundaries

4.2.6 Use cases in INVADE project

According to D10.1, each pilot site will test different Pilot Use Cases (PUCs), to test and validate the performance of the INVADE platform. There are four different PUCs:

- PUC.1: Mobile Energy storage using EVs for V2G (Vehicle to Grid), V2B (Vehicle to Buildings) and V2H (Vehicle to Homes) operations. Currently none of the pilots have this.
- PUC.2: Centralised energy storage using and array of batteries at the substation or street level.
- PUC.3: Distributed energy storage using individual batteries at household level.
- PUC.4: Hybrid level energy storage solutions addressing a combination of PUC.2 and PUC.3.

Table 2 describes the elements that will be considered for each pilot site. First, the flexibility service according to the main beneficiary. Then, the Public Use Cases (PUCs) that is going to be tested in each pilot site is presented. This will help the reader to understand the main objective of the pilot site.

Also based on the deliverable D10.1, as well as from the communication with the Pilot Site Responsible (PSR), the elements placed on each pilot site are described. Once this information was established, the initial modelling approach was defined, allowing the development of the system boundaries for the base scenario and the INVADE scenario. In Table 2, the INVADE scenario is defined. The LCA work is split into different tasks, depending on the elements to assess. Since WP6 deals with storage technology analysis and the potential environmental impact assessment, the work is divided between VTT (responsible for WP6) and UPC (responsible for T3.7 in WP3). VTT will deal in all pilot sites with the LCA of the storage systems, and will be documented in D6.4. UPC will develop the LCA for the rest of technologies as well as the pilot site, and will be documented in D3.4 and D3.5. VTT is collaborating with UPC in the definition of the LCA methodology. The last column of Table 2 shows the pilot specific data sources, to specify whether there is availability for primary data or only secondary data sources will be used.

Table 2: INVADE Pilot-sites description

Pilot site	Flexibility service (from D4.3)	Use cases (from D10.1)	Initial modelling approach description (telco meetings)
Norway, Lyse	Prosumer: - ToU optimization - Kw_{MAX} control - Self-balancing	**PUC.1** and **PUC.3** 10 PVs (3-7 kWp) 70 EV-chargers 30 batteries x 10kWh 10 space heaters 10 water boilers 500 users in housing cooperatives.	One average household will be modelled to assess the potential environmental impact. PV: 10 units. (3 kW) 17 m^2 First-life storage: 10 kWh 2nd-life storage: 4,2 kWh. EV charger: 11 kW Local controllers to control: Water boiler: 1 unit (1,9 kW) Space heater: 1 unit (0,8 kW)
Netherlands, ElaadNL	DSO: - Congestion management - Voltage/ reactive power control Prosumer: - ToU optimization - KwMAX control - Self-balancing	**PUC.1** Sub-1: Homes – 22 homes (25 charging points) Sub-2: Large offices + parkings (25 office and garages with 300 chargers) Sub-3: Small public offices (ElaadNL) Sub-4: Large public office (across NL)	Sub-1: AC EV Charger: Alfen Eve Mini (7,2 kW). 25 units Sub-2: 300 one-way Charging Points of different nature: from 7,4 kW one-phase to 22 kW three-phase. They will all include EV Smart Charging controllers from Greenflux.
Bulgaria, Albena	Prosumer: - ToU optimization - kW_{MAX} control - Self-balancing	**PUC.1** and **PUC.2** (Smart charging, V2B and EVs that are stationed at long term parking lot) 200 kWh batteries at a community level for PVs	Entire pilot site PV: 100 units (27 kWp) First-life storage: 200 kWh Local controllers to control: Water boiler: 2 units (542 kW)

Spain, **Eypesa**	DSO: - Congestion management - Voltage/ reactive power control - Controlled islanding BRP: - Self-balancing portfolio optimization	PUC.2 200 kWh battery at a secondary substation level Power Electronics Device (PED)	Entire pilot site.
Germany, Badenova	DSO: - Congestion management - Voltage/ reactive power control Prosumer: - Self-balancing	**PUC.4** <u>Centralised Energy Storage</u> 1 ESS (120 kWh) PV Plant 1 (10 kW, 60 PV panels) PV Plant 2 (11,52 kW, 88 PV panels) PV Plant 3 (5,6 kW, 34 PV panels) PV Plant 4 (2,8 kW, 24 PV panels) <u>Distributed Energy Storage</u> Case 1 (17,1 kW, 60 PV panels, 1 storage, 9,216 kWh) Case 2 (3,7 kW, 20 PV panels, 1 storage, 3,7 kWh) Case 3 (9,9 kW, 1¡ 33 PV panels, 1 storage, 9,8 kWh)	<u>Centralised Energy Storage PUC</u> Pilot Site PV: 60+88+34+24 = 206 (from 2,8 to 11,52 kWp) Storage: 1 unit, 120 kWh <u>Distributed Energy Storage PUC</u> Pilot Site PV: 60 + 20 + 33 = 113 (from 3,7 to 17,1 kWp) Storage: 3 units (from 3,7 to 9,8 kWh)

5 Pilot sites technologies

One of the main goals of this report is to define the impact of certain technologies during their entire lifetime. In particular, solar panels and batteries use minerals that are not so abundant on Earth (e.g. cobalt) and they are usually manufactured far from the place of the installation, adding pollutant emission for the transportation. Being material and energy intensive, a specific and detailed analysis should be performed, in order to validate whether the installation of these technologies is worth or no.

5.1 PV Panels

Photovoltaic panels are, together with batteries, the most important technology of the INVADE project. Different kind of PVs are used in the pilot sites. The main difference is in the cell type, polycrystalline or monocrystalline. The first ones are usually manufactured with a lower silicon quality and therefore their efficiency is lower than the monocrystalline ones [7]. The installed PV panels differ as well regarding the manufacturer and the power rate, as explained in Table 3. For solar panels, and for all the other technologies as well, the LCA includes all the processes from the extraction of raw materials to the disposal, recycling or recovery of the used materials.

Table 3: Pilot-site PV panels types classification

Pilot Site	Manufacturer	PV panel MODEL	Cell Type	Rated Power per panel
Germany, Badenova	Sharp	SH 165	Polycrystalline	10 kWp
	LC Solar	LC 130	Polycrystalline	11,52 kWp
	Sharp	SH 165	Polycrystalline	5,6 kWp
	Sharp	SH 120	Polycrystalline	2,8 kWp

	Solar World	Mono Black	Monocrystalline	17.1 kWp
	Yingli	YL-275	Monocrystalline	5.2 kWp
	Q-Cells	64-300WP	Monocrystalline	9.9 kWp
Bulgaria, Albena	Yingli Solar	Yingli YL275P-29b	Polycrystalline	27 kWp
Norway, Lise	IBC Solar	N/A	Monocrystalline	2,9 kWp

Secondary data will be analysed for PV panels. They can be extracted from LCA software databases. In there, resources and material flows can be found regarding the manufacturing of the two kind of photovoltaic panels. Anyway, many studies about the environmental impact of this technology have been done, both on mono and polycrystalline cells. For example, there are some LCA studies which include the energy requirements for production, comparison with other energy sources and economical aspects as well [8]; others focus on multi-crystalline photovoltaic systems in specific countries [9], [10]; many others do the comparison between different materials used for the manufacturing processes and the ways of disposal [11]. In addition to all the different specifics that can influence the solar panel GWP, the PV-panel manufacturing is one of the most important. Considering the different kinds of installation (on facades or on flat/slanted roof) can give diverse outcomes. According to the ecoinvent database, the GWP factors for the different PV type installations can vary from 6301 to 8236 kg CO2-eq/ unit, comparing different PV panels that have 3 kW as peak power. These outcomes show how certain details can highly influence the pollutant emissions of a product. Figure 19 shows the system boundaries of a PV panel manufacturing process from the raw material extraction until the assembling of the PV panel.

In deliverable D3.5, the two different PV panels types (Monocrystalline and polycrystalline) installed in the different pilot sites will be studied in order to obtain detailed results about their Global Warming Potential and eventually other consistent indicators.

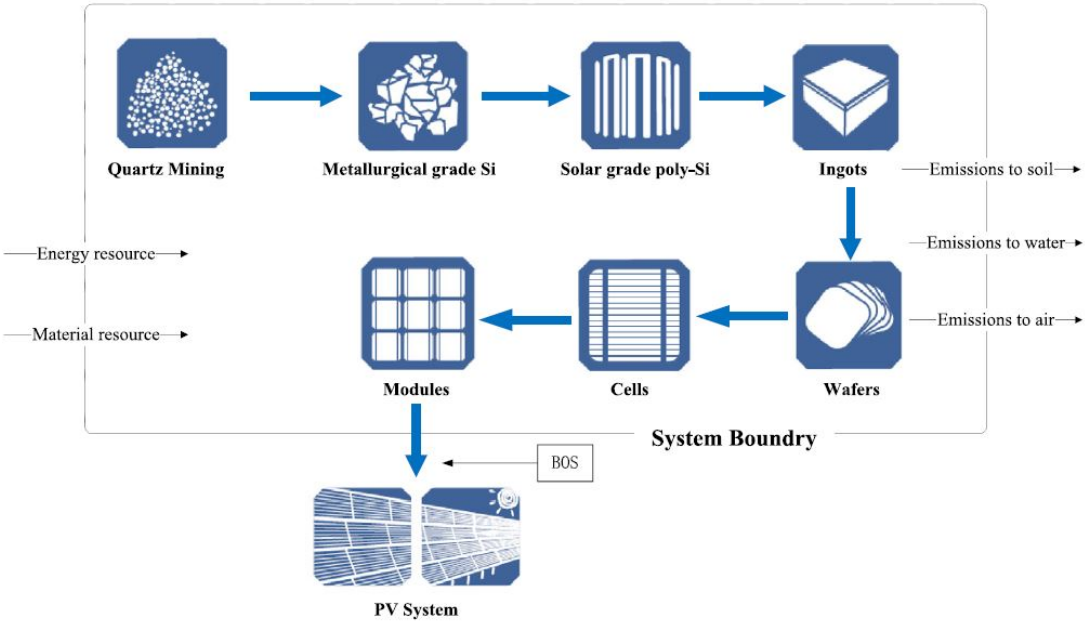


Figure 19: Life Cycle system boundaries of a multi-Si PV system. [12]

5.2 Batteries

All the pilot sites in the INVADE project have stationary batteries. They are used as centralized energy storages (Bulgaria, The Netherlands and Spain), decentralized (Norway), or both (Germany). They are explained more in details in Table 4.

Regarding this specific technology, the LCA has ultimate goal to assess the environmental impact of the different battery installations, rather than a cross-comparison. Recycling or recovery of the used materials should be prioritized to decrease the environmental impacts.

The two more mature and common kind of batteries were studied: Li-ion and Redox, with focus on the first ones.

The main components of a Li-ion cell are anode (negative electrode), cathode (positive electrode), electrolyte and a separator between them.

.

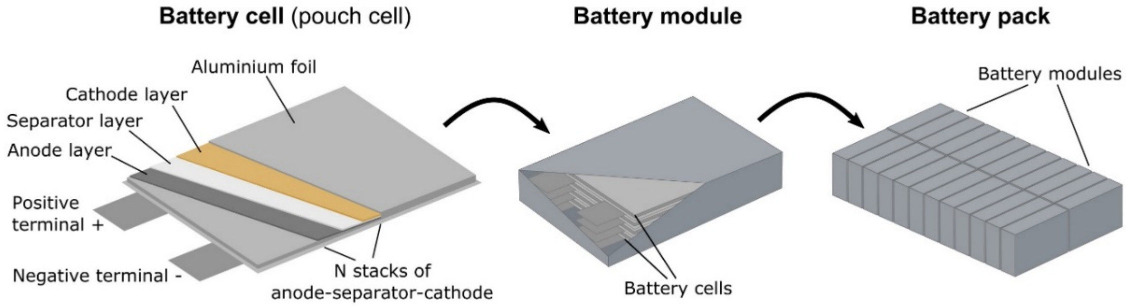


Figure 20 - Structure of a Li-ion cell and battery pack

The cells are then assembled in modules and finally in the battery pack, to which is associated a cooling system and a battery management system (BMS). According to Majeau-Bettez et al [13], the battery production and assembly, production of BMS and positive electrode production are the main contributors to the GWP of the entire life cycle of the battery (around 200 kg CO_2-eq/ kWh storage capacity).

The stationary application of Li-ion batteries is expected to increase the penetration of intermittent renewable energies like solar and wind in the grid and reduce the impact from consuming grid electricity. Furthermore, the GWP value in the use phase depends on the electricity grid mix and, more specifically, on peak hours, as explain more in details in section 5.5.1 .

According to different studies [14] [15] [16] , the GWP of the recycle stage could vary from 8 to 32 kg CO_2-eq/ kWh storage capacity. Besides recycling, the refurbishment of batteries for different applications is a process that is becoming more used in recent periods. Interesting calculations about the degradation factor, in which different state of health, work temperature and depth of discharge were used, have been developed from VTT and they can be found in the deliverable D6.4.

Regarding the Redox batteries, the stacks and the tanks can be dimensioned and tailored independently, and this fact makes them very suitable for stationary large-scale storage systems. The LCA results show that the main contribution on the GWP is due to the production of vanadium for the electrolyte (almost 90% of the total emissions).

Table 4: Pilot-site storage systems classification

Pilot Site	Manufacturer	Model	Battery type	Energy Output	Additional information
Germany, Badenova	Storion	StorE 20/120	Vanadium Redox	120 kWh	Centralized
	Sony	Olivine	LIB	9,216 kWh	Case 1 (decentralized)
	Enerwit	EnergyStore	LiFeYPO4	3,7 kWh	Case 2 (decentralized)
	LG Chem	Resu 10.0H	LIB	9.8 kWh	Case 3 (decentralized)
Spain, Estabanell	Wattius	Tailor-made	LFP	210 kWh	Centralized
Bulgaria, Albena	TesVolt	TS HV 70	NMC	200 kWh	Centralized
Norway, Lise	Eaton	N/A	LMO+NMC	10 kWh	Decentralized
	Eaton	2nd life battery	LMO+NMC	4,2 kWh	Decentralized
The Netherlands, Elaad NL	Samsung SDI	Alfen	NMC	138 kWh	Centralized

5.3 Flexible Loads & Local Controllers

Flexibility services can be provided by storage devices such as batteries. However, there are different types of storage technologies that can be considered for providing flexibility services. This is the case of water boilers and space heaters. Their thermal storage can also provide demand-side management services and so, flexibility. Usually these devices are already installed in households, but to be able to provide these services, local controllers are required.

Flexible loads are considered in the pilot sites of Norway and Bulgaria, since they are considering water boilers and space heaters, and water boilers, respectively. Table 5 details the flexible loads considered in each pilot site, regarding the manufacturer, the model, and the power consumption.

Table 5: Flexible loads description

Pilot Site	**Product**	**Manufacturer**	**Model**	**Power Consumption**	**Additional information**
Bulgaria, Albena	Water boiler 1	ACV	Heat Master HR1000	542 kW	12 m^3 water capacity
Bulgaria, Albena	Water boiler 2	ELDOM	2000		27 m^3 water capacity
Norway, Lise	Water boiler	OSO	N/A	1,9 kW	
Norway, Lise	Space heater	NEXANS	N/A	0,8 kW	

Since water boilers and space heaters have been installed prior to the starting of the INVADE Project, the LCA covering the phases from raw material extraction until the installation phase are out of the scope of the study. On the other hand, so as to be able to transform these loads to flexible loads, local controllers have been installed. This is why the local controller element is going to be environmentally assessed under the INVADE scenario (Table 6).

Table 6: Local controllers description

Pilot Site	Product	Manufacturer	Model	Power Consumption
Bulgaria, Albena	Local controller	Schneider Electric	MESE TM251	40,4 W
Norway, Lyse	Local controller Smart Home Gateway	Smartly AS	N/A	N/A

5.4 EV chargers

Electric Vehicle chargers are certainly the newest technology which will be analysed for this project. In fact, not so many LCA studies have been performed on this product and the current literature does not give enough data about the environmental impact of the life cycle of these chargers. In this project, there are two locations including EV chargers in their Pilot Use Cases (PUCs), Norway and the Netherlands.

The main EV chargers considered are AC-EV chargers, transform energy in one direction- from the grid to the EV, charging the battery. Later on, smart controllers such as the ones implemented in the Dutch pilot site permit the implementation of demand-side management activities such as controlling the charging process of the EV considering the energy prices for ToU optimization. There are also EV chargers that contain the controller to implement demand-side control of the charging process.

The newest type of EV chargers are those that, in just one EV charger allow the charging and discharging process of the EV, as well as controlling it according to price signals or control signals. These are named V2G EV charger.

Each pilot site has installed one or several types of EV charger installed. Based on D10.1 and the telco meetings developed with each pilot-site, an average model is being implemented. Furthermore, in case of several types of EV chargers, the most representative one is being detailed in Table 7, which will be the one assessed under the LCA scope.

In the case of the Dutch pilot site, the subcase 1 has already installed the one-way EV chargers. However, it order to evolve them into smart chargers, Greenflux Smart Charging Controllers are being implemented, as it is detailed in Table 8.

Table 7: EV chargers and controllers description

Pilot Site	Manufacturer	Model	AC Rated Power	One-way/ Smart / V2G
The Netherlands, GreenFlux Home	Alfen	EVE Mini	11 kW – 22 kW	Smart (Installed in Sub-1)
The Netherlands, GreenFlux Office	Alfen	EVE Mini	11kW - 22 kW.	Smart (Installed in Sub-2)
Norway, Lise (households)	Schneider	EVlink smart wallbox	11 kW	Smart

Table 8: EV charging controller

Pilot Site	Manufacturer	Model	Power consumption	Additional information
The Netherlands, GreenFlux Home	EV smart charging controller	Greenflux	0.5 kW	Smart controller (SUB-1)

5.5 Electricity grid mixes

5.5.1 The importance of the peak hours

The INVADE LCA needs to take into account the various components (PV Panels, EV chargers, Local controllers, Flexible Loads, but mainly distributed and centralized energy storage systems). Besides that, all the different pilot projects sites have in common the fact they are connected to their country's electricity grid. Additionally, when the related data is available, local grids referring to the pilot sites are included (e.g. badenova for the German pilot site). In order to develop an analysis which is in line with the LCA methodology, the pollutants emitted to produce electricity should be taken into consideration. Average country electricity grid mixes are typically used in LCA, but for this analysis it would not be sufficient. The overall aim in many pilots is shaving the electricity peaks during hours of higher consumption to obtain a more flattened energy curve, both for production and consumption. Moreover, the INVADE project aspires to use aggregators like batteries, to store energy when there is an over production provided by DERs, and discharge when there is an over consumption. Peak hours are relevant to consider since they have a big role in the energy usage trend during the day. These are usually related to heating or cooling reasons and to the fact that people come home after a workday and they start to use appliances in their homes. Understanding what of the day-time the production (and so the consumption) is high or low, allows us to determine which energy sources can be used to fulfil the needs at a given hour. Based on that it is possible to determine their environmental impact as well. Usually, fossil fuelled power plants, but also the hydroelectric facilities are used to produce more electricity during the peak hours, because they are the fastest to react to the demand and they can produce big amounts of energy in a short time. To modify the available energy capacity, batteries can be used and doing so, it is expected that less fossil fuels would be used to fix the electricity demand during peak hours.

5.5.2 Data collection and general methodology

The hourly electricity production mix has been analysed following the data of the e-transparency platform ENTSO-E, an online data platform for European electricity system data. It was established through the Regulation (EU) No. 543/20131, sometimes called the Transparency Regulation, which also prescribes which data must be published. considering the actual generation per production type [17]. This platform currently uses the data directly shared from the country's TSO. All the data refer to 2017, being the last and most completed ones available for a whole year; when different, it has been said in the specific pilot site description.

To explain the methodology used to analyse the peak hours, a brief example created for the month of January 2017 for the Spanish electricity grid mix, is shown below.

In **¡Error! No se encuentra el origen de la referencia.**, an example taken from the 1st to the 4th of January 2017 is depicted. The data represents the peak hour generation per production type during each day. For example, the 3rd of January 2017, during the daily peak hour production (from 7pm to 8pm), 9907 MW from natural gas were produced. Per every month of the year, an average of the electricity production from the different sources, during peak hours, has been analysed.

Also, in Table 9, the first 4 days of January with the related peak hours and hourly power production from different sources are shown. The modelling of the average for the whole model has been taken as the sum of the power production per type divided by the number of days of the month (e.g. NG = (4703+7076+9907+8206)/4 = 7486,5 MW). Clearly, the analysis has been done for every day of each month and for all the different sources included in the electricity grid mix.

Table 9: Electricity power production during peak hours (1st-4th January 2017) in Spain

Daily peak hour	NG	Hard coal	Nuclear	Wind Onshore	Others
	Actual Aggregated [MW]	Actual Aggregated [MW]	Actual Aggregated [MW]	Actual Aggregated [MW]	Actual Aggregated [MW]
21:00 - 22:00	4703	5955	7101	3609	5592
19:00 - 20:00	7076	6560	7103	3383	9270
19:00 - 20:00	9907	6786	7102	4304	7629
19:00 - 20:00	8260	6817	7097	7099	6532

Obtained the average data per energy resource per month, a scaling down of the electricity grid mix during the month can be done, referring the calculations to the reference unit of 1 kWh. If for example, during January 2017, the total average power produced per day during peak hours was equal to 36682 MW, and the contribution of hard coal was 6529,5 MW (17,8%), which scaled down to 1 kWh becomes 0,178 kWh. In Table 10, the results of the scaled down electricity production in January in Spain is depicted.

Table 10: Scaling down to 1 kWh of the gross electricity production in January 2017 in Spain

	Total	NG	Hard coal	Nuclear	Wind Onshore	Others
[%]	100%	22,94%	17,77%	19,47%	18,44%	21,39%
[kWh]	1	0,229	0,178	0,195	0,184	0,214

Thanks to the scaling down, a model of the electricity grid mix in Spain was done on the software GaBi, to look at the different environmental impacts of the sources used in the country. Figure 22 shows the model created on GaBi for the month of January in Spain. Also there, "Electricity from hard coal" is selected and the correspondent value set is 0,178, which corresponds to the scaled down value to achieve an overall functional unit of 1 kWh.

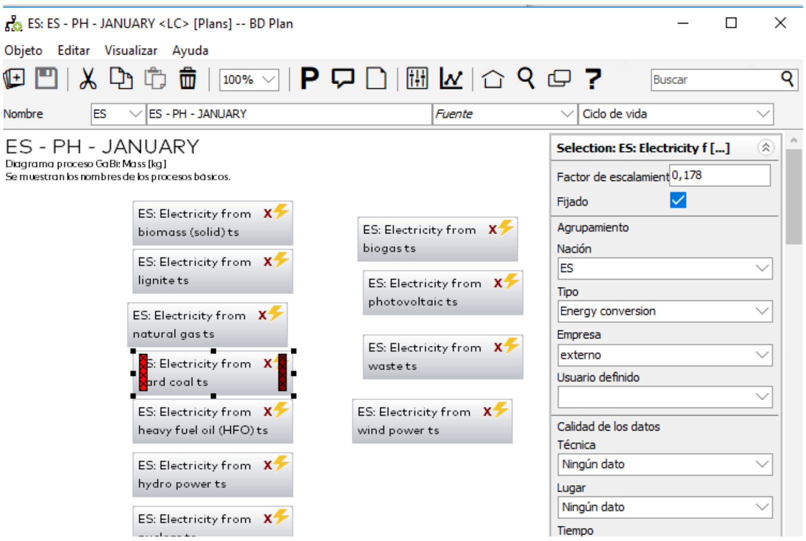


Figure 21 – GaBi model of the electricity grid production in January 2017 in Spain

The results obtained are related to the Global Warming Potential, using the impact assessment method LCIA – CML 2015. The outcomes for the month of January 2017 are shown below in Figure **22**:

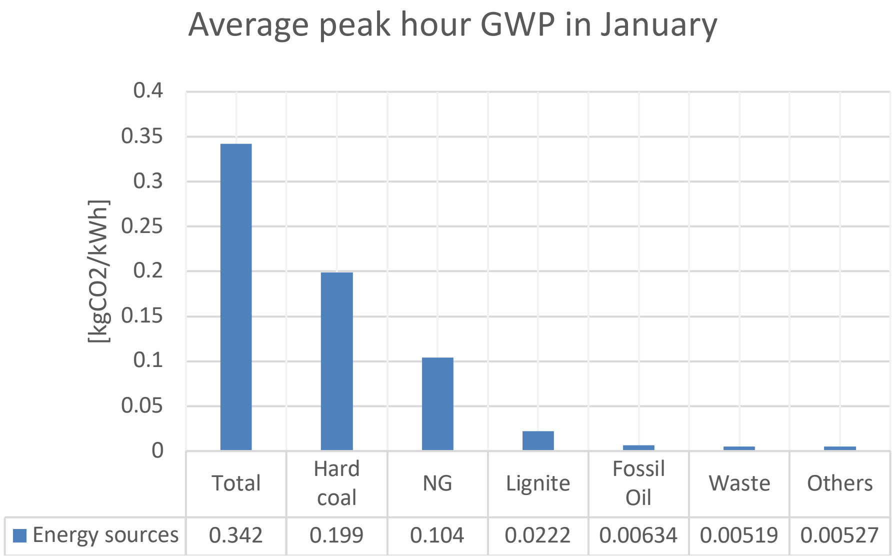


Figure 22 - Average peak hour GWP in January 2017 in Spain

Hard coal accounts for 0,199 kg CO_2 per every kWh produced with this source in January 2017. The total GWP, taking into account all the different sources, is equal to 0,342 kg CO_2/kWh.

The described analysis has been done for every month of the year 2017. In order to have a way to compare the obtained outcomes, a "base" GWP of the electricity grid mix has been developed using the data from every single hour of the year 2017. By doing so, an average of the hourly production per energy source was obtained and then modelled on GaBi, considering both peak hours and off-peak hours. The obtained results are illustrated in the table below (Table **11**).

Table 11: Average including both peak and off-peak hour GWP for the year 2017 in Spain

	Total	Hard coal	NG	Lignite	Fossil Oil	Waste	Solar	Others
[kg CO_2/kWh]	0,331	0,176	0,106	0,020	0,009	0,007	N/D	0,013

Figure 23 shows the GWP for different sources of electricity, considering the average of the EU countries, to let the reader understand which are the most polluting ones, according to GaBi software. They are based on the functional unit of 1 kWh. It means that the figure shows how many kg of CO_2 are emitted if 1 kWh from every single resource is produced. The data set represents the average region specific electricity supply for final consumers, including electricity own consumption, transmission/distribution losses of low voltage electricity supply and electricity imports from neighbouring countries for that specific energy source.

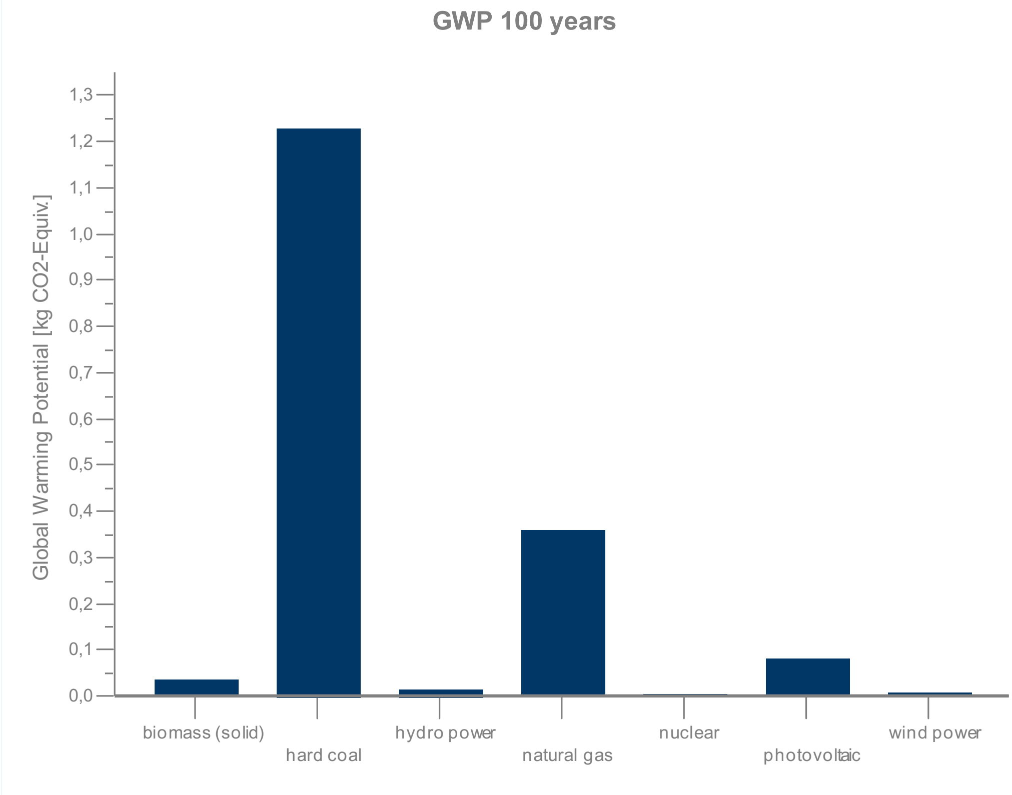


Figure 23 - Global Warming Potential of different sources according to GaBi database (EU 28 average)

5.5.3 Assumptions and system boundaries

For every pilot site country, the average GWP (including both off-peak and peak hours) has been generated and described. Then, it has been compared with data from the available literature and from a different database (e.g. *ecoinvent*) to validate the model. It was noted that the differences between the generated and the database GWP values analysed are similar and so they have been considered consistent. The differences are due to different factors: the performed models on GaBi take into account just the power (in MW) produced in the different power plants in the selected country (it does not include the import/export). The transmission losses are considered in the database electricity grid mix results (GaBi model), but not in the model developed in this deliverable. For further deliverables, a deeper analysis of the losses in the current model, including differences between High, Medium and Low voltage networks, will be performed using as a reference the work of Moro et al. [18]

Regarding the own consumption of hydroelectric plants, the power spent to pump up the water to the reservoir is part of the analysis. The collection of data from the *Transparency Platform (TP)* allows to use the most recent available data (2017/2018) while for the software databases are from the year 2014. According to an European Commission paper which studied the ENTSO-E TP [17], the provided data are the most completed ones available online, however further implementations on their quality have to be done to obtain a functional and accurate tool. Further implementation of the model could be taken into account, but for the scope of this deliverable, just the gross electricity production from different energy sources has been considered.

Fossil fuels, biomass, waste are the fuels used in both "traditional" and CHP power plants. This research studies the total used amount of these energy resources and the power in MW they deliver, without specifying which percentages are used in CHP power plants. This is why the CHP electricity production is implied in this report, even if a specific analysis about this power plants is not shown. Citing the GaBi database: "*[…] shares on direct to combined heat and power generation (CHP), are taken from official statistics (International Energy Agency, and US-EPA eGRID for USA regions) for the corresponding reference year*."

Regarding the labels shown in graphs and tables, some energy sources are merged together: this is the case of the label "NG" which includes natural gas and coal gases, "solar" which includes PV panels and solar thermal and "Hydro" which includes all the different kinds of hydroelectric production (Hydro Pumped Storage, Hydro Run-of-river and poundage, Hydro Water Reservoir).

If any specific pilot project site has particular assumptions and boundaries, they are explained in the section dedicated to its own electricity grid mix.

5.5.4 Dutch electricity grid mix

5.5.4.1 General overview

In the Netherlands, the ENTSO-E Transparency Platform gives generic data about the hour by hour electricity production in the Dutch country. The "Actual Generation per Production Type" data do not include all the different energy sources used to produce electricity for every day of the year. Due to the lack of hourly data for the electricity grid mix in the Netherlands, another approach or at least a new source should be chosen for deliverable D3.5.

Regarding this deliverable, only data about the Electricity generation by source (in GWh, from 2016) from the International Energy Agency (IEA) website have been considered (Figure 24).

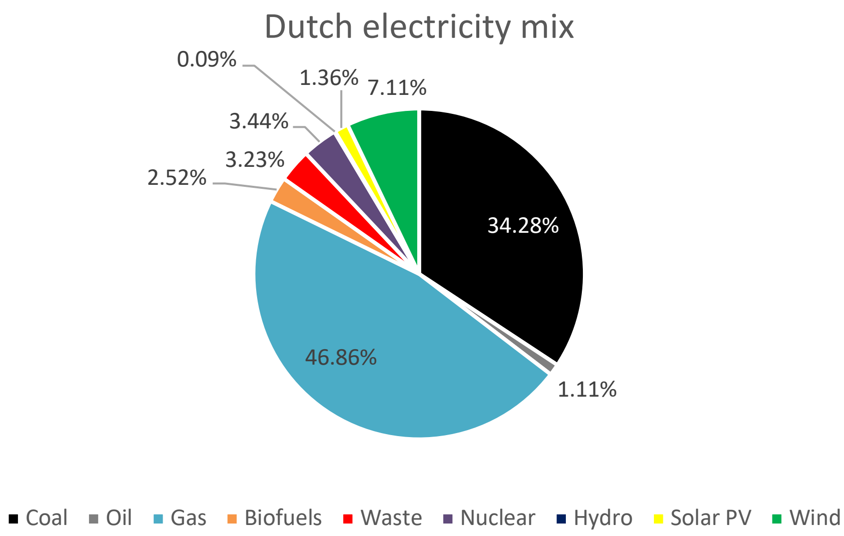


Figure 24 - Electricity production from different sources in the Netherlands (2016) – Source: IEA

Figure 24**¡Error! No se encuentra el origen de la referencia.** shows a country mainly based on fossil fuels. Natural gas and Coal account for more than 80%. A minor part is dedicated to renewables, based on offshore and onshore wind, accounting for the 7,11%. Waste and nuclear production,3,44% and 3,23% respectively, deliver a quite fix amount of energy per day. Hydropower, with just 0,09% doesn't have almost any relevance in the electricity mix.

This mix probably leads to high levels of GWP, which could be even worse during peak hours. This is why, especially in the Netherlands, a study on the highest production hours should be conducted.

5.5.5 Norwegian electricity grid mix

5.5.5.1 General overview

ENTSO-E website currently uses the data from its own *Transparency Platform* for Norway.

The installed capacity to produce electricity in Norway is highly based on hydropower (96%, 31,626 MW). Of these 31,626 MW, 1,392 MW are pumped storage power plants and 75% of the production is flexible (more than 1000 water reservoirs) [20].

Another 2% of the production capacity comes from 25 wind farms and the remaining 2% is a mix of different sources: waste, hard coal, coal gases, biogas, biomass and heavy fuel oil (the order is from the most used to the less used, according to GaBi database). Because of the little amount of all these different resources and the lack of data about the exact percentages of utilisation, all these sources have been merged using the waste electricity production GWP to perform the analysis.

It is possible to see the validity of this choice, comparing the results of the obtained base GWP with the one given by GaBi database.

Table 12: GWP differences in Norway

	Own Model	GaBi DB	ecoinvent DB
Kg CO_2/kWh	0,0258	0,0255	0,009

5.5.5.2 Results

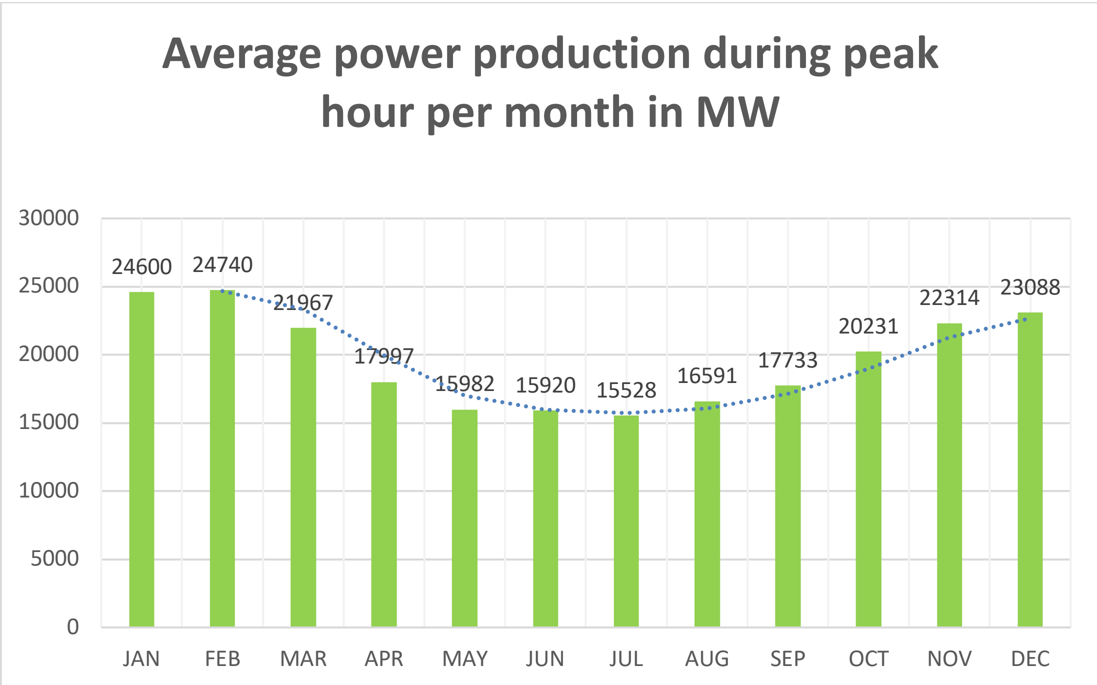


Figure 25 - Average monthly power production during peak hours in Norway (2017)

Figure 25 shows the production of electricity in Norway during peak hours. It varies harmoniously from the highest points during the first months of the year, going down during the central ones and going up again at the end of the year. The highest average value is in February (24740 MW), followed by January (24600 MW) and December

(23088 MW). On the other hand, July sees the lowest production during peak hours (15528 MW), then June (15920 MW) and May (15982 MW).

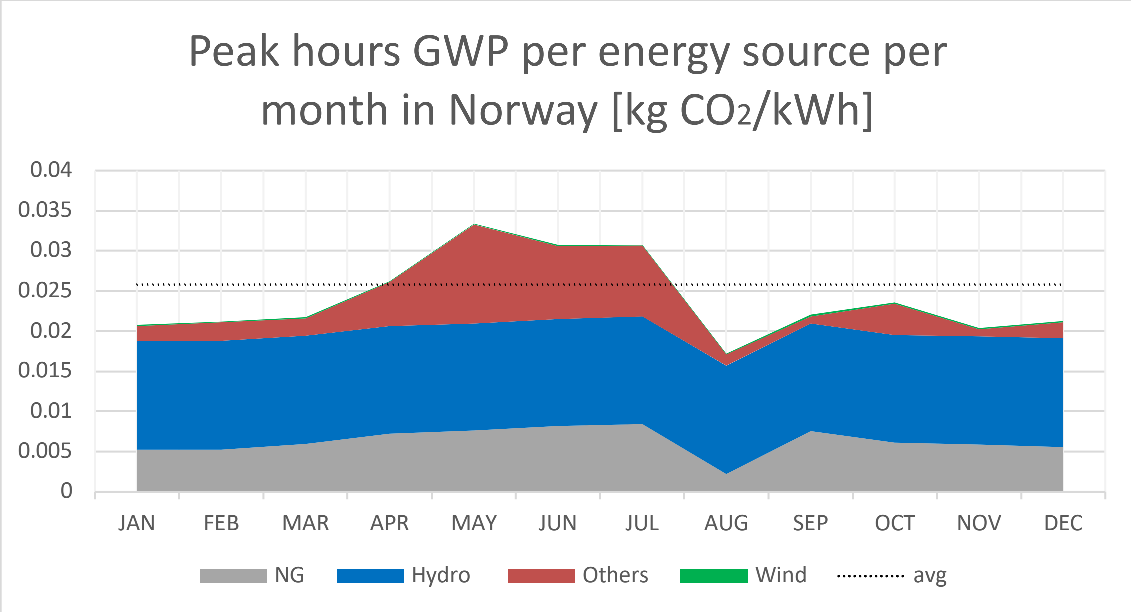


Figure 26 - Peak hours GWP, divided by different energy sources and compared with average 2017 GWP

Table 13: GWP results of the Norwegian electricity grid mix analysis from 2017

Total	NG	Hydro	Others	Wind	
0,0207	0,00523	0,0136	0,00182	0,000121	**JAN**
0,0212	0,00523	0,0136	0,00227	0,000109	**FEB**
0,0218	0,00597	0,0135	0,00214	0,000128	**MAR**
0,0263	0,00726	0,0134	0,00545	0,000105	**APR**
0,0334	0,00767	0,0133	0,0123	0,000117	**MAY**
0,0307	0,00823	0,0133	0,00908	0,000121	**JUN**
0,0307	0,00845	0,0134	0,00882	0,0000795	**JUL**
0,0243	0,00808	0,0135	0,00266	0,000098	**AUG**
0,0223	0,00756	0,0134	0,00117	0,000174	**SEP**
0,0236	0,00608	0,0134	0,00396	0,000162	**OCT**
0,0204	0,00586	0,0135	0,000901	0,000138	**NOV**
0,0213	0,0056	0,0135	0,00201	0,000135	**DEC**

(Green = GWP lower than average GWP 2018, Red = GWP higher than average GWP 2018)

During the months in which the production is lower (summer ones), more fossil fuels are used to reach the generation's peaks. So, for these months, the GWP is higher compared to the base one. Instead, when there is a need for extra monthly production, in Norway hydropower storage is widely used. In Table 14, the percentages of the energy sources used per month during peak hours are shown.

Every coloured cell is related to the following analysis. Red and Green represent the big differences between the uses of a resource in following months, while Orange represents the interesting data analysed to be further discussed.

Table 14: Percentages of the energy sources used per month during peak hours

NG	Hydro	Others	Wind	
1,41%	96,50%	0,28%	1,81%	**JAN**
1,41%	96,60%	0,35%	1,63%	**FEB**
1,61%	96,20%	0,33%	1,91%	**MAR**
1,96%	95,60%	0,84%	1,57%	**APR**
2,07%	94,30%	1,90%	1,75%	**MAY**
2,22%	94,60%	1,40%	1,81%	**JUN**
2,28%	95,20%	1,36%	1,19%	**JUL**
2,18%	96%	0,41%	1,46%	**AUG**
2,04%	95,20%	0,18%	2,60%	**SEP**
1,64%	95,30%	0,61%	2,42%	**OCT**
1,58%	96%	0,36%	2,06%	**NOV**
1,51%	96,20%	0,31%	2,02%	**DEC**
2,08%	94,95%	0,71%	2,26%	**avg**

January, February and March have all a higher percentage in the use of water resources and a lower percentage of natural gas and others more pollutant sources. The same concept is adapted to the months of October (which has even a higher percentage of use of wind power), November and December. This is why they have lower GWP than the base one. In August it is the same as well.

September has a really low GWP because of a higher usage of hydropower, a small percentage of other fossil fuels and a higher amount of electricity production from wind.

The months of April, May, Jun and July have all higher GWP compared with average. The cause of this event is the high utilisation of the “other” energy sources that have higher CO2-factor than hydro and wind.

5.5.6 Bulgarian electricity grid mix

5.5.6.1 General overview

ENTSO-E platform currently uses the data directly shared from the Bulgarian TSO, *ESO.*

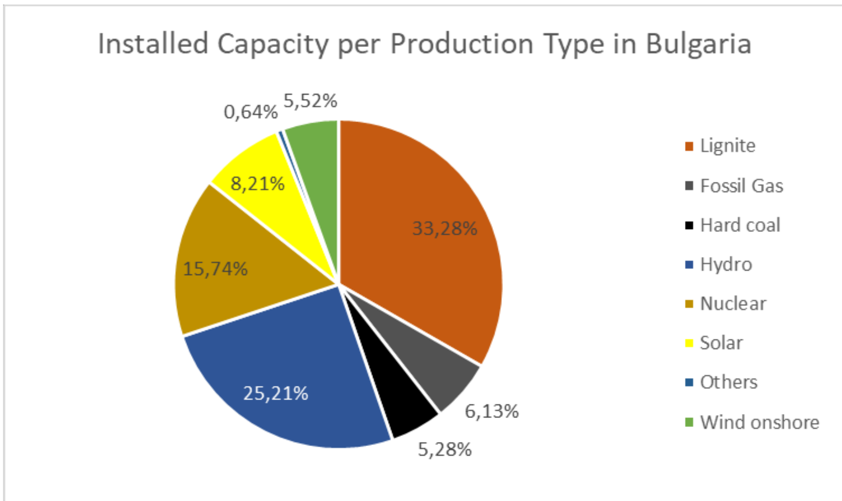


Figure 27 - Installed capacity per production type in Bulgaria. Data source: ENTSO-E

The electricity grid mix in Bulgaria is mainly focused on fossil fuels and hydroelectric power. With a 33,28% lignite power plants are the most common ones in the country, followed by natural gas (6,13%) and hard coal (5,28%). In the renewables hydro leads the way with a 25,21%, then solar (8,21%, mainly PVs) and wind on shore (5,52%). For the base load nuclear is widely used (15,74%).

The considered GWP has been modelled on the software GaBi and, as detailed in Table 15, this value can be compared to GaBi database and ecoinvent database as well.

Table 15: Comparison between different GWP data in Bulgaria

	Own Model	GaBi DB	ecoinvent DB
Kg CO_2/kWh	0,584	0,743	0,628

Specifically, for Bulgaria, the model does not take into account the own consumption of hydro storage power plants. Regarding the carbon dioxide emitted during the process of the electricity production from waste, the values were taken according to the Greek emissions for this same process (because of the lack of data from Bulgaria and geographical nearness of the two countries). This has been done considering the fact the electricity production from waste in Bulgaria is around 1%, thus it doesn't affect the

GWP values significantly. The data for this analysis come from the year 2018 (from January until October) while the last two months of the year were analysed thanks to the data from 2017, because at the time the study was performed, there were not available data for November and December 2018.

5.5.6.2 Results

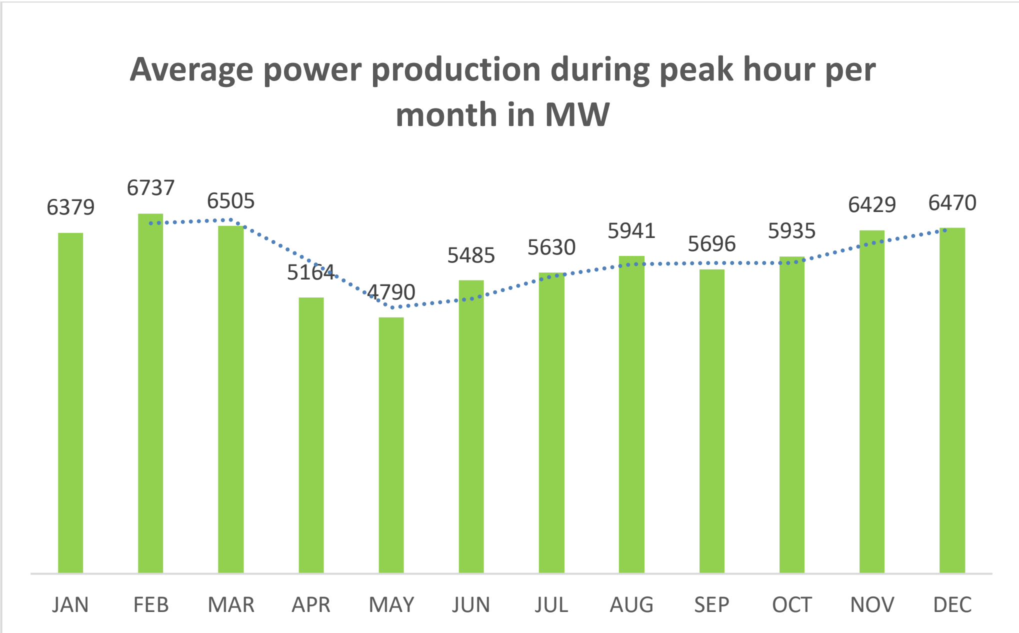


Figure 28 - Average monthly power production during peak hours in Bulgaria

The power production in Bulgaria is the highest in February (6737 MW). Looking at the other months, there is huge gap. The following high quantity electricity produced months are March (6505 MW), December (6470 MW), November (6429 MW) and January (6379 MW). Then, during the rest of the year the monthly energy production is in the range between 5164 MW (April) and 5941 MW (August) with the only exception of May (4970 MW).

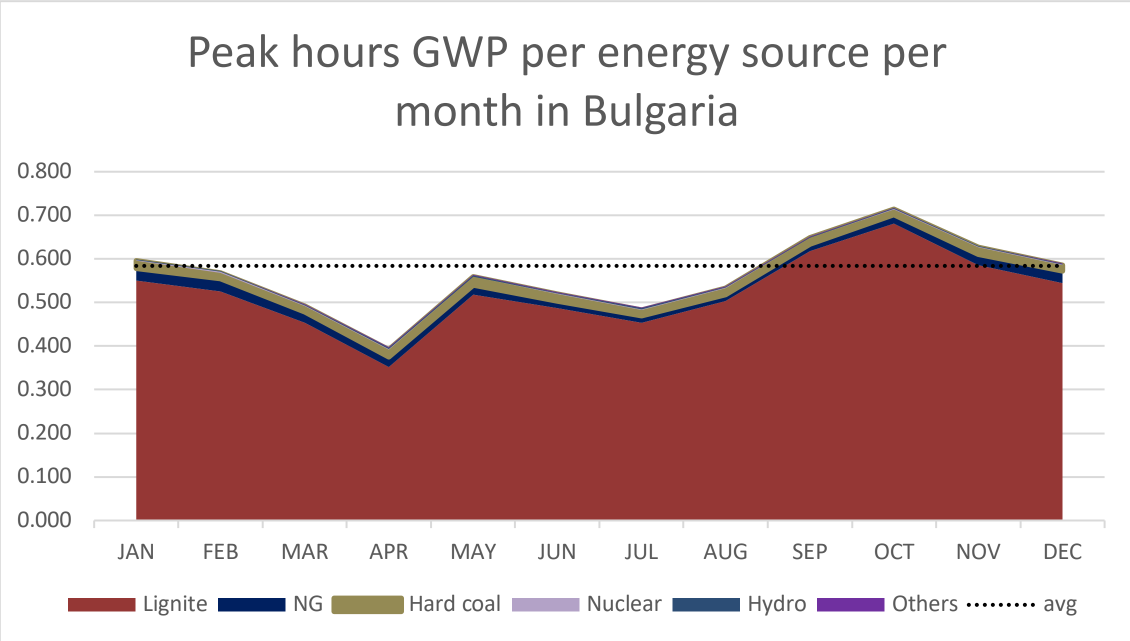


Figure 29 - Peak hours GWP, divided by different energy sources and compared with average 2017 GWP

Table 16: Peak hours GWP in kg CO_2/kWh, divided by different energy sources

Total	Lignite	NG	Hard coal	Nuclear	Hydro	Others	
0,599	0,551	0,0279	0,0166	0,0016	0,0013	0,0005	**JAN**
0,573	0,526	0,0285	0,0141	0,0016	0,0015	0,0013	**FEB**
0,496	0,453	0,0255	0,0128	0,0016	0,0019	0,0012	**MAR**
0,397	0,352	0,0232	0,0166	0,0016	0,0026	0,0011	**APR**
0,563	0,518	0,0226	0,0179	0,0011	0,0023	0,0011	**MAY**
0,524	0,487	0,0166	0,0154	0,0018	0,0015	0,0017	**JUN**
0,488	0,453	0,0160	0,0141	0,0018	0,0018	0,0013	**JUL**
0,537	0,503	0,0149	0,0141	0,0017	0,0018	0,0015	**AUG**
0,652	0,618	0,0160	0,0141	0,0009	0,0017	0,0013	**SEP**
0,717	0,681	0,0202	0,0128	0,0011	0,0015	0,0004	**OCT**
0,63	0,586	0,0250	0,0154	0,0016	0,0013	0,0007	**NOV**
0,59	0,544	0,0279	0,0141	0,0016	0,0014	0,0010	**DEC**

(Green = GWP lower than average GWP 2018, Red = GWP higher than average GWP 2018)

The obtained results are interesting because they show that during the months in which the production is the highest, the GWP is always higher than the average one.

Table 17: Percentages of the energy sources used per month during peak hours.

	Biomass	Lignite	Fossil Gas	Hard coal	Hydro	Nuclear	Solar	Waste	Wind
JAN	0,53%	40,66%	4,73%	1,30%	17,57%	33,01%	0,00%	0,07%	2,13%
FEB	0,55%	38,93%	4,81%	1,10%	20,27%	31,26%	0,00%	0,06%	3,01%
MAR	0,50%	33,50%	4,26%	1,05%	25,46%	32,31%	0,00%	0,06%	2,85%
APR	0,55%	26,05%	3,89%	1,29%	33,67%	31,68%	0,00%	0,07%	2,80%
MAY	0,61%	38,35%	3,76%	1,37%	30,74%	22,34%	0,30%	0,08%	2,45%
JUN	0,50%	35,98%	2,75%	1,20%	19,97%	37,23%	1,05%	0,08%	1,24%
JUL	0,51%	33,50%	2,65%	1,12%	24,20%	36,31%	0,61%	0,07%	1,03%
AUG	0,48%	37,22%	2,45%	1,08%	23,22%	34,31%	0,00%	0,07%	1,17%
SEP	0,50%	45,67%	2,72%	1,07%	21,95%	25,68%	0,21%	0,07%	2,15%
OCT	0,47%	50,33%	3,37%	1,00%	19,48%	22,44%	0,00%	0,10%	2,80%
NOV	0,49%	43,29%	4,15%	1,16%	17,35%	31,75%	0,00%	0,07%	1,74%
DEC	0,48%	40,21%	4,71%	1,06%	18,37%	31,86%	0,00%	0,06%	3,25%
AVG	0,52%	38,64%	3,69%	1,15%	22,69%	30,85%	0,18%	0,07%	2,22%

According to Table 17, a detailed analysis can be performed to describe the outcomes obtained:

- The months with the highest production and the highest GWP always use more lignite than the average (AVG). Clearly, this in an important correlation between GWP and fossil fuels. Furthermore, the months with the highest percentage of use of lignite, they are the ones with the highest GWP (October, September and November in this order).

- In particular, January, February and December have also higher percentage of use of natural gas.

- March has a high percentage concerning fossil gas (the highest between the months which have lower GWP than the average), but it has a low percentage of hard coal compared to the average. This fact allows the monthly GWP to remain inside the limits of the average yearly value.

- Every month that has a lower GWP than the base one, has produced more electricity from hydropower than the average case (a part from June). The same happens for the nuclear production (a part from May).

- In June, a really high percentage of nuclear has been used (37,23% compared to an average of 30,85%). In addition, the use of solar power during the peak hours is one of the reason why this month has a lower GWP.

- In May, not so much electricity from nuclear was produced (22,34%), but the all the renewables (biomass, hydro, solar, waste and wind) have been used more than the average, allowing the month to have a low GWP.

5.5.7 Spanish electricity grid mix

5.5.7.1 General overview

The installed capacity for electricity production in Spain is based on three main resources: fossil gas (30683 MW), hydropower (25926 MW) and onshore wind (22834 MW). Anyway, the power plants that rely on these sources, rarely work at their maximum capacity. The fossil gas ones are reliable for base production but the natural gas is expensive and polluting and it is tried to avoid its use as much as possible; the hydroelectric and wind power plants do not work always at their maximum capacity because of clearly climate conditions. This is why, also power plants using fossil hard coal (9535 MW) and nuclear (7117 MW) are largely used and often close to their maximum capacity. In the case of nuclear power plants, they are always used as baseline due to their long time-response to any power change. Solar power has a quite important role as well, with 6722 MW installed all over the country.

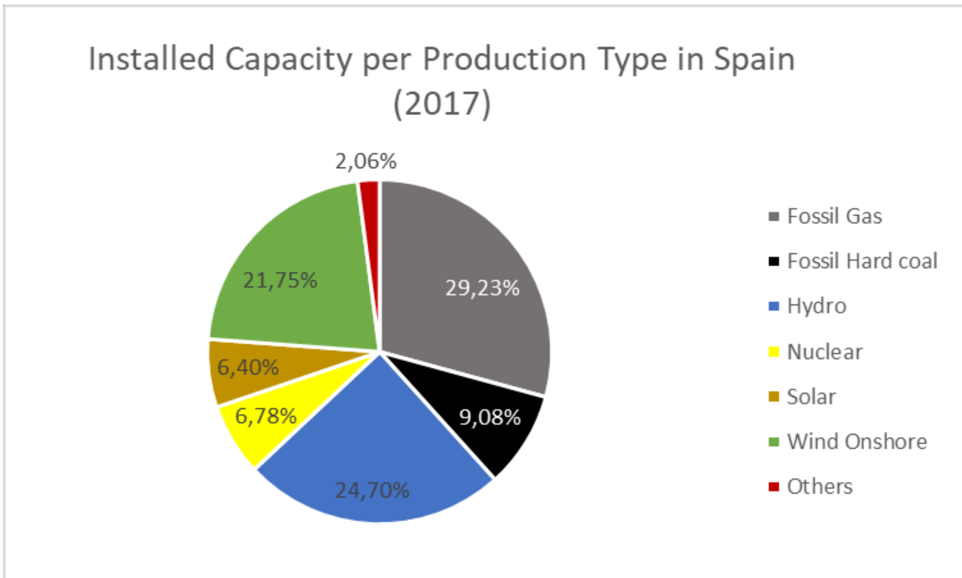


Figure 30: Installed capacity per production type in Spain. Data source: ENTSO-E

To have a good understanding on when the production of electricity is higher during the day, two example days (one during winter and the other during summer) are shown in Figure 31.

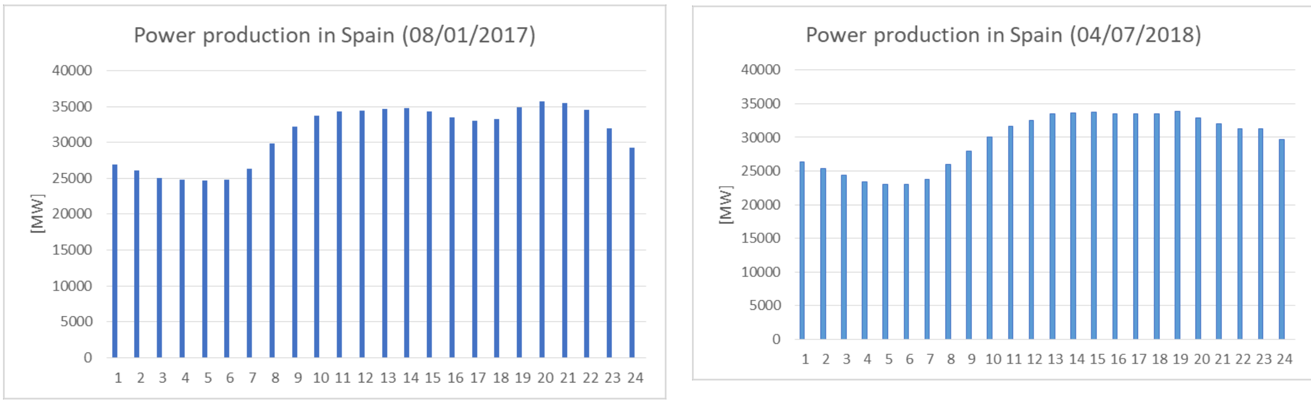


Figure 31: Daily power production during two different days: Sunday, the 8th of January and Tuesday, the 4h of July

The two days represent well the general production behaviour during the warmer and colder months in Spain. In January, the production peak hours are during the coldest moments (in the evening), because of the heating needs, while in July the curve is well distributed during the warmest hours (in the middle of the day), because of the cooling applications.

5.5.7.2 Results

Figure 33 shows an analysis of the power production per month in Spain for the year 2017.

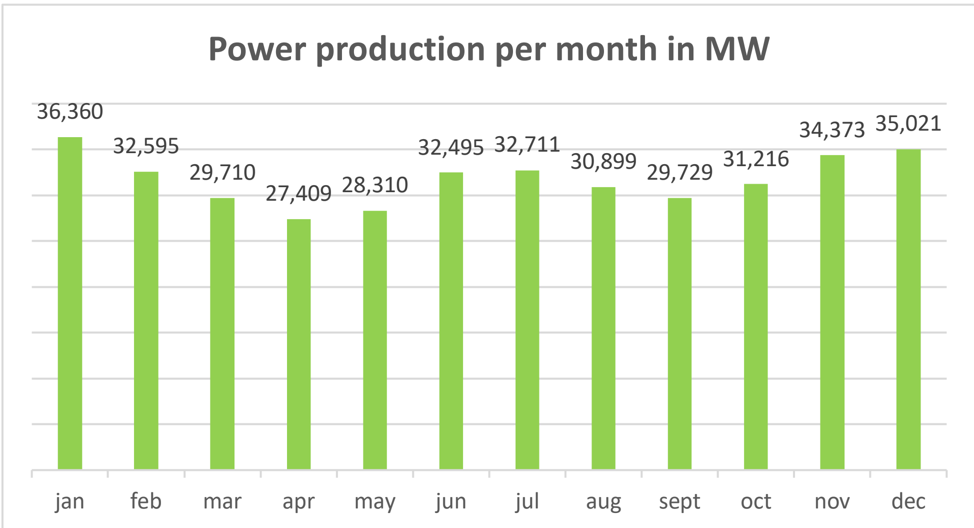


Figure 32 - Monthly power production in Spain (2017)

The months with the highest production are the winter ones (January, December, November, and February, in this order) followed by July and June. It means that peak power production is higher when the climate conditions are more extreme (a part for

August, whose value could be related to the fact that during summer vacations there is less consumption from companies and industries).

An outcome when looking at the ecological footprint would be the correlation between the top values in the electricity production and the CO_2 emitted per kWh. Therefore, for example, in the months mentioned above, there should be the highest values for the GWP. In Figure 33, the dotted line represents the average GWP considering both peak and off-peak hours for the electricity grid mix in 2017 (0,331 kg of CO_2/kWh, it's the LCA value of the created GaBi model). Just for 5 months during the year, the peak hour GWP is higher than the off-peak hours GWP. The hydro does not appear in this figure because its environmental impact is much lower compared to the other sources, even if it is used more, so it is part of the label "Others".

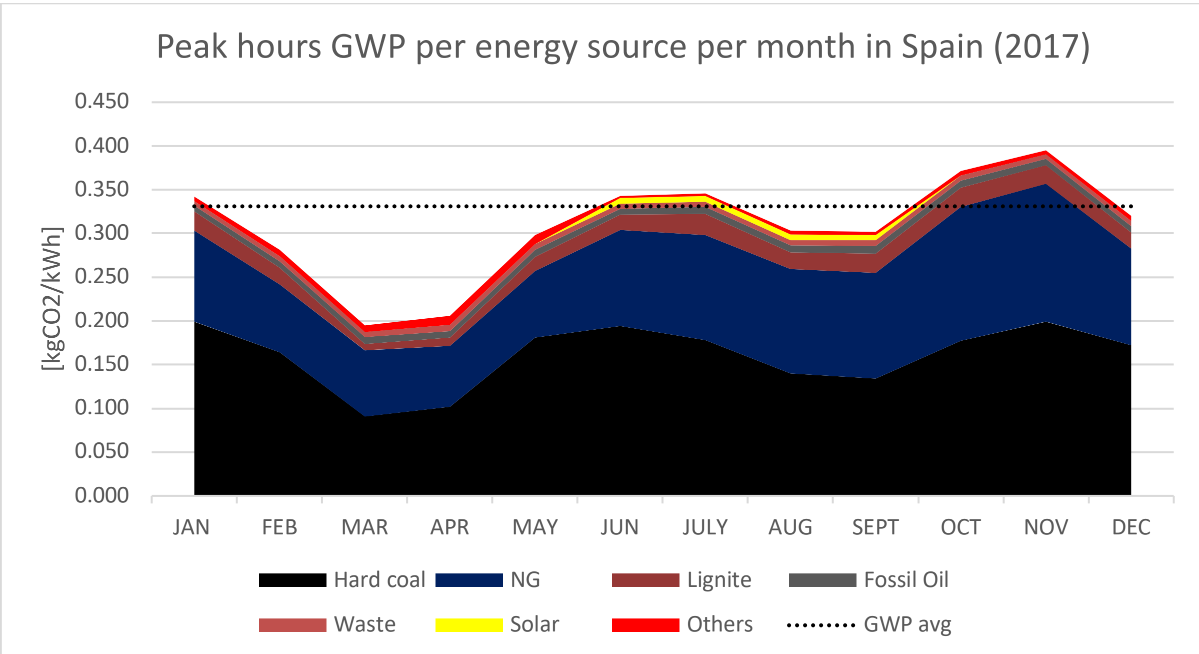


Figure 33 - Peak hours GWP, divided by different energy sources and compared with average 2017 GWP in Spain

Table 18: Peak hours GWP divided by different energy sources.

GWP	Hard coal	NG	Lignite	Fossil Oil	Waste	Solar	Others	
0,342	0,199	0,104	0,022	0,006	0,005	N/D	0,005	**JAN**
0,281	0,164	0,078	0,019	0,007	0,006	N/D	0,007	**FEB**
0,195	0,091	0,076	0,007	0,008	0,006	N/D	0,008	**MAR**
0,206	0,102	0,069	0,010	0,007	0,007	N/D	0,011	**APR**
0,298	0,181	0,076	0,016	0,008	0,006	N/D	0,010	**MAY**
0,343	0,194	0,110	0,017	0,007	0,006	0,006	0,003	**JUN**
0,346	0,178	0,120	0,024	0,008	0,006	0,007	0,003	**JULY**
0,303	0,140	0,119	0,019	0,008	0,006	0,006	0,004	**AUG**
0,302	0,134	0,121	0,022	0,009	0,006	0,006	0,004	**SEPT**
0,371	0,177	0,153	0,022	0,008	0,006	N/D	0,005	**OCT**
0,395	0,199	0,158	0,021	0,007	0,005	N/D	0,004	**NOV**
0,320	0,172	0,111	0,018	0,007	0,006	N/D	0,006	**DEC**

The outcomes shown in Table 18 arise a different value than the expected one. For example, regarding the month of December and February, higher GWP values were expected than April and May, which are months with the lowest peak production of the year. A possible answer could be derived from the energy sources used during these months:

- From March to April the GWP increases while the power production decreases: in this monthly transition, less hydro, nuclear and wind (the less pollutant energy resources) were used, almost same percentage of hard coal and NG, but higher use of solar power (which is the one of the renewable energies with the highest emission factor). Moreover, in March, there was a small use of lignite.

- In December, compared to November, much less hard coal and natural gas were used, while wind power was widely exploited.

- In February, the same situation compared to January, happened. Less fossil fuels used and more solar and wind power produced. In the months between February and May, there was a low utilisation of natural gas. Especially in March and April, also the hard coal was used way less than the average (PROMEDIO), resulting in low values of GWP

- Also in February there was a massive use of hydroelectric capacity (18,78%), while in the months between July and November, this resource was less used (because of the really warm summer and the shortage of rainfall nationwide)

- In November, nuclear power plants were less exploited (just 5000 MW of power, in comparison with usual rates between 5500 and 7000 MW)

- The solar power helped lowering down the GWP during the summer months, but not enough to let June and July be under the GWP average for the year.

Looking at the report “The Spanish electricity system – 2017” by REE [21], it is possible to get some interesting data. As it is possible to see in Table 19, the hydroelectric production dropped from the month of June on because of little rain nationwide. At the same time, increased amounts of coal and natural gas was burnt in order to replace the missing production from hydro.

Further information regarding the energy resources used throughout the year in Spain can be read in Appendix A,

Table 19: Percentages of the energy sources used per month during peak hours.

	Biomass	Lignite	NG	Hard coal	Fossil Oil	Hydro	Nuclear	Others	Solar	Waste	Wind
jan	0,96%	2,18%	22,94%	17,77%	0,77%	14,96%	19,47%	0,44%	1,21%	0,84%	18,44%
feb	1,11%	1,88%	16,96%	14,73%	0,88%	14,85%	21,60%	0,47%	2,89%	0,88%	23,50%
mar	0,96%	0,75%	16,58%	8,09%	1,03%	18,78%	23,74%	0,53%	5,17%	0,94%	23,32%
apr	0,87%	1,01%	15,21%	9,09%	0,93%	13,77%	24,57%	0,47%	11,90%	1,06%	20,39%
may	1,13%	1,61%	16,71%	16,22%	1,02%	13,23%	19,52%	0,51%	13,03%	1,01%	15,61%
jun	1,03%	1,65%	24,17%	17,35%	0,93%	10,24%	17,16%	0,46%	13,08%	0,93%	12,63%
jul	1,15%	2,39%	26,44%	15,88%	0,96%	7,37%	17,95%	0,37%	13,76%	0,93%	12,56%
aug	1,18%	1,89%	26,24%	12,45%	1,02%	8,42%	22,06%	0,44%	13,08%	1,00%	12,07%
sep	1,23%	2,24%	26,61%	12,05%	1,07%	8,57%	22,06%	0,51%	12,65%	1,03%	11,78%
oct	1,11%	2,23%	33,75%	15,85%	0,95%	7,94%	18,60%	0,50%	3,48%	0,95%	14,61%
nov	1,06%	2,15%	34,74%	17,84%	0,92%	8,53%	14,62%	0,41%	2,79%	0,78%	16,06%
dec	1,00%	1,76%	24,44%	15,36%	0,88%	10,04%	19,31%	0,43%	2,01%	0,87%	23,72%
PROMEDIO	1,07%	1,81%	23,73%	14,39%	0,95%	11,39%	20,06%	0,46%	7,92%	0,94%	17,06%

Every coloured cell is related to the previous analysis. Red and Green represent the big differences between the use of a resource in following months; Orange represents the interesting data analysed before, in which a resource has been used much more or much less than the average value.

5.5.8 German electricity grid mix

Data for the electricity grid mix are provided from *badenova*, the regional utility company in the area of Freiburg (Figure 35). Data for the electricity mix is related only to the pilot sites and not Germany in general. Hence, the results are more valuable. Data for the average German electricity mix are given in Figure 35. All data is related only to the electricity mix there is no information about peak and off-peak hours. It is not possible to obtain more accurate data about the electricity mix during peak and off-peak hours in Germany or from badenova. Thus, deliverable D3.5 will calculate with the electricity mix of badenova given in Figure 35.

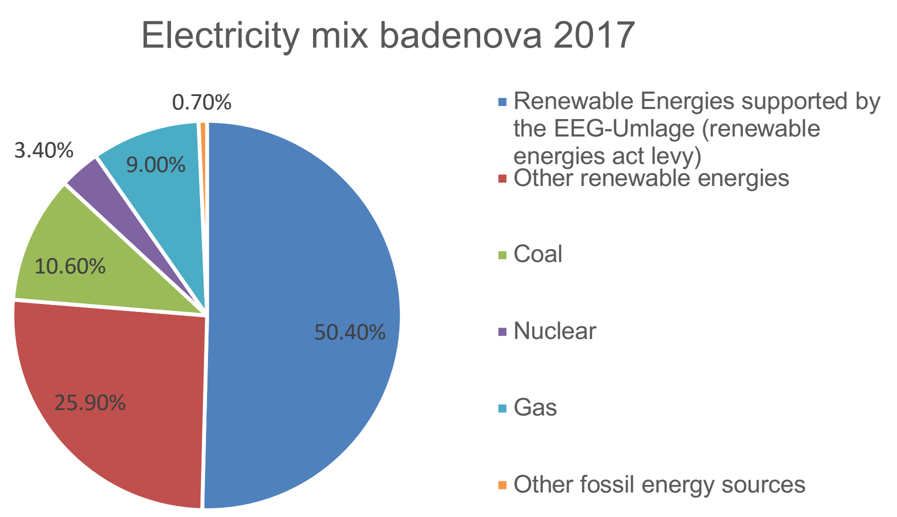


Figure 34 – Electricity mix split up by energy source

Table 20: Energy sources of the renewable energy share within the badenova electricity mix.

	Energy source	Percentage
Other renewable energies (25.9%)	Hydro power	100 %
Renewable energies supported by the renewable energy act levy (50.4%)	Wind onshore	20.2 %
	Wind offshore	4.3%
	Hydro power	4.6%
	Biomass	10.6%
	PV	9.3%
	Waste	1.4%

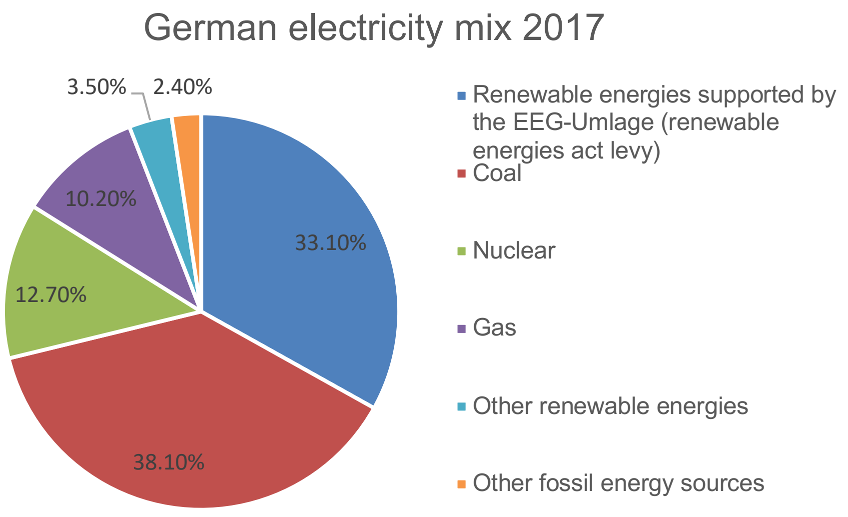


Figure 35 – Electricity mix by energy source in Germany

Being completely different from the average German electricity grid mix, the GWP outcomes for the badenova electricity mix are diverse, as shown in Table 21. The environmental impact of the badenova electricity mix is clearly lower than the average German electricity grid mix.

Table 21: badenova and average German grid mix GWP

	badenova electricity mix	**German electricity mix**
CO_2 emissions [kg/kWh]	0,139	0,435

6 Conclusions and further research needs

There are several ways to perform a LCA, and there no clear guidelines on how to assess energy systems in terms of sustainability. The present deliverable has provided the methodology according to the ISO 14040 and 14044 for any product or service. At the first stage of the project, a screening LCA is detailed, considering the overall goal and scope, the system boundaries and the data requirements to perform the final LCA lately. This assessment does not intend to develop cross-comparison between pilot-sites, since there are important differences between pilot sites in terms of energy resources and manufacturing facilities. Neither the comparison between pilot-site technologies nor devices are the scope of this project.

Life Cycle Assessment is directly related to sustainability and exploitation, since the environmental performance of the platform has an impact and can affect the business models planned for the INVADE platform and its value proposition. The indicators extracted from the LCA models will affect the Total Societal Impact (TSI), which is a financial performance indicator associated with sustainability. Hence, the LCA can be an instrument to support the TSI that the INVADE Project can achieve.

The project is focused on the carbon footprint calculation, which is equivalent to GWP impact category. However, additional indications should be considered when dealing with devices that are energy and material intensive like batteries and PV panels. Indicators as Acidification Potential, Ozone Depletion Potential (OPDP), and Primary Energy Demand might be required to be included to analyse the global potential environmental impact of the pilot site.

Data collection is one of the most important steps in LCA. Mainly, the data collection was focused on research articles and publically or commercially available Life Cycle Inventory databases. Hence, the participation of the pilot site responsible person and the possibility to obtain direct data regarding the manufacturing process can help the development of the research. There is a lack of data in terms of batteries, the re-manufacturing process in 2nd-life batteries, and EV chargers, since they are technologies that are evolving so fast and there are confidentiality issues behind.

The current energy structure and the energy consumption patterns play a key role when developing the LCA model of each pilot site. In addition, the peak hour analysis has given contradictory results. If it was expected to have higher values of the GWP for all the peak hours compared to the off-peak ones, this has not happened. It must be said that the three studied countries (Norway, Bulgaria and Spain), have an installed capacity from hydropower of at least 25%. This means that during the peak hours, this flexible resource is used and the GWP is not really affected by it. It will be more interesting to analyse the behaviour of the two other countries (the Netherlands and Germany), in order to discover if there is any correlation between the sources used during peak hours and a higher carbon footprint of the grid.

The further research will be focused on the assessment of the electricity grid mix from the Netherlands and Germany. For the development of D3.5, each technology will be modelled based both on secondary data and primary data if it is available. Further communication between the pilot site responsible persons and the research group will be needed to develop the model of each pilot site. Furthermore, once the pilot sites are running, data collection about the energy consumption will be collected.

7 References

[1] D. Beal *et al.*, “Total Societal Impact: A New Lens for Strategy.” [Online]. Available: https://www.bcg.com/publications/2017/total-societal-impact-new-lens-strategy.aspx.

[2] “ISO 14040: Environmental management - Life cycle assessment - Principles and framework,” 2006.

[3] *ILCD Handbook: General guide for Life Cycle Assessment -Detailed guidance*. .

[4] E. P. on L. C. Assessment, “No Title.” [Online]. Available: http://eplca.jrc.ec.europa.eu/.

[5] “ILCD Handbook: Review schemes for Life Cycle Assessment (LCA).”

[6] “ISO 14044:2006. ISO 14044 Environmental Management- Life Cycle Assessment- Requirements and Guidelines,” 2006.

[7] M. Gul, Y. Kotak, and T. Muneer, *Review on recent trend of solar photovoltaic technology*, vol. 34, no. 4. 2016.

[8] J. Pearce, C. Watkins, and L. Grafman, “LCA of silicon PV panels,” *Appropedia*, pp. 6–9, 2014.

[9] H. B. Madessa, “Performance analysis of roof-mounted photovoltaic systems - the case of a Norwegian residential building,” *Energy Procedia*, vol. 83, pp. 474–483, 2015.

[10] Y. Fu, X. Liu, and Z. Yuan, “Life-cycle assessment of multi-crystalline photovoltaic (PV) systems in China,” *J. Clean. Prod.*, vol. 86, pp. 180–190, 2015.

[11] M. Vellini, M. Gambini, and V. Prattella, “Environmental impacts of PV technology throughout the life cycle: Importance of the end-of-life management for Si-panels and CdTe-panels,” *Energy*, vol. 138, pp. 1099–1111, 2017.

[12] J. Hong, W. Chen, C. Qi, L. Ye, and C. Xu, “Life cycle assessment of multicrystalline silicon photovoltaic cell production in China,” *Sol. Energy*, vol. 133, pp. 283–293, 2016.

[13] G. Majeau-Bettez, T. R. Hawkins, and A. H. Strømman, “Life Cycle Environmental Assessment of Lithium-Ion and Nickel Metal Hydride Batteries for Plug-In Hybrid and Battery Electric Vehicles,” *Environ. Sci. Technol.*, vol. 45, no. 10, pp. 4548–4554, May 2011.

[14] U.S. EPA, “Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles,” 2013.

[15] X. Zeng, J. Li, and N. Singh, “Recycling of spent lithium-ion battery: A critical review,” *Crit. Rev. Environ. Sci. Technol.*, vol. 44, no. 10, pp. 1129–1165, 2014.

[16] B. Li, X. Gao, J. Li, and C. Yuan, “Life Cycle Environmental Impact of High-Capacity Lithium Ion Battery with Silicon Nanowires Anode for Electric Vehicles,” *Environ. Sci. Technol.*, vol. 48, no. 5, pp. 3047–3055, Mar. 2014.

[17] C. Economics, “A review of the ENTSO-E Transparency Platform,” pp. 1–58, 2017.

[18] A. Moro and L. Lonza, “Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles,” *Transp. Res. Part D Transp. Environ.*, vol. 64, no. July 2017, pp. 5–14, 2017.

[19] TenneT, “TenneT - Installed capacity and fuel type.” [Online]. Available: https://www.tennet.org/english/operational_management/system_data_preparation/Reported_production_capacity/Installed_capacity.aspx. [Accessed: 10-Dec-2018].

[20] International Hydropower Association, “Hydropower status report,” *Hydropower Status Rep.*, pp. 1–83, 2017.

[21] W. Fleeson *et al.*, “The Spanish Electricity System,” 2017.

A. Appendix

Table 1 – Impact categories according to ISO 14044

Impact Category	**Description**	**Category Indicator CML 2015**
Global Warming Potential (GWP)	Potential contribution of different air emissions to global climate change.	GlobalWarming Potential (GWP 100 years) [kg CO_2-Equiv.]
Acidification Potential (AP)	Potential for emissions to increase the acidity of water and soil systems. E.g. Acid rain. The major contributors to acidification are sulphur dioxide and nitrogen oxides from fossil fuel combustion.	Acidification Potential (AP) [kg SO_2-Equiv.]
Eutrophication Potential (EP)	Addition of chemical nutrients to surface waters, which promotes the excessive growth of plant life in those waters, such as algae. This can lead to the death of other aquatic life. The major contributors to EP are the excessive spills of phosphorusand nitrogenfrom agriculture purposes, and also pollution from septic systems and sewers.	Eutrophication Potential (EP) [kg Phosphate-Equiv.]
OzoneDepletion Potential (ODP)	Thinning of the stratospheric ozone layer, which protects the earth from harmful ultraviolet radiation. The major contributorsareemissionsof chlorofluorocarbonsand hydrofluorocarbons.	OzoneLayerDepletion Potential (ODP, steady state) [kg R11-Equiv.]
SmogPotential (SP)	Formation of ground-level ozone, known as smog. The main contributors are nitrogen oxides emissions and VOC.	Freshwater Aquatic Ecotoxicity Potential (FAETP inf.) [kg DCB-Equiv.] Acidification Potential (AP) [kg SO_2-Equiv.] Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.] Photochemical. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
Toxicity	Potential of an emission to cause harm to plant and animal species, taking into account the emissions' toxicity and its concentrations in different media.	Acidification Potential (AP) [kg SO_2-Equiv.] Freshwater Aquatic Ecotoxicity Potential (FAETP inf.) [kg DCB-Equiv.] Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
Resource Depletion	Resource consumption faster than it can be replenished. They are divided in two categories: Renewable and non-renewable.	Abiotic Depletion (ADP) [kg Sb-Equiv.]

Water Depletion	Water consumption in a non-balanced way, producing water scarcity.	Not available in CML
Land Use and Transformation	Modification of the natural environment into built environment.	Not available in CML
PrimaryEnergy Demand (PED)	Energy form found in nature which has not been subjected to any conversion process. It measures the amount of energy that entered the product system. (E.g. energy in crude oil, energy in coal, wind, solar, wood)	Not available in CML. Not considered an Impact category.
Particulate Matter (PM)	Exposure to particulate matter in the air, emitted by fuel combustion, waste incineration, construction or agricultural dust or fires.	Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]

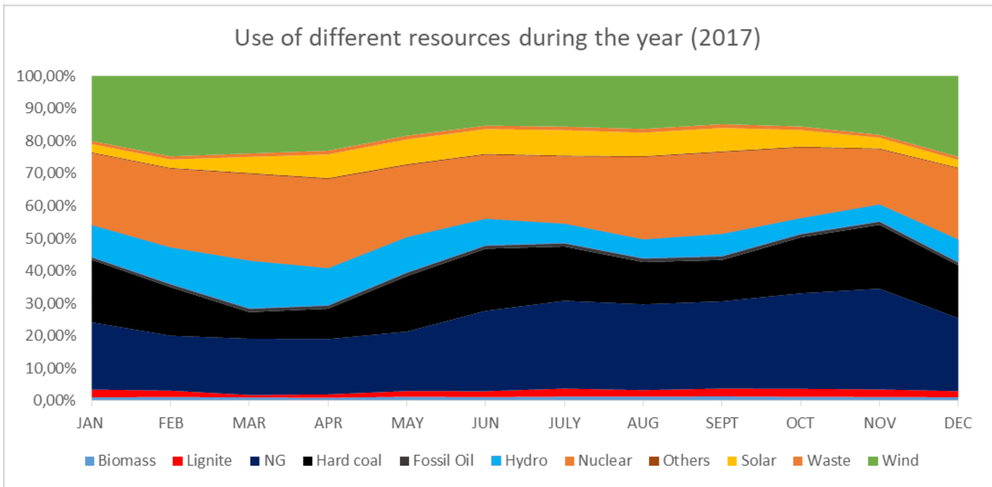


Figure 36: Use of different resources during the year, considering both peak and off-peak hours in Spain

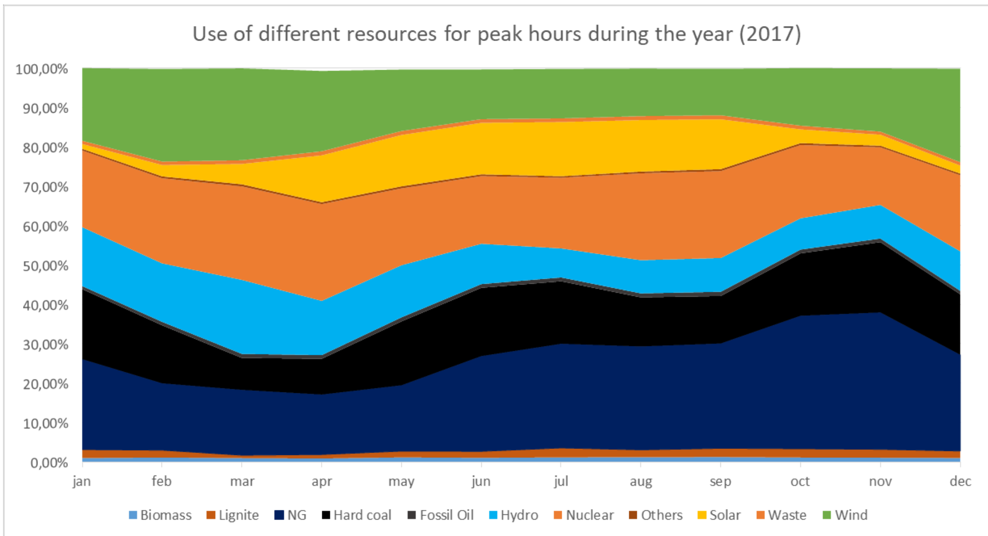


Figure 37: Use of different resources during the year, considering just peak hours in Spain

Table 22: Percentages of the energy sources used per month, accounting both peak and off-peak hours in Spain

	Biomass	Lignite	NG	Hard coal	Fossil Oil	Hydro	Nuclear	Others	Solar	Waste	Wind
JAN	1,10%	2,40%	20,69%	19,25%	0,84%	9,88%	22,10%	0,31%	2,50%	0,95%	19,99%
FEB	1,23%	1,93%	16,91%	14,95%	0,96%	11,30%	24,16%	0,31%	2,55%	0,99%	24,71%
MAR	1,08%	0,74%	17,31%	8,20%	1,14%	14,75%	26,61%	0,36%	4,94%	1,04%	23,83%
APR	0,98%	1,04%	17,00%	9,37%	1,02%	11,48%	27,36%	0,39%	7,24%	1,18%	22,95%
MAY	1,29%	1,74%	18,32%	17,07%	1,13%	10,89%	22,06%	0,39%	7,62%	1,15%	18,34%
JUN	1,19%	1,80%	24,73%	19,12%	1,05%	8,22%	19,66%	0,33%	7,58%	1,07%	15,25%
JULY	1,33%	2,46%	27,04%	16,69%	1,08%	6,00%	20,64%	0,32%	7,79%	1,09%	15,56%
AUG	1,34%	1,97%	26,45%	12,98%	1,15%	5,87%	25,26%	0,34%	7,20%	1,16%	16,27%
SEPT	1,40%	2,40%	26,85%	12,73%	1,20%	6,85%	25,07%	0,36%	7,16%	1,18%	14,79%
OCT	1,28%	2,45%	29,39%	17,22%	1,08%	4,89%	21,62%	0,36%	5,09%	1,11%	15,51%
NOV	1,23%	2,30%	31,01%	19,68%	1,04%	5,26%	16,91%	0,31%	3,29%	0,90%	18,07%
DEC	1,14%	1,85%	22,48%	16,25%	0,97%	7,02%	21,81%	0,30%	2,34%	1,00%	24,83%
PROMEDIO	1,22%	1,92%	23,18%	15,29%	1,06%	8,53%	22,77%	0,34%	5,44%	1,07%	19,18%