Energy Local Storage Advanced system

D5.2 First assessment of the environmental impact at local level related to all demo sites

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Executive Summary

Decentralised small and medium-size energy storages enable a more flexible operation of energy systems than is possible today. The project Energy Local Storage Advanced system (ELSA) brings distributed storage solutions to maturity. Its objective is to enable their integration into the energy system as well as their commercial use. An ELSA battery energy storage system is based on 2nd life batteries from Renault and Nissan electric vehicles and, combined with a local ICT-based Energy Management System, it is installed at six pilot sites in five EU countries. The project's Task 5.3 aims at assessing the environmental impact of the storage system deployed at the six pilot sites by performing a full Life Cycle Assessment (LCA) from "cradle-to-grave".

Due to the fact that real-life data from the pilot site installations is necessary in order to conduct an LCA and the fact that the ELSA battery energy storage systems installation at the pilot sites is partially done in parallel to the work in Task 5.3, this work is done in two steps (corresponding to D5.2 & D 5.5). This first assessment of environmental impacts (D5.2) presents the work done and results achieved in the first step. The methodology of LCA is described, their application on the ELSA battery energy storage systems is explained, and first results of LCA calculations are presented.

An LCA for a representative battery pack performed by Nissan was conducted. The latter comprises calculations for six environmental impact categories and comes out, among others, with a total GWP of 1.8 t CO_{2eq} for the battery production and extraction from an electric vehicle for 2nd life use of a 24 kWh battery including all the components composing the battery pack (casing, management system, internal cabling, etc.). This environmental impact is only partially to be allocated to the ELSA storage system, because the battery production is necessary for the battery's first use in a vehicle anyway.

Furthermore, a model calculation of the Global Warming Potential (GWP), the most important of the six investigated environmental impact categories, has been performed for the expected energy flows of a standardized ELSA pilot model using hypothetical data close to the ones to be expected for real situations. The model calculation of the GWP for the hypothetical site which are connected to the energy flows revealed an annual reduction of the GWP from 213.6 t CO_{2eq} to 209.5 t CO_{2eq} (- 4.1 t CO_{2eq}). In the calculated model scenario, this reduction is caused by the reduced curtailment of a PV-plant whose effect on the GWP more than compensates the effect of the additional energy consumption caused by the losses in the battery system. It also more than compensates the environmental impact of the battery production after two years of operation already.

These results suggest that a reduction of the GWP through installation of an ELSA system is possible if the operation of the system enables, for instance, a reduction of curtailment of

electricity from renewable energy sources, and thereby a reduction of the use of electricity from mainly fossil sources. The comparatively low share of environmental impact of the battery pack suggests that the environmental impact of an ELSA system is mainly determined by its use phase and the changes caused by the ELSA system in the energy mix used at the site of installation.

A full LCA based on real-life data from the ELSA pilot site taking into account potential material inputs and outputs to the system and a thorough discussion of the allocation of the environmental impact of the battery production will be performed in a second step (D5.5: "Final impact assessment of the environmental impact at local level related to all demo site"; scheduled delivery date: September 2017).

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List of Acronyms and Abbreviations

BEMS	Building Energy Management System
D	Deliverable
ELSA	Energy Local Storage Advanced system
EEMS	ELSA Energy Management System
EV	Electric Vehicle
GHG	Green House Gas
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCPD	Directive on Large Combustion Plants
Li	Lithium
LMO	Lithium Manganese Oxide
LV	Low Voltage
PV	Photovoltaic
RES	Renewable Energy Sources
TRL	Technology Readiness Level
WP	Work Package

1 Background

1.1 The Elsa Project

Decentralised small and medium-size energy storages enable a more flexible operation of energy systems than is possible today. They can help to optimise the energy supply of buildings and districts, and enable the integration of a higher share of intermittent renewable energy sources. Yet, though many storage solutions are already technically mature and economically viable, their widespread application is hindered by the current legal and regulatory framework.

1.1.1 Objectives

The ELSA project (Energy Local Storage Advanced system) aims at bringing distributed storage solutions to maturity. Its objective is to enable their integration into the energy system as well as their commercial use. ELSA addresses existing development needs by combining 2nd life batteries with an innovative local information and communication technology-based (ICT-based) ELSA Energy Management System (EEMS) in order to develop a low-cost, scalable and easy-to-deploy battery energy storage system. These storage solutions are conceived as energy services. Existing legal and regulatory barriers are analysed, and international standards are pushed forward. At the same time, ELSA develops innovative service-oriented business models. Sustainability and social acceptance are taken into account through comprehensive environmental and socio-economic impact assessments as well as the involvement of citizens and stakeholder groups.

1.1.2 Planned activities

ELSA further develops technology that is already close to maturity. ELSA storage systems are planned to be applied at six demonstration sites representing different use cases, that is, different application contexts and services provided such as peak demand shaving, demand response provision, ancillary (grid) services, power quality improvement, PV power generation smoothing, etc. Several feedback loops and the constant involvement of relevant stakeholders guarantee the optimal implementation of the pilots. The projects validation and evaluation of the storage systems at six trial sites ensures a scalability and feasibility of the results beyond the project.

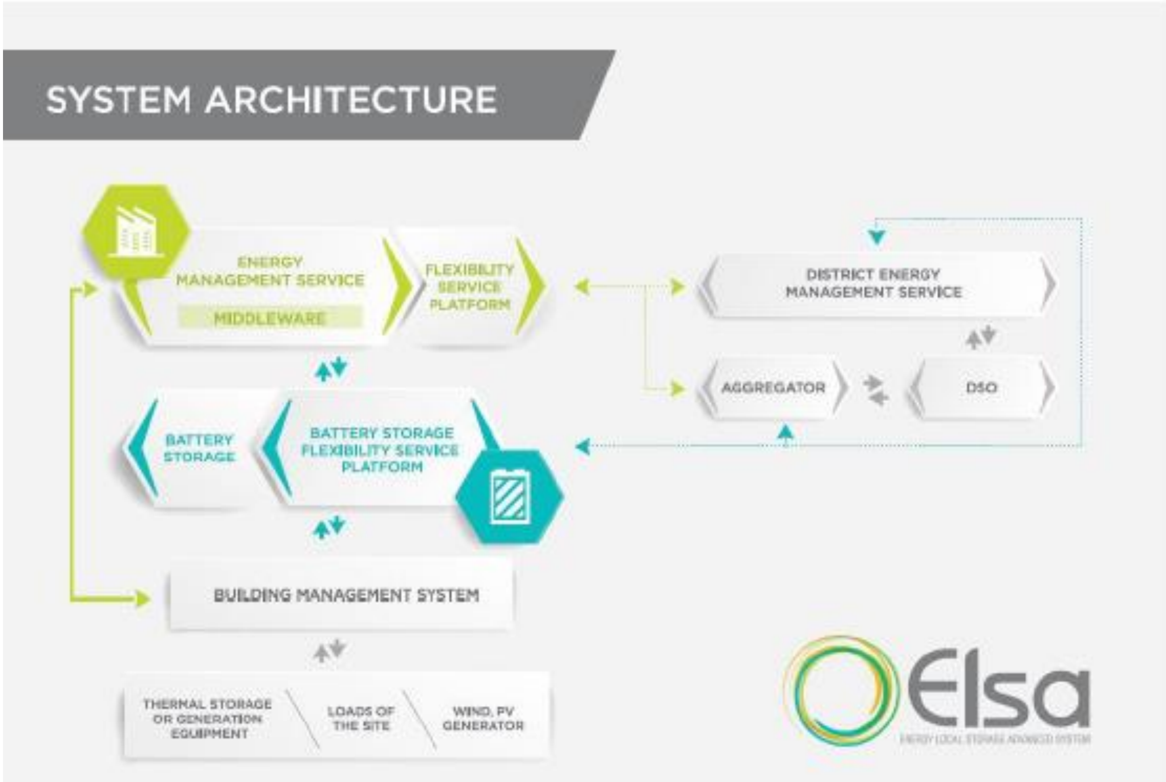


Figure 1: ELSA architecture; Source: B.A.U.M.

1.2 Elsa Pilot Sites

Six pilot sites have been identified for the technical, techno-economic and financial evaluation of the storage systems tested within the ELSA project. The evaluation of the storage deployment at the ELSA trial sites will deliver best practices from which the ELSA consortium will derive a set of unambiguous specifications and recommendations for the adaptation of the regulatory framework in order to enable small-scale storage deployment to be economically and technically viable for effective integration of electricity generation technologies using intermittent renewable energy sources (RES) across the EU. The test sites were selected to cover all the relevant applications for distributed storage installed at low voltage (LV) level. The following trial sites have been selected:

1.2.1 Ampere Building at la Défense (Paris, France); Category: Building

The Ampere Building, which was built in 1985, is a ten-floor office building owned by the real estate company SOGEPROM. Currently, the building is undergoing a complete renovation towards a sustainable construction. In the framework of the ELSA-project, an electrical storage with a total capacity of 32 kWh will be installed. Additionally, the building will be equipped with:

- A 130 kW heat pump for heat and cold generation
- A connection to the heat distribution network of La Défense
- Solar panels

1.2.2 Gateshead College Skills Academy for Sustainable Manufacturing and Innovation (SASMI) facility (Gateshead, UK); Category: Building

The Gateshead College Skills Academy for Sustainable Manufacturing and Innovation (SASMI) is a 5,713 m2 building consisting of classrooms, offices and workshops. It is located adjacent to the Nissan manufacturing facility in Sunderland, UK.

At the SASMI training centre, existing and new equipment will be connected with the installed building management system aiming at optimizing the building's energy consumption. At the SASMI pilot site, the following equipment will be newly installed:

- • 3 x 16 kWh Nissan Leaf 2nd life batteries
- • 50 kWp PV array
- • Additional sensors, meters and BMS programming changes (to be confirmed)

1.2.3 Nissan factory (Barcelona, Spain); Category: Industry

The Nissan factory in Barcelona is a more than 100,000 m^2 vehicle production plant where light commercial vehicles, vans and the Nissan e-NV200 are produced. The plant has an annual electric energy consumption of more than 100,000 MWh. The ELSA pilot installation will consist of a 300 kWp photovoltaic parking system, an ELSA system consisting of 42 Nissan EV battery packs (1,000 kWh total capacity) and an ELSA energy management system connected to the local monitoring system.

The pilot system will provide electricity for part of the factory lighting and is aimed at trialling energy optimization scenarios i.e. the system will not respond to signals of external actors but will apply charge/discharge algorithms in an autonomous way.

1.2.4 E.ON Energy Research Center (ERC) at RWTH Aachen University (Aachen, Germany); Category: District

The E.ON ERC is a multi-disciplinary research institution of RWTH Aachen University. The Aachen pilot site combines three buildings, the main building, the test hall and the Sense building, to an ELSA district.

The main building is the main office building of the center. It has been designed and built to be an experiment in itself including advanced Building Management System integrating different solutions for heating and cooling including geothermal storage, CHP, heat pump. Addionally, the building is equipped with a set of solar panels on the roof.

The test hall is the building for the larger experimental setups of the center. It contains multiple test stands for different purposes, like climate chambers that are used to test heat pumps or other thermal systems. The test hall will be equipped with the ELSA storage system consisting of six 2nd Life Renault Kangoo batteries with an estimated capacity of 66 kWh.

The Sense building is a simple office building with no special characteristics or electrical flexibilities. In addition to the three buildings, the Aachen pilot site includes a wind turbine of 500 kW. The wind turbine will be included as a virtual source of energy by simulations and ICT tests.

The aim of the newly installed storage unit is to increase the flexibility of the local services for the three connected buildings and wind turbine, which, for the purpose of the trial, are treated as a small district. The existing BMS will be expanded and by incorporating the new components and functionalities of the ELSA solutions results in a system that controls the operation of the energy system including the batteries following external signals or local regenerative energy production in real time.

1.2.5 City of Kempten (Kempten, Germany); Category: Distribution System, District

The test-site-district "Auf dem Bühl” in Kempten is an existing residential area with six multifamily houses. Solar panels were installed on three of the district’s buildings for direct consumption by the residents. They are used for supplying the inhabitants with electricity. These buildings have no flexible loads because the individual consumers are not controllable.

Systems which will be installed at the Kempten test site as part of the ELSA pilot include:

- 6 x 11 kWh Renault Kangoo 2nd life batteries
- 37.1 kWp PV system
- 7 egrid measurement boxes
- Bouygues battery Energy Storage Management System (ESMS)

The aim at the Kempten pilot site is to optimize balancing consumption and production peaks in the local city quarter. The expected outcome of the trial is a minimization of the inserted fixed capital for installed network capacity and the improvement of the power quality (Smart Grid) as well as the provision of flexibility optimising activities on the energy market (Smart Market).

1.2.6 City of Terni (Terni, Italy); Category: Distribution System

ASM Terni has been continuously investing in the electricity grid in order to increase the feed-in share of electrical energy generated from RES. Currently, approximately 20 % of the city's overall electricity demand is covered by RES.

The ASM TERNI pilot site is a district and its objectives are to mitigate and smooth the fluctuating power output generated by the nearby PV farm in order to follow, ultimately, the requests from the DSO in terms of grid efficiency. The said district is composed of 4 Blocks of energy units:

1. 240 kWp equivalent (180 kWp + 60 kWp) PV farm, connected to the LV section of the network (existing)

2. 95 kWh ELSA battery energy storage, capable to be charged with a peak of 18 kW and able to supply 72 kW of power, to be installed as part of the ELSA project

3. ASM Terni buildings comprising i) a 4,050 m2 three-storey office building; ii) a 2,790 m2 single-storey building consisting of technical offices, a computer centre and an operation control centre and iii) a 1,350 m2 warehouse (existing).

4. One electric vehicle (EV), called Renault Zoe R240 and featuring a 22 kWh lithium-ion battery (to be on site by the end of 2016).

1.3 Goals of Work package 5

The goals of work package 5 are to perform an assessment of (1) the economic and (2) environmental impact of the electric storage scale-up taking into account the full integration into the local electricity grid, the distributed generation and the further deployment of RES. The investigation of the economic impacts is further subdivided in an investigation of business models (Task 5.1) and an evaluation of the economic impact of the implementation of such business models on the electric grid operation (Task 5.2).

Key business success factors related to system costs, direct value generation, integration in virtual power plant schemes and services provided to grid stakeholders will be evaluated. This work is done in parallel to the ELSA system development in which the objective is to progress from the current Technology-Readiness-Level 6 (TRL) towards TRL 9 at the end of the project.

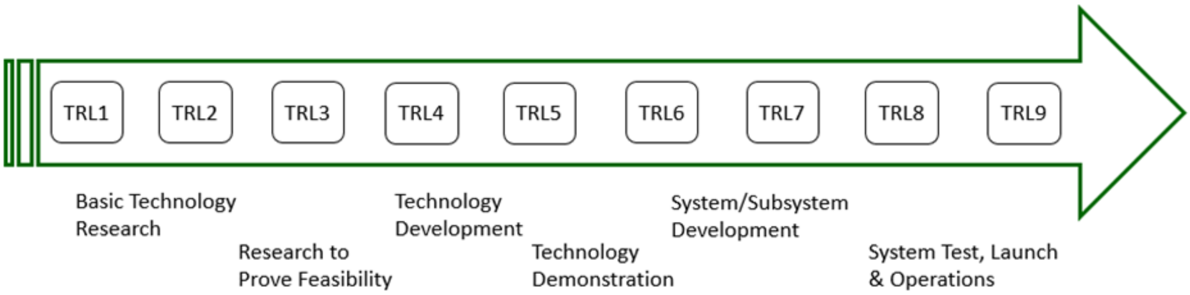


Figure 2: Technology Readiness Levels; Source: Nasa Technology Readiness Level

Further, WP5 focuses on how a sustainable economic activity based on a stationary battery storage system could create new jobs and reduce the overall environmental impact.

Within WP5, Task 5.3 covers the assessment of the environmental impact of the deployed storage systems by conducting a life cycle assessment (LCA). The preliminary and final results of this work are presented in the two consecutive deliverable reports D5.2 and D5.5.

1.4 Goals of Task 5.3: Environmental impact of large-scale storage deployment

The European Commission Directive on Large Combustion Plants (LCPD) shows the potential impact of traditional electricity generation on the environment. The LCPD aims at reducing acidification, ground level ozone and particle concentration in the atmosphere throughout Europe by controlling emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter from large combustion plants (LCPs). These pollutants contribute significantly to acid deposition in soils and freshwater, plant and aquatic habitat damage as well as corrosion of building materials. The work in this task consists of a full LCA evaluation “from cradle to grave” of the storage systems deployed at the six ELSA pilot sites. Furthermore, an overall assessment of the storage systems’ environmental impact as well as the possible impact on the electricity generation will be made.

1.4.1 Environmental impact of the storage system

Life Cycle Assessment aims at evaluating all environmental impacts associated with the deployment of the battery storage system or the storage services at all stages of its lifetime from “cradle to grave”: from resource extraction and processing, through construction, manufacturing and retail, distribution and use, repair and maintenance, disposal/ decommissioning and reuse/recycling. As the batteries to be installed come from automotive applications, a strong link with vehicle LCA is needed. Furthermore, the allocation of the environmental impact of the battery “production” and “end-of-life” phase to the batteries first (EV) and second (stationary battery system) life needs to be discussed.

1.4.2 Environmental impact of electricity generation including storage systems

Large deployment of storage capacity could significantly change the pattern of the environmental footprint associated to the electricity generation by fostering the transition towards a mainly renewable energy-based generation system. By favouring self-consumption, affordable storage systems installed at building level could foster the use of renewable energy sources and increase the rate of nearly zero energy buildings. Whether this is the case and to which degree are two out of several questions to which Task 5.3 is supposed to provide some elements of an answer.

2 Technical background and methodology

2.1 Technical background

With a high power and energy density, Lithium (Li)-ion batteries have a clear advantage over other chemical battery compositions (Armand, et al., 2008), which makes them the number one choice of battery for hybrid and full electric vehicles today (Wikipedia, 2016).

Lithium is the chemical element with the highest reduction potential, which means that Li-ion batteries have the highest possible cell potential. Furthermore, Lithium as one of the smallest and lightest existing atoms allows producing batteries with a high gravimetric and volumetric capacity. The power density of Li-ion batteries depends on the chemistry and is also high for some types.

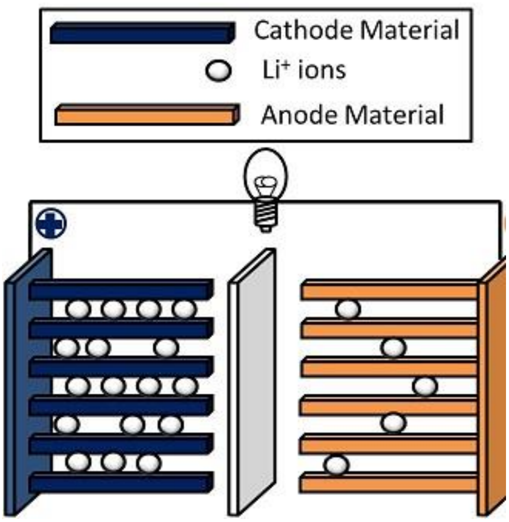


Figure 3: Schematic of a Li-Ion battery; source: (Wikipedia, 2015)

These properties of Li-Ion batteries render them interesting for diverse applications, notably for electric mobility, but also for electric grid applications including grid-balancing services allowing for an increased power feed-in from renewable energy sources (Nitta, et al., 2015). Considering the global expansion of electric vehicles (Statista, 2016), the still relatively high production cost of Li-ion batteries, and notably potential bottlenecks in lithium production and refinery, the interest from both research and industry in re-using batteries from electric vehicles is high.

From an environmental perspective, Li-ion batteries are considered the "lesser evil" as they contain less toxic material than e.g. lead or cadmium-based batteries. In general, Li-ion batteries are categorised as non-hazardous waste. Battery performance, cost and safety characteristics depend on the battery chemistry (Wikipedia, 2016). The battery packs installed in the ELSA storage system (Renault Kangoo ZE and Nissan Leaf batteries) are lithium manganese oxide (LMO) based batteries.

Existing LCA studies on the environmental impact of Li-Ion batteries in electric vehicles (EV) can provide some insight into the issues to be investigated in ELSA. Several of them have shown that the Li-ion batteries are, in fact, not the dominating factor regarding the environmental impact of electric mobility. Rather, the environmental impact is for the largest part dominated by the operation phase of the vehicle. The batteries' share of the total environmental impact of an EV during its life-time is estimated to be 15 %. Of that, only a small share of the environmental impact is caused by the extraction and treatment of lithium. Rather than that, the main environmental burden must be ascribed to other components of the battery and the battery system (Notter, et al., 2010).

A Li-ion battery consists of three primary functional components: a positive electrode (cathode), a negative electrode (anode) and electrolyte. The designation of cathode and anode refer to the discharging mode. In charging mode, the role of the electrodes is inversed. As the relative electric potential has always the same polarity (the negative electrode is always more negative than the positive one), the names positive and negative electrode are clearer.

In most cases, the anode consists of carbon (graphite) with intercalated lithium ions, while the cathode is a metal oxide with a lithium ion content that depends on the state of charge. A lithium salt in an organic solvent forms the electrolyte (Silberberg, 2006).

The main share of the environmental impact of the battery production is ascribed to metal supply (especially copper and aluminium) and process energy. Metals are used in the production of the cathode and anode as well as the battery management system and battery pack. Copper is used in the production of the anode as the collector foil. Additionally, copper is used in other components, such as cables. Aluminium is used in the collector of the anode, which is made of aluminium foil. The battery pack and battery management system can contain different metals, such as iron (or steel), tin, gold or copper. A particularly high energy demand is associated to the production of aluminium, the production of graphite, the productions of wafers for the battery management system, the roasting process for manganese carbonite and heat for drying the electrodes (Notter, et al., 2010).

Apart from the environmental impact of the battery itself, the study of ELSA Task 5.3 assesses the environmental impact of the different battery storage applications implemented at the six ELSA pilot sites (see chapter 1.2). The trialled storage applications range from an office building to a university Research and Demonstration centre, from an industrial site to a local grid with solar energy generation.

2.2 Life Cycle Assessment

The introduction to LCA methodology presented here is essentially based on the textbook by Baumann et al. (2004) The Hitch Hiker's Guide to LCA – An orientation in life cycle assessment and application. LCA stands for life cycle assessment, a methodology for assessing the environmental impact of a product from "cradle to grave" – meaning through all stages of the product's life from extraction of raw materials through material processing, manufacture, distribution, use, repair and maintenance to disposal or recycling. The procedure of LCA has been standardised as part of the ISO 14000 environmental management standards (ISO 14040 and 14044). According the ISO standards, conducting an LCA involves four main phases, which are described in the following chapters 2.2.1 to 2.2.4.

2.2.1 Goal and scope definition

The first phase of an LCA is the "goal and scope definition". It determines the overall objective of, and the exact questions to be answered by, the LCA. During this process, a number of decisions must be taken. Traditionally, the goal and scope definition is done in close cooperation of the commissioning party of the LCA and the practitioner who conducts the LCA. Thereby, the scope and the requirements for the LCA study are determined based on the study's goal. This step is integral for every LCA study, as different goals require different approaches regarding LCA methodology. Apart from the reasons for conducting the study, this phase also collects information on how the results will be used and who will have access to them.

The first step in defining the goal and scope of the LCA states which specific products, product designs or process options are covered by the LCA. Furthermore, the type of LCA to be conducted must be selected based on the stated goals. In general, a distinction is made between accounting, change-oriented and standalone-type LCA studies. Standalone-type LCA studies usually describe a single product with the objective to gather information on its environmental characteristics. An accounting-type LCA compares different options, but takes a retrospective view, while a change-oriented LCA is also comparative, but has a "looking into the future" component. Thus, change-oriented LCA studies can be applied to assess the environmental impacts of different courses of action.

One of the most important discussion points during the goals and scope definition is the decision on the **functional unit**. The functional unit of an LCA study describes a reference flow to which all other flows are related. The functional unit must be quantitative and relate to the studied system. It further enables a comparison between different systems. In an LCA study on Li-ion batteries used in EVs on behalf of the United States Environmental Protection Agency (Amarakoon, et al., 2013), the functional unit was, for example, set as a certain amount of kilometres driven.

Apart from the functional unit, **the environmental impact categories** to be studied must be determined. The choice of impact categories influences which kind of data has to be collected for the Life Cycle Inventory (LCI). The impact categories should be chosen to reflect, as far as possible, the complete impacts of the inputs and outputs of the studied product system rather than the goal for conducting the LCA study. In (Hawkins, et al., 2012), a comparative study on the environmental impacts of conventional and electric vehicles, for example, the impact categories global warming potential, terrestrial acidification, particulate matter formation, photochemical oxidation formation, human toxicity, freshwater eco-toxicity, terrestrial eco-toxicity, freshwater eutrophication, mineral resource depletion and fossil resource depletion were chosen.

Also part of the goal and scope definition is the **description of the system boundaries**. The system boundaries must be set in relation to the natural system in space and time, and in relation to technical systems. In setting the system boundaries – deciding which flows to include and exclude for the LCA study – a number of assumptions and limitations, under which the study is conducted, are formed.

Setting the system boundaries is complicated by such processes that are linked to more than one product or function. In that case, the environmental impact has to **be allocated** to these different products or functions. An allocation problem is handled most commonly in one of three ways: increasing the level of detail of the studied system, allocation through partitioning or by system expansion. If partitioning is chosen as allocation method, the environmental load is divided between the products or functions while in system expansion the studied system is credited with the environmental load avoided by replacing an equivalent product on the market.

2.2.2 Life cycle inventory

During the Life Cycle Inventory (LCI), the flows from and to nature for the studied product system are analysed. To conduct the LCI, a flow model of the technical system detailing the input and output flows of the system is constructed based on available data. Apart from raw material input, input of water and energy as well as their release to air, water or land are taken into account. The flow model adheres to the system boundaries set in the goal and scope definition and is restricted to flows relevant to the product system's environmental impact.

After data collection, resource use and emissions connected to the investigated system are calculated in relation to the functional unit.

2.2.3 Life cycle impact assessment

In the impact assessment, the significance of potential environmental impacts is evaluated based on the LCI flow result. This stage in an LCA consists mainly of three steps:

- Classification (assignment of inventory parameters to impact categories)
- Characterisation (calculation of relative contribution of emissions and resource consumption to the different categories of environmental impact)
- Weighting

2.2.4 Interpretation

The interpretation chapter summarises the results from the inventory analysis and impact assessment. The outcome of the interpretation phase is usually a set of conclusions and recommendations. In a standard LCA, this stage includes:

- Identification of significant issues based on the results of the LCI and LCIA phases
- Evaluation of the study (completeness and consistency check)
- Conclusions, recommendations and reporting

2.3 LCA within the ELSA project

Within the framework of the ELSA project, the LCA must encompass the individual situational conditions of the six ELSA pilot sites. Their system boundaries as well as the reference scenario are different for each of the pilot cases. The discussion about the proper choice of the functional is presented in section 3.1.1.

Furthermore, one of the central questions in assessing the environmental effect of the ELSA battery system is one of allocation. How is the fact that the ELSA battery storage system is based on second life batteries taken into account? To what extent must the environmental load of the battery's first life be considered in the framework of this study? This question will be discussed in the final version of this study, deliverable D5.5. Here, only the scope of the issue is shortly presented.

Although the system boundary and reference case may differ across the six ELSA pilot sites, the same life-cycle phases can be distinguished for the installed batteries' first as well as second life. For the batteries' first life, for example, the following life phases can be defined (Matheys, et al., 2006):

1. Extraction of raw materials
2. Processing of materials and components
3. Use phase of the battery in the vehicle

4. Recycling of discarded batteries
5. Final disposal or incineration

Although the environmental impact of the different life phases are reported to vary greatly for all battery chemistry and vehicle battery types, several LCA studies for EV batteries declared the use or operation phase to be the dominating life phase for environmental impact (Amarakoon, et al., 2013). This high impact of the operation phase strongly depends on the choice of electricity generation for battery charging (Notter, et al., 2010).

For the batteries' second life installed as battery storage system at the ELSA pilot sites, the following life phases are distinguished:

1. Production phase: extraction and processing of raw materials, and production of components and infrastructure for the stationary battery system (excl. components available from the first life cycle).
2. Battery use phase: generation, transport and distribution of electricity for charging the battery, incl. losses during charging-discharging cycles; changes induced in generation and use of heat (e.g. because of CHP, power-to-heat); replacement of individual battery cells, maintenance and repair.
3. End-of-life phase: recycling and final disposal of system components and infrastructure for the stationary battery system (excl. components available from the first life cycle).

Considering the high impact factor reported for choice of electricity generation in the environmental assessments studies of EVs, the assessment of the impact of different electricity generation for battery charging during the batteries second life is considered a focus point in the framework of this study.

3 Life Cycle Assessment

3.1 Goal and scope

In the framework of the ELSA project, the LCA consists of two parts. The first part covers the environmental impacts already generated in the first life phase. Though it can be argued that these impacts are generated independently of a second life use, the discussion about allocation of a part of these impacts to the second life phase is not automatically closed.

Thus, an LCA was performed for a 24 kWh Nissan EV Li-Ion battery pack, which covers the extraction of raw materials and production of the battery including all the components composing the battery pack (casing, management system, internal cabling, etc.), its dismantling from the vehicle at the end of the first life, and related transports of the battery.

The second part of the LCA performed in ELSA covers the environmental impacts of the second life phase. For that, a calculation of the environmental impact of the ELSA battery energy storage system's use phase was done.

In a first step, a model calculation with hypothetical data close to expected real situations was performed for the environmental impact of the changes induces by an ELSA battery system in the electric energy flows of a hypothetical site. For simplicity, just one environmental impact category was considered: the Global Warming Potential (GWP). Based on this model calculation, first conclusions on the environmental impact of the different life phases as well as the significance of using second life batteries are drawn. The results of this first step are presented in this Deliverable 5.2: "First assessment of environmental impact".

In a second step, the calculation of six environmental impact categories will be done with real data from the ELSA pilot sites after installation of the battery storage system. Furthermore, the material flows (e.g. additional constructions, electrical components, etc.) are inventoried and assessed. The results of the second step will be the content of D5.5: "Final impact assessment of the environmental impact at local level related to all demo sites", which is scheduled to be published in September 2017.

3.1.1 Discussion of the functional unit

As described in chapter 2.2.1, the functional unit defines what precisely is being studied and quantifies the service delivered by the product system in order to provide a reference point to which the inputs and outputs can be related. The functional unit further enables a comparison and analysis of alternative goods or services.

This study analyses the use of second life Li-ion batteries from electric vehicles as stationary battery storage applications as an environmentally viable option to further decrease the environmental impact of electric mobility by extending the battery lifetime while, at the same time, enabling an increased integration of RES into the grid.

The functional unit chosen in LCA studies on Li-Ion batteries in EVs is most often related to a certain distance driven (Amarakoon, et al., 2013). In a study focused on the contribution of Li-ion batteries to the environmental impact of EVs, the functional unit was e.g. set as one average kilometre driven by a vehicle with electric drivetrain on the European road system (Notter, et al., 2010).

In contrast, the functional unit chosen in the framework of LCA studies on battery energy storage systems is often related to capacity or consumption. In a study quantifying the environmental impact of combined PV storage systems, the functional unit was set at 1 kW_{el}

(Jülch, et al., 2015). A comparative analysis of the environmental performance of different electricity storage systems utilized the functional unit of 1 kWh of energy delivered back to the grid from the storage system (Oliveira, et al., 2015).

Considering these examples, we argue that for the scope of this study, a viable choice of functional unit could relate to the service life of the storage system (e.g. x years of system use) or a specified amount of energy stored (e.g. x amounts of charging-discharging cycles). Thus, in the framework of this study, a viable option of functional unit for assessing the environmental impact of the ELSA battery energy storage system at its six pilot sites would be **2000 charging-discharging cycles**. Alternatively, **one year of operation** can be taken as functional unit. This facilitates notably the assessment of the impact of changes in the energy origin mix caused by an ELSA system as energy flows are generally known for calendric years.

3.1.2 Choice of impact categories

In the framework of this first assessment report, the model calculation which is executed for assessing the effect of a change in the energy flows on a site equipped with an ELSA system has been performed for just one impact category: the global warming potential (GWP; kg CO_2-eq).

The impact category (total) GWP describes the amount of heat a greenhouse gas traps in the atmosphere relative to the amount of heat trapped by 1 kg of carbon dioxide. Thus, the GWP enables assessing the environmental impact of emissions of different gases and expresses them in terms of the equivalent amount of carbon dioxide which has the same environmental impact as the investigated amount of emitted gases.

Different gases have a different capacity to hold infrared (heat) radiation back in the atmosphere. Further, they remain in the atmosphere for different times. To display the difference in GWP of the same amount of different gases, the notion of relative GWP exists. For the relative GWP different values exist in literature. Table 1 gives an overview of the relative GWP of different gases as used by the International Panel on Climate Change (IPCC) in (IPCC AR5, 2013).

Table 1: Relative GWP values for a time horizon of 100 years according to IPCC AR5 (2013)

Greenhouse gas	Relative GWP (100 years time horizon)
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous oxide (N_2O)	265
Chlorofluorocarbons, e.g. $CCIF_3$	13,900

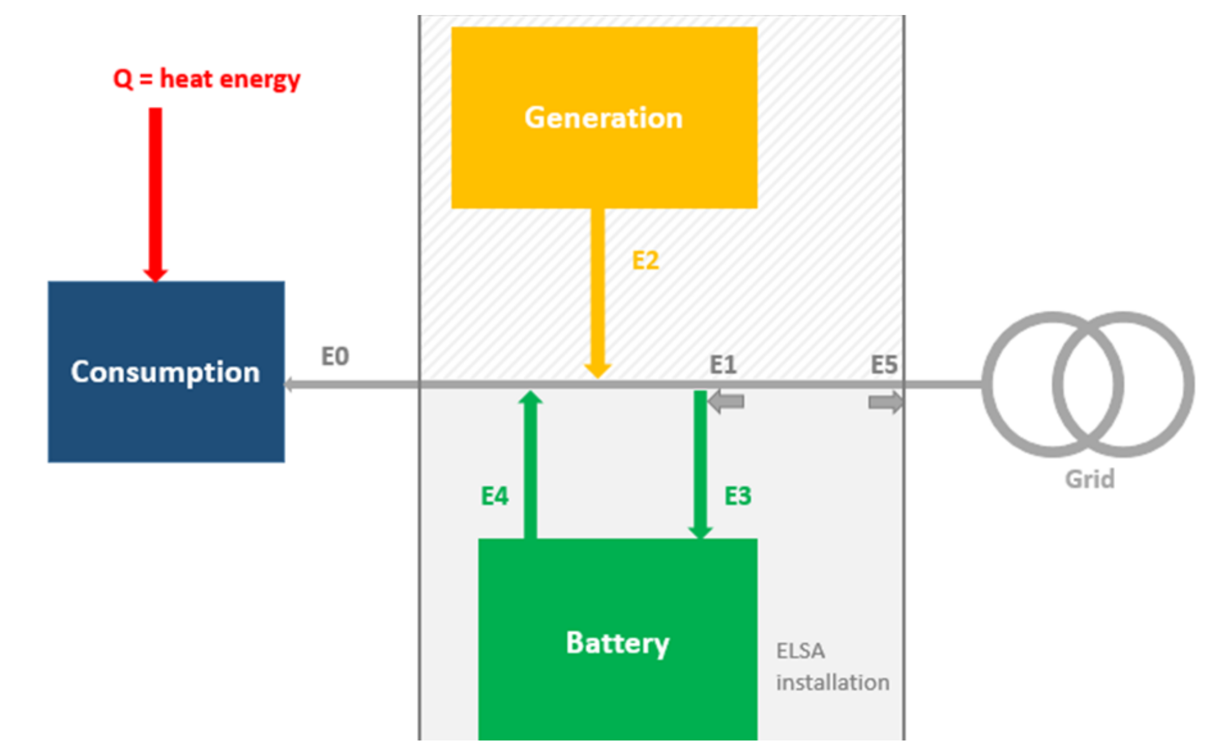
Fluorinated hydrocarbons, e.g. CHF_3	12,400
Nitrogen trifluoride (NF_3)	16,100
Sulfur hexafluoride (SF_6)	23,500

Alltogether, the following environmental impact categories have been chosen:

- (Total) Global Warming Potential (kg CO_2-eq)
- Primary energy demand (MJ)
- Acidification potential (kg SO_2-eq)
- Photochemical ozone creation potential (kg C_2H_4-eq)
- Abiotic resource depletion potential (kg Sb-eq)
- Eutrophication potential (kg PO_4-eq)

3.1.3 Description of the ELSA pilot sites

In performing an LCA for a product or a product system, its system boundaries must be specified in several dimensions: boundaries between the technological system and nature, Life cycle inventory, limitation of the geographical area and time limit, boundaries between production and production of capital goods, boundaries between life cycle of the product system and related life cycles of other products (Baumann, et al., 2004). In the framework of the ELSA project, different system boundaries must be specified for each of the six pilot installations. Additionally, the material flow is individual to each pilot site (e.g. additional construction, technical equipment, components, etc.) and must be taken into account.



Consumption: Totality of all electricity and/ or heat consuming elements of the ELSA pilot site
Generation: Totality of all electricity generating elements within the ELSA pilot site
Battery: ELSA battery system
Depicted are further the different energy flows with (grey background) and without the installation of the ELSA battery system. Energy generation plants are not installed at all pilot sites (shaded grey).
Distinguished are:
E0: annual amount of electricity consumed within the boundaries of the ELSA pilot site (without losses within the battery and on-site generation units)
E1: annual amount of electricity from the grid to the ELSA pilot site
E2: annual amount of electricity generated within the boundaries of the ELSA pilot site
E3: annual amount of electricity flow into the ELSA battery
E4: annual amount of electricity flow out of the ELSA battery
E5: annual amount of electricity from the ELSA pilot site fed into the grid
Q: annual amount of heat consumed within the boundaries of the ELSA pilot site

Figure 4: Schematic representation of the energy flows in the ELSA system

The description of the pilot site-specific system boundaries and material flow will be presented in D5.5: "Final impact assessment of the environmental impact at local level related to all demo sites" (Expected publication date: September 2017).

For the performance of the GWP model calculation, a standardised model representing the general composition of an ELSA pilot site installation and the respective energy flows has been set up. Figure 4 depicts and describes the different energy flows assumed to be potentially relevant for changes induced in the environmental impact of the ELSA pilot sites through the installation and operation of the ELSA energy storage systems.

3.2 Life cycle inventory

As described in chapter 2.2.2, energy and material flows of a product system to and from nature within the defined system boundaries are recorded and assessed in an LCI. For assessing the environmental impact of the system, a reference case of the status quo (pilot site without installation of the ELSA battery energy storage system) is described. As the battery storage systems have not yet been installed at the respective pilot sites, LCI performance of the full ELSA pilot installations is not feasible at this stage of the project. Therefore, the LCI will be part of ELSA D5.5.

Furthermore, due to confidentiality reasons, a full LCI of the battery pack itself is not included in this study. Rather, a full LCA of a Nissan EV battery pack is performed by Nissan Motor co., Ltd. The results provided for the selected environmental impact categories are considered representative for all battery models to be installed within the framework of the ELSA project.

3.2.1 The battery pack

The ELSA battery energy storage systems at the six ELSA pilot sites are based on Li-Ion batteries from three different electric vehicle models: the Nissan LEAF, the Nissan eNV200 and the Renault Kangoo.

The LCA for a Nissan EV battery pack is performed by Nissan Motor Co., Ltd. For the LCA, the data of a battery pack with the nominal capacity of 24 kWh produced at the Nissan UK production site in Sunderland is utilized. The results include the environmental loads of the full battery pack, including casing, management system, internal cabling, etc. They do not include the electronic equipment needed exclusively for the second life, i.e. the stationary ELSA systems.

3.3 Life cycle impact assessment

In the framework of this deliverable, the life cycle impact assessment is limited to (1) the production, extraction from the vehicle and transport of the Nissan battery pack (see chapter 3.3.1) and (2) changes induced in the energy flows at a hypothetical model pilot site as a result of the installation and use of an ELSA energy storage system.

3.3.1 Calculation of the environmental impact of the battery pack

Table 2 summarises the environmental impact of a 24 kW Nissan battery pack in terms the chosen six environmental impact categories. For the calculation, CML 2001 was chosen as impact assessment method.

Table 2: Result of the LCA performed for a 24 kWh Nissan battery pack for the life phases of production and end-of-life/recycling; CML2001 – April 2013)

	Production	Logistics for production	Logistics for gathering from ELV	Total
CML2001- Apr 2013: Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	0.13	0.00	0.00	0.13
CML2001- Apr 2013: Acidification (AP) [kg SO_2-Equiv.)	11	1	0	12
CML2001- Apr 2013: Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1.8	0.1	0.0	1.9
CML2001- Apr 2013: Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	1,765	43	0	1,809
CML2001- Apr 2013: Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	0.77	0.03	0.0	0.81
Primary energy from non-renewable resources (net cal. value) [MJ]	27,366	638	0.1	28,004

3.3.2 Model calculation of the GWP of the use phase of the ELSA battery energy storage system

At the time of the redaction of this document, only rough estimates were possible for the change of the energy flows that are triggered by the installation of ELSA storage systems at the six pilot sites. For this reason, the evaluation of the related changes in the environmental impact, that is, the environmental impact of the ELSA storage systems' use phase (without impacts due to maintenance and replacement of parts), is not possible, yet. It will be investigated in D5.5.

However, a discussion of the potential mechanisms influencing the environmental impact of the ELSA storage systems is possible. For the sake of simplicity, this discussion is limited here on that environmental impact parameter which attracts most of the public attention: GWP expressed in equivalents of tons of CO_2 emissions.

For calculating the environmental impact of an ELSA storage system, the following needs to be considered:

- The production, use, and end-of-life treatment of the ELSA system goes along with emissions and use of resources, thus generating environmental impacts. Basically, this is presented in the previous section. However, an open issue is how the production, maintenance and end-of-life treatment of those components which are used in the first and the second life are allocated. This point will be investigated in the final environmental study D5.5.

- New buildings, additional components such as electronic converters only needed for the stationary (second life) generate an environmental impact during their production, maintenance and end-of-life treatment go along with environmental impacts that need to be allocated fully to the 2nd life. As data on these components are still missing, this will also be investigated in D5.5.
- The energy flows Q and E1 to E5 shown in Figure 4 denote the energy flows which are relevant for the investigation of the change in the environmental impact introduced by the ELSA system. E1, E2 and E5 might be zero before and/ or after the installation of the ELSA storage system. E3 and E4 are always zero before the installation.
- These energy flows can change when an ELSA system is installed and the related change in the environmental impact is considered as the environmental impact of the ELSA system's use phase. For sake of simplicity, the impacts caused by measures of maintenance and replacement of components, which belong also to the use phase, are disregarded.
- E0, that is, the electricity consumption at the pilot site is considered not to change. If, under real operation condition, the measured value of E0 changes after the installation of the ELSA storage system, this cannot be attributed to the installation and use of the ELSA system. As a consequence, the calculated environmental impact of the ELSA storage system needs to be renormalized to the value of E0 before the installation, if this happens.
- E3 and E4 are zero before the installation of the battery. After the installation, both are no longer zero and E3 is always higher than E4 because the battery operation goes along with energy losses. As a consequence, E1 increases in most scenarios that can be imagined because more electric energy is needed to cover the losses of the battery.
- E2 might increase, too, as a result of the installation of the battery, for instance, because the latter might help avoiding curtailment of self-generated electricity, in particular from PV plants. In principle, a decrease of E2 can also be imagined for some specific circumstances, for instance if the generation of E2 is related to the use of an expensive fuel that can be saved as a result of the installation and use of the ELSA system.
- Finally, any change of E5 is possible in principle as a result of the changes of E1 to E4.
- The equation E0 + E3 + E5 = E1 + E2 + E4 must always be observed. It is a consequence of the law of conservation of energy.

- Q only changes as a result of the installation and use of the ELSA system if there is a connection of the thermal and the electric energy supply, e.g. due to a combined heat and power generation (CHP) or use of surplus electricity from a PV installation for water heating. As a consequence, an investigation of Q is only necessary if such a link exists.
- For the calculation of the environmental impacts, the energy flows Q, E1 and E2, which are directly related to the generation of heat and electricity, need to be considered.
- Q and E2 are related to local generation and both local and non-local environmental impacts, E1 is entirely related to non-local ones.
- E3, E4 and E5 must not be considered separately in the assessment of the environmental impact as they are only indirectly related to the generation of heat and electricity and their consideration would mean that emissions and material use, and related environmental impacts are double charged.
- As Q, E1 and E2 might change, the environmental impact of the heat and electricity generation might change with the installation and use of an ELSA storage system. In particular, the energy losses related to charging and discharging the battery go along with an increase of the electricity need.
- As a consequence, the environmental impact changes. This change corresponds to the environmental impact of the ELSA storage system's use phase.
- The energy mix for the flows Q and E1, that is the composition of the primary energy and the conversion technologies generating these energy flows, might change, if an ELSA storage system is installed. For instance, the latter might lead to a higher share of natural gas and a lower share of hard coal in the electricity mix of E1, thus lowering emissions and environmental impact even if E1 remains unchanged.
- An ELSA system might lead to a different time-profile of the energy flows Q and E1. This might change the efficiency of the plants contributing to the generation of Q and E1, even if their amounts and the generation mixes remain unchanged. For instance, an ELSA system might allow a hard coal power plant to run more equally, thus increasing the average efficiency of electricity generation.

To illustrate how an ELSA system might modify the environmental impact of a site, the following scenario has been investigated (see Table 3 for calculations and results):

- Let a dummy site have an annual electricity consumption of 700,000 kWh and no heat consumption Q before the installation of an ELSA system.
- Let 300,000 kWh of the electricity consumption be met by a local PV plant (E2) and 400,000 kWh from the grid (E1).

- Let the value of E2 be the result of a curtailment by 5 % due to the impossibility to make use of the entire electricity that the local PV plant might generate. That means it was 315.789 kWh without curtailment.
- Let no electricity be fed into the grid (E5 = 0). Then, E0 = E1 + E2 and E3 = E4 = 0.
- Let the mix of origin of the electricity from the grid (E1) be the same as the German electricity mix in 2015.
- Let the specific emission factors for different origins of electricity for the GWP be the same as those published by the German Federal Environmental Agency in 2013 (Umweltbundesamt, 2014).
- Then the GWP of the electricity consumed at the dummy pilot site is 213.6 tons of CO_2eq before the installation of an ELSA storage system.
- Let now be an ELSA system installed with a nominal capacity of 96 kWh. Let it be charged and discharged once per day, the state of charge varying between 10 % and 90 %. Hence, the energy charged into the battery per year, E3, equals 28.032 kWh.
- The GWP related to any modifications of the site due to the installation of the ELSA storage system, including new electronic components, buildings, etc. is disregarded for the sake of simplicity.
- Let further be the losses per charging cycle be 20 % of E3 that is 5.606 kWh. Hence, the energy discharged from the battery per year, E4, equals 22.426 kWh, and the total consumption at the site E0 = E1 + E2 +E3 – E4 = 705.606 kWh, i.e. increased by the amount of the energy losses in the battery.

Table 3: GWP of a dummy ELSA site before and after the installation of an ELSA storage system[1]

origin of electricity	specific GWP [g CO2eq/kWh]	share of origin for E1	without ELSA system		with ELSA system	
			E1 [kWh]	E2 [kWh]	E1 [kWh]	E2 [kWh]
PV	55,2	6,0%	24.000	300.000	23.389	315.789
lignite	1070,1	24,0%	96.000		93.556	
hard coal	919,0	18,0%	72.000		70.167	
natural gas	429,7	9,0%	36.000		35.084	
petrol	777,3	1,0%	4.000		3.898	
wind (onshore)	8,8	12,0%	48.000		46.778	
wind (offshore)	4,3	2,0%	8.000		7.796	
hydropower	2,7	3,0%	12.000		11.695	
geothermal energy	217,2	0,0%	0		0	
solid biomass (mix)	25,4	4,0%	16.000		15.593	
biogas (mix)	422,6	4,0%	16.000		15.593	
liquid biofuels (mix)	316,8	0,0%	0		0	
sewage gas CHP	26,2	1,5%	6.000		5.847	
landfill gas CHP	25,7	1,5%	6.000		5.847	
nuclear energy	5,0	14,0%	56.000		54.574	
sum	**-**	**100,0%**	**400.000**	**300.000**	**389.817**	**315.789**
sum	**-**	**-**	**700.000**		**705.606**	
GWP [tons CO2eq]	-	-	197,0	16,6	192,0	17,4
GWP [tons CO2eq]	**-**	**-**	**213,6**		**209,5**	

- Let it now be possible to make use of the full generation potential of the local PV plant thanks to the ELSA battery system. The curtailment is zero and E2 is 315.789 kWh. E1 is lowered accordingly. Its mix of origin is not changed, nor is the efficiency and related specific GWP of power plants changed.
- Then the GWP of the electricity consumed at the dummy pilot site is 209.5 tons of CO_{2eq} after the installation of an ELSA storage system.
- The GWP reduction of 4.1 tons of CO_{2eq} per year is due to the removed curtailment of the PV plant. This more than compensates the GWP increase related to the energy losses in the battery.
- A closer analysis shows that GWP increase related to the energy losses in the battery is exactly compensated by the GWP decrease related to the reduced curtailment of the PV plant, if the latter is 2.1 % before the installation of an ELSA system and all other assumptions are the same.

[1] Note that the presentation of the figures is in continental format because a German excel-version was used for the calculations. For changing to the Anglo-Saxon format, all points must be replaced by commas and vice-versa.

3.4 Interpretation

The scenario presented in chapter 0 shows that a reduction of the GWP through the installation of an ELSA battery energy storage system is possible, for example, if the installation allows making use of renewable electricity that would otherwise be curtailed for some reason.

The GWP reduction achieved by the installation and second life use of the ELSA energy storage system (4.1 t CO_{2eq} per year, 20.5 t CO_{2eq} for 5 years) is significantly higher than the total GWP generated by the production of the battery pack (7.2 t CO_{2eq} for 4 battery packs of 24 kWh each).

Hence, at least in systems with a high presence of thermal power plants in the supply mix, the environmental impact of the ELSA energy storage system is mainly determined by its use or operation phase, and the net effect of the installation of an ELSA system on the environment is positive.

Similar results have been found both in assessing the environmental impact of different electricity storage systems (Oliveira, et al., 2015) as well as in LCA studies on electric vehicles with different battery technologies (Matheys, et al., 2006) (Notter, et al., 2010).

However, in order to draw any definitive conclusions on the environmental impact of the ELSA battery storage system, an LCA based on measured data for real energy flows is needed. Additionally, the material flows related to the second life installation and use of an ELSA energy storage system and peripherals must be taken into account.

4 Conclusion

Due to the ELSA battery energy storage system not yet having been installed at any of the six pilot sites, the ability to draw conclusions on the environmental impact of the ELSA system at the respective local level is limited. The main conclusion to be drawn from the result of the LCA for the battery pack and the GWP model calculation based on realistic, but hypothetical assumptions regarding the energy flows in the second life use phase is that the environmental impact of the battery production plays presumably a minor role compared to the effects of the change in the energy flows caused by the installation of the ELSA system.

The model calculation further suggests that a reduction of the GWP through installation of an ELSA system is possible if the operation of the system enables a positive change in the energy origin mix such as a reduction of curtailment of electricity from renewable energy sources and, correspondingly, a reduced use of fossil energy sources.

For this scenario, considering the relatively low impact of the battery pack production in comparison with the effect of the use of the system, a roll-out of small-to-medium battery energy storage systems, such as the ELSA system, would be accompanied by a presumably positive modification of the environmental impact in many situations. This is even more the case if one considers that the environmental impact of the battery pack production and end-of-life phase needs to be allocated on the 1st and 2nd life in one way or another.

However, surmising that the environmental impact of the ELSA battery system is mainly determined by the system's use or operation phase and applied energy mix, the environmental impact of the system's operation phase, and changes introduced by an ELSA battery system, would be considerably less when considering an energy mix dominated by energy generation sources associated with low GHG-emissions (e.g. such as hydropower).

Ultimately, an LCA based on real-life data from application of the ELSA system at the six ELSA pilot sites is needed in order to assess in more detail whether the installation of an ELSA system can result in the reduction of negative environmental impact, e.g. by enabling a more efficient use of renewable energy sources or by increasing the average efficiency of electricity generation through more constant operation of energy generation plants.

Furthermore, material input and output of the ELSA system must be inventoried and assessed and the allocation of the environmental load of the battery pack to its first and second life must be discussed. As these tasks are dependent on data from the planned pilot installations, they will be tackled at a later stage in the project and discussed in D5.5: "Final impact assessment of the environmental impact at local level related to all demo site".

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