added value of STORage in distribution sYstems

Deliverable 7.4
Report on Environmental and Social Analysis of a Large-Scale Storage Implementation

Revision	1
Preparation date	2020-07-09
Due date	2020-04-30
Lead contractor	JR
Dissemination level	PU

Authors:

Johanna Pucker-Singer	JR
Ingrid Kaltenegger	JR
David Neil Bird, Anna Eisner	JR
Camilla Neumann, Andreas Tuerk	JR
Jernej Zupančič, Andrej Gubina, Tomi Medved, Edin Lakic	UL
Nicolas Hassid	ACT/FLEX
Raquel Garde Aranguren	CEN

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Deliverable administration	
No & name	**D7.4 Report on Environmental and Social Analysis of a Large-Scale Storage Implementation**
Status	Released — **Due** M60 — **Date** 2020-04-30
Author(s)	J. Pucker-Singer, I. Kaltenegger, D. A. Bird, A. Eisner, C. Neumann, A. Tuerk (JR); J. Zupančič, T. Medved, E. Lakic, A. Gubina, (UL), N. Hassid (ACT)
Description of the related task and the deliverable in the DoA	Task 7.4. Environmental and social analysis of a large-scale storage implementation An environmental and social analysis is performed for the selected large-scale storage integration scenarios. The environmental assessment is based on LCA including the production, operation and end-of-life phase of the different technologies in the scenarios (e.g. storage systems, power grids, heat and electricity generation units). Results from environmental analysis on the demonstration activities are adapted and up-scaled. The most important environmental impacts and benefits (e.g. greenhouse gas emissions, cumulative energy, air pollution) are quantified. Further environmental impacts (e.g. land area demand, material resource consumption) are identified and described in a qualitative way depending on the availability of data and information. Within a social analysis social indicators (e.g. employment, health and safety, prevention of forced and compulsory labor) will be identified and assessed for the large-scale storage implementation.

Planned resources PM

VTT	THNK	VITO	VLER	BASN	UL	BEN	EG	VIES	
					1				
B9	**LOPT**	**JR**	**ACT/ FLEX**	**PROS**	**CEN**	**EXL**	**UCL**	**ABB**	**Total**
		12	1		1				15

Comments

V	Date	Authors	Description
0	2019-04-01	JR	Report structure
0	2020-06-05	JR, UL, ACT/FLEX, CEN	Draft version for review to CEN
0	2020-06-24	JR	Revised version sent to WP leader
1	2020-06-25	UL	Checked and released to the Coordinator for internal QA and subsequent submission to the EC.
1	2020-06-26	VTT	Coordinator asks for revision of executive summary and some additional formal points
1.1	2020-07-10	JR	Sends updated version to Coordinator

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Disclaimer

The information in this document is provided without guarantee or warranty, that the content fits for any particular purpose. The user thereof uses the information at its sole risk and liability.

The documents reflect only the author's views and the Community is not liable for any use that may be made of the information contained therein.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

1 Publishable executive summary

The European project STORY demonstrates and evaluates innovative approaches for energy storage systems in the residential and industrial sectors. This report describes the assessments performed in *Task 7.4. “Environmental and social analysis of a large-scale storage implementation*”. Within in this Task three different assessments were performed: (1) Life Cycle Assessment, (2) Social Life Cycle Assessment, and (3) Employment creation by increased use of PV and battery energy storage.

Life Cycle Assessment

To estimate the environmental impact of storage integration in the distribution grid, a Life Cycle Assessment (LCA) was performed for different storage implementation scenarios. LCA is a method to estimate the environmental impacts throughout a product’s life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. The goal of this LCA was to assess the environmental changes occurring from battery integration into the low voltage (LV) grid. Therefore, we performed LCA for network development scenarios with and without batteries.

The investigated network development scenarios represent a typical European distribution grid supplying households and electric vehicles with electricity. The electricity consumption on LV grid is covered by local photovoltaic (PV) plants and by electricity supply from the main grid, flowing from high voltage (HV) to medium voltage (MV) to LV levels. In the scenarios with a battery, electricity from PV plants is either consumed directly, stored in the battery, or injected into the MV grid. Surplus electricity from PV plant, when it is available, is injected into the MV power grid and replaces another type of electricity generation (e.g. country specific electricity generation mix, natural gas CC power plant) or is stored in a pumped storage power plant.

For each scenario the environmental impacts were calculated for the yearly electricity consumption as well as per MWh of consumed electricity. The LCA especially focused on the environmental impact categories greenhouse gas (GHG) emissions and cumulative primary energy demand. The LCA results show that different factors influence the GHG emissions of network development scenarios with PV and battery storage:

The most important factor is the amount of PV power installed in the distribution grid and the ability of the grid to transport the PV electricity. In the investigated scenarios the grid model showed no limitation in technical parameters for the LV grid. So curtailment is not needed in any of the scenarios. Transporting the electricity to another place in the network (“grid as a storage”) has less losses than storing the electricity in the battery system. Also, additional GHG emissions from the manufacturing of the batteries arise, although the contribution of battery manufacturing on the total GHG emissions of the scenarios was rather low (2-11% of total GHG emissions). These factors lead to the result that the scenarios with batteries have higher GHG emissions compared to the scenarios without batteries.

The results on the cumulative primary energy demand also showed that scenarios with a battery have in total a higher annual primary energy demand compared to the scenario without a battery.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

This again is explained by (1) the higher losses in the scenarios with batteries and (2) the technical ability of the system to transport all the electricity from PV.

Social Life Cycle Assessment

Like LCA, Social Life Cycle Assessment (sLCA) incorporates the traditional LCA methodological steps while having social impacts as a focus. The main issues we assessed using sLCA were:

- Where do the raw materials for the batteries come from?
- Are they “critical minerals and/or minerals of concern”? (from conflict-affected and high-risk regions)?
- Where and how are the batteries assembled?
- Which issues are connected to these raw materials and processes?

So, in a first step, desktop research has been done to gain an overview of the batteries and the raw materials used in the different demos within STORY. The next step focused on social hot spots. Here two main subcategories were identified to have the highest relevance in these countries: unsafe working conditions and child labour. A survey among the partners in the project also showed that only little information on social issues can be gained from the information that are supplied with the Safety Data Sheets and other information provided to the user.

With only little information, only a rough assessment on potential risks could be done, where some issues are raised: First, there is certain dependency of Europe from critical raw materials and their (few) producers. A second issue is the fact that some raw materials are considered conflict materials, as they come from conflict-prone areas, which are often connected to social and human rights issues such as forced labour. A third issue is the research for new materials for batteries to replace materials and processes with high (negative) social impacts.

Employment creation

In a third assessment the social indicator employment creation was investigated. The assessment is based on a combination of literature research as well as expert interviews and industry data. It showed that the implementation of PV and storage can lead to significant employment opportunities on a global and European level:

PV manufacturing is mostly located in Asia, however, jobs for construction and O&M are created in Europe. For a network development scenario with 12 MW PV installed this would mean on average 23 jobs created in total and 18 in Europe. For 33 MW PV installed this corresponds to 62 jobs on average created, 48 assuming the manufacturing takes place outside of Europe. The production of batteries is also mostly located in Asia however, it is expected that the share of lithium-ion batteries produced in Europe could increase significantly until 2030. It is estimated that 90-180 direct jobs/GWh will be created in Europe and approximately 6 times this number for indirect jobs.

The results obtained from these three assessments feed into Task 7.5., where an overall assessment of storage integration is performed. It brings together the technical, economic, environmental, and social aspects and draws a holistic picture of storage integration into the distribution grid.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426

2 Introduction

The European project STORY (Added value of STORage in distribution sYstems) demonstrates and evaluates innovative approaches for energy storage systems in the residential and industrial sectors.

The overall objective of STORY is to show the benefit storage can bring for a flexible, secure, and sustainable energy system. The project specifically focuses on the added value of energy storage in distribution systems. STORY includes six demonstration sites, which range in size from individual buildings to the district level and are in five member states. They include different energy storage types, different renewable energy technologies, and target different project goals. All demonstration activities deliver input on technological performance, stakeholder acceptance and on the overall process of storage integration.

The knowledge gained from the demonstration activities feeds into a business model analysis and a large-scale impact assessment, used to evaluate the large-scale integration of small-scale storage units in the European distribution networks. A lot of benefits are expected to arise from a large-scale integration of storage solutions in the distribution system. Storage integration in combination with appropriate business models empower different actors (e.g. distribution system operators, aggregators, consumers, storage operators) to position new services on the electricity market.

Task 7.4. "Environmental and social analysis of a large-scale storage implementation" specifically investigates environmental and social impacts of storage integration.

Within Task 7.4 three different assessments were performed:

(1) **Life cycle assessment**: Environmental impacts of large-scale storage integration were evaluated using the method of Life Cycle Assessment (LCA). This assessment is strongly linked to Task 7.3 "Large-scale impact simulation", which delivered the network development scenarios, which were investigated using LCA.
(2) **Social life cycle assessment**: Social impacts of storage integration were evaluated using the method of Social Life Cycle Assessment (sLCA). This part focused on the method itself, as sLCA is compared to LCA a rather new method. Furthermore, we describe the results of a desktop research and a survey among the project partners on the socio-economic interactions in the supply chain of batteries, focusing on raw materials.
(3) **Employment creation**: An additional social indicator we investigated in more detail was employment creation. This part of the report introduces a European employment factor for the calculation of created jobs by renewable energy technologies as PV and batteries.

This report describes the methodologies used, the investigated systems and the results of this assessment.

The project partners JOANNEUM RESEARCH (JR), FLEXIBILITY (FLEX – former ACTILITY), CENER (CEN) and University of Ljubljana (UL) worked together in Task 7.4. JR had the scientific lead in all three impact assessments. The life cycle assessment is based on work performed in Task 7.3 by UL, so there was a strong exchange between JR and UL on the investigated network

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

development scenarios, basic data and result interpretation. CEN contributed with specific data and real-world experiences on the battery system in the Spanish demonstration site and performed a desktop research on raw materials used in battery systems that fed into LCA and sLCA. Regarding sLCA, FLEX contributed with social science knowledge gained in other Smart grid projects.

3 Life cycle assessment

To estimate the environmental impact of storage integration in the distribution grid, a Life Cycle Assessment (LCA) is performed for different storage implementation scenarios. The goal of the LCA is to assess the environmental changes occurring from battery integration. We perform LCA for network development scenarios with and without batteries.

In the following sections we give an overview on the LCA methodology including the investigated environmental impact categories. We outline the assessed network development scenarios and their functional unit. We describe the input data for the assessment and show and discuss our results on greenhouse gas (GHG) emissions and cumulative primary energy demand in detail. Results on other environmental impact categories can be looked up in the Appendices.

3.1 Methodology

LCA is a structured, standardized and internationally recognized method for environmental assessments. According to ISO 14040, LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

An LCA considers all relevant processes and materials, in this case: the generation of electricity for households and electric vehicles, auxiliary energy and materials (e.g. heating and cooling energy for MV/LV substation batteries), production of plant components, transmission system losses and storage losses.

The following environmental impact categories are investigated using LCA:

Greenhouse gas emissions

The greenhouse gas emissions included in the LCA are shown in Table 1.

Table 1. Global Warming Potential on a 100 year time horizon (GWP 100) was used to express the contribution of the listed gases (e.g. CH_4, N_2O, R-14) to global warming, in terms of equivalent amount of CO_2 (CO_2-eq) (IPCC, 2013).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table 1: Investigated Greenhouse gas emissions and their CO_2-equivalent factors (including Climate Carbon Feedback) (IPCC, 2013)

Category	GHG	CO_2-equivalent
	CO_2	1
	CH_4	34
	N_2O	298
Chloro-fluorocarbon (CFC)	CFC-113	6 586
	CFC-114	9 615
	CFC-115	7 370
	CFC-13	15 451
	CFC-12	11 547
	CFC-11	5 352
Hydrochloro-fluorocarbons (HCFC)	HCFC-141b	938
	HCFC-142b	2 345
	HCFC-123	96
	HCFC-124	635
	HCFC-22	2 106
	HCFC-21	179
Organ-chloride	HCC-30	11
	R-10	2 019
	R-40	15

Category	GHG	CO_2-equivalent
Hydrofluorocarbon (HFC)	HFC-134a	1 549
	HFC-143a	5 508
	HFC-152a	167
	HFC-116	12 200
	HFC-125	3 691
	HFC-32	817
	R-14	7 390
	HFC-23	13 856
	HFC-43-100mee	1 952
	HFC-227ea	3 860
	HFC-236fa	8 998
	HFC-245fa	1 032
	PFC-318	10 592
	PFC-5-1-14	9 300
	PFC-218	9 878
	PFC-3-1-10	10 213
	PFC-4-1-12	9 484

Acidification potential

To determine the acidification potential the emissions sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) are included. The following equivalent factors are used, to calculate the impact of 1 kg of these gases to acidification, which is expressed in SO_2-eq. (IINAS, 2017).

Table 2: Investigated gases contributing to acidification and their SO_2-equivalent factors (IINAS, 2017)

Gas	SO_2-equivalent
SO_2	1
NO_x	0.7
NH_3	3.762

Ozone creation potential

To determine the ozone creation potential the emissions carbon monoxide (CO), non-methane volatile organic carbons (NMVOC), nitrogen oxides (NO_x) and methane (CH_4) are included. The following equivalent factors are used, to calculate the impact of 1 kg of these gases to ozone creation, which is expressed in C_2H_4-eq (IINAS, 2017).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table 3: Investigated gases contributing to ozone creation potential and their C_2H_4-equivalent factors (IINAS, 2017)

Gas	C_2H_4-equivalent
NMVOC	1
CO	0.11
CH_4	0.014
NO_x	1.22

Particulate emissions

The investigated particles include different particle sizes (PM 2.5, PM10, PM>10) and are generally described as “particulate emissions”.

Cumulative primary energy demand

The cumulative primary energy demand includes all primary energy, needed to provide electricity to household and electric vehicles in the investigated scenarios. The cumulative primary energy demand is divided into the categories:

- fossil (crude oil, coal, lignite, natural gas)
- renewable (e.g. solar, wind, water, biomass)
- others (e.g. nuclear, municipal waste, waste heat from industrial process)

3.2 Network development scenarios

The investigated network development scenarios are a result from the previous Task 7.3, where a large-scale impact simulation of small-scale storages was performed (Zupančič et al., 2018).

In Task 7.3 a simulation platform was developed, and a distribution grid model was implemented in the platform. The grid model covers all important parts of the distribution system. Medium- and low voltage (MV and LV) networks are supplied from high voltage (HV) connection point (Figure 1). The network model covers rural and urban configuration on both medium and low voltage section. Detailed model includes three-phase models of consumption, generation, and storage as new emerging connected devices. Database based on yearly measurements of energy flows was used as the simulation input including household consumption profiles and renewable generation from photovoltaic (PV) generation. Electric vehicle model and their charging strategy were important network parameters investigated in addition to electric energy storage as the focus.

Focus of Task 7.3. was on a technical analysis and results consisted of network parameters, such as voltage levels, losses, loading of the elements and consumption and generation profiles. The scenario results showed how different amount of storage, renewables, and electric vehicles, affect the network during different seasons.

For further information on the simulation platform, the technical analysis and the economic potential see Deliverable 7.3 "Report on large scale impact simulation” (Zupančič et al., 2018).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

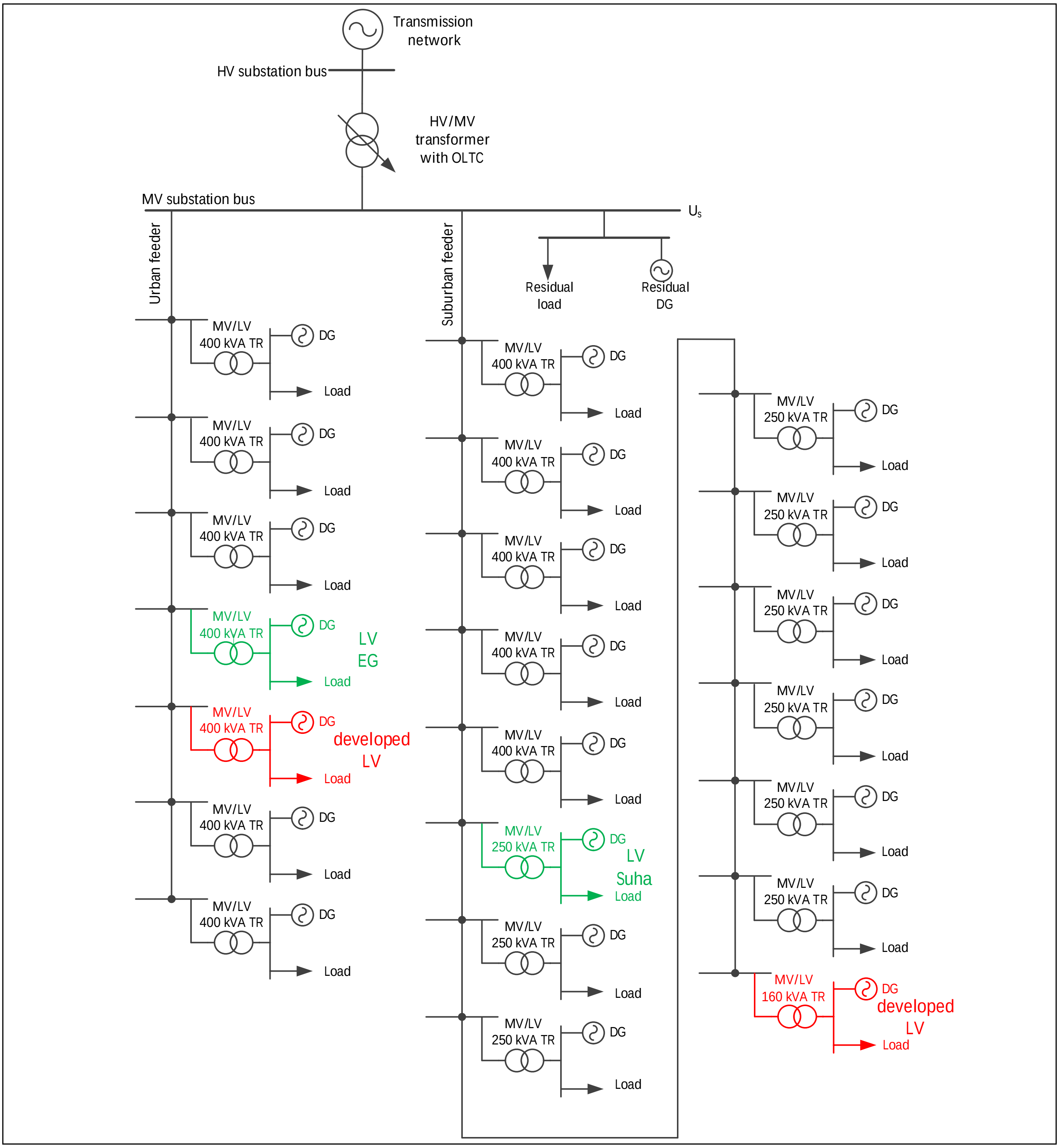


Figure 1: In Task 7.3 modelled network structure - Single-line MV distribution network scheme with two feeders. Location of fully modelled synthetic LV networks (red) and real networks (green) are also shown (Zupančič et al., 2018)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

In this report an environmental assessment is performed for 8 selected network development scenarios simulated in Task 7.3. Based on these scenarios we investigate the environmental impacts of scenarios with a battery storage compared to scenarios without a battery storage, using LCA.

The investigated network development scenarios represent a typical European distribution grid and could be located anywhere in Europe. For illustration, the geographical area covered by the grid could be a small town of around 12,000 inhabitants.

The scenarios are characterised by (Table 4):

- the installed power from renewable energy sources (PV power plants in the distribution grid),
- the installed capacity of electric vehicles (EV)[1],
- the installed storage capacity and the storage unit type (lithium ion battery installed in households or a community size lithium ion battery system connected at the MV/LV transformer station supplying the LV network).

These characteristics are included in the short name of the scenarios. Percentage values refer to 30 MVA nominal power of the HV/MV transformer (Example: 110% RES means 33 MW installed power of RES units). For the LCA the scenarios are grouped into two categories:

1) Scenarios with a low RES installed power (low PV penetration) and a low EV installed capacity, and
2) Scenarios with high RES installed power (high PV penetration) and a high EV installed capacity.

The technical analysis showed that even in scenarios with high PV penetration no or very few curtailments of PV units is needed.

Figure 2 depicts a simplified scheme of the scenarios including the system components and energy flows most relevant for the LCA. Each scenario considers the supply of electricity to both households and electric vehicles. The electricity consumption on LV grid is covered by local PV plants and by electricity supply from the main grid, flowing from HV to MV to LV levels. In the scenarios with a battery, electricity from PV plants is either consumed directly, stored in the battery, or injected into the MV grid. Surplus electricity from PV plant, when it is available, is injected into the MV power grid.

[1] EV are considered as consumption. Storage capacity of EVs is not considered.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

Table 4: Scenarios selected for environmental assessment (Parameters are given in percentage of transformer nominal power rate of 30 MVA)

Scenario - Short Name	#	RES installed power	EV installed capacity	Storage installed capacity (Unit type)	Group
1_40%RES_5%EV_0%Batt	1	40%	5%	0%	"Low PV, low EV"
2_40%RES_5%EV_15%Batt(Household)	2	40%	5%	15% (Household)	
4_40%RES_5%EV_30%Batt(Household)	4	40%	5%	30% (Household)	
6_110%RES_40%EV_0%Batt	6	110%	40%	0%	"High PV, high EV"
3_110%RES_40%EV_15%(Grid)	3	110%	40%	15% (Grid)	
7_110%RES_40%EV_30%(Household)	7	110%	40%	30% (Household)	
9_110%RES_40%EV_80%(Household)	9	110%	40%	80% (Household)	
10_110%RES_40%EV_80%(Grid)	10	110%	40%	80% (Grid)	

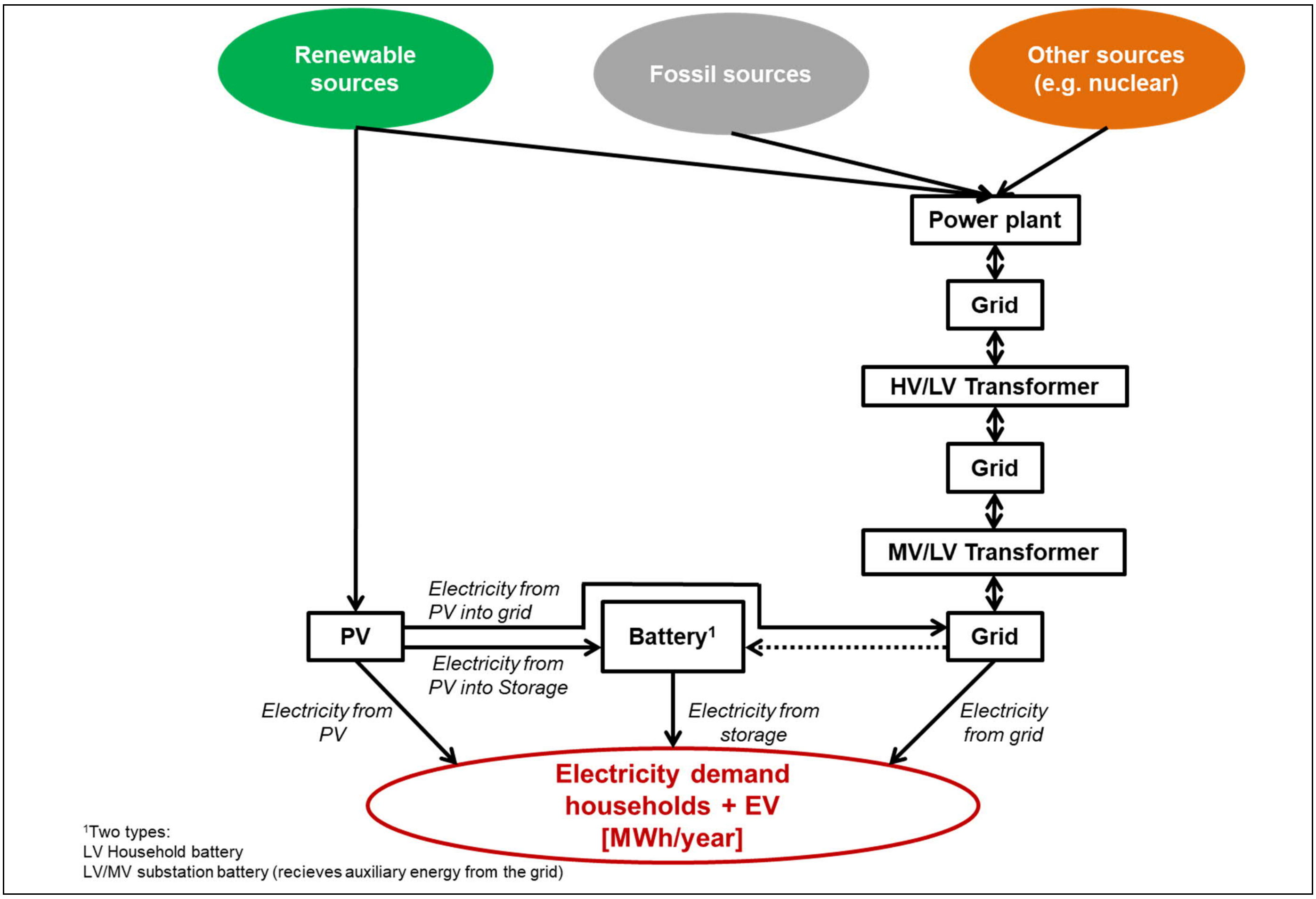


Figure 2: A simplified scheme of the investigated scenarios showing energy flows and system components most relevant for the LCA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table 5 gives the annual energy balance for the investigated scenarios including the electricity consumption in the household and by the EV. The annual energy balances are calculated using daily profiles generated for the four seasons by the simulations. The energy balances display some of the main differences in the scenario:

- Scenarios with low PV penetration (40% RES) produce 20.5 GWh/year electricity with PV, whereas scenarios with high PV penetration (110% RES) produce 52.6 GWh/year.
- Scenarios with low EV (5% EV) have a lower electricity consumption compared to scenarios with high EV (40% EV).
- Electricity from PV injected into the MV power grid is higher for scenarios without battery systems, as some of the energy is stored locally in batteries and used later in the LV grid.
- Losses are higher for systems with battery due to storage losses, which are related to the efficiency of the storage and auxiliary systems. Systems with LV/MV substation batteries (Grid) have the highest losses. These battery systems need auxiliary energy for heating in winter and cooling in summer, which is included in the category "Losses".

Table 5: Annual energy balance for the investigated large-scale scenarios [MWh/year]

Scenario	PV generation	PV into HV grid	HV grid	Losses (grid, TR, storage)	Consumption (household + EV)
	[MWh/year]				
1_40%RES_5%EV_0%Batt	20 527	1 459	50 993	1 707	68 354
2_40%RES_5%EV_15%Batt(Household)	20 527	1 113	51 260	2 320	68 354
4_40%RES_5%EV_30%Batt(Household)	20 527	1 002	51 532	2 703	68 354
6_110%RES_40%EV_0%Batt	52 621	23 688	48 906	2 219	75 619
3_110%RES_40%EV_15%(Grid)	52 621	21 423	52 368	7 947	75 619
7_110%RES_40%EV_30%(Household)	52 621	22 295	48 317	3 024	75 619
9_110%RES_40%EV_80%(Household)	52 621	19 709	47 314	4 608	75 619
10_110%RES_40%EV_80%(Grid)	52 621	13 486	45 296	8 813	75 619

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table 6 shows the (1) share of local PV generated electricity injected in the power grid, (2) share of losses in consumed electricity, and (3) share of electricity generated with local PV in consumed electricity.

Table 6: Share of PV electricity injected into the HV grid in the generated electricity, share of losses and share of electricity generated with PV in consumed electricity for the investigated scenarios

Scenario	% PV generation injected into HV [%]	% Losses[1)] in consumption [%]	% PV in consumption [%]
1_40%RES_5%EV_0%Batt	7%	2%	28%
2_40%RES_5%EV_15%Batt(Household)	5%	3%	28%
4_40%RES_5%EV_30%Batt(Household)	5%	4%	29%
6_110%RES_40%EV_0%Batt	45%	3%	38%
3_110%RES_40%EV_15%(Grid)	41%	11%	41%
7_110%RES_40%EV_30%(Household)	42%	4%	40%
9_110%RES_40%EV_80%(Household)	37%	6%	44%
10_110%RES_40%EV_80%(Grid)	26%	12%	52%

1) Total losses (transformer, grid, storage)

In the LCA, the effect from surplus PV generation on the electricity generation mix of the system needs to be included. Depending on the scenarios, the MV/HV transformer shows negative flows, representing electricity flowing into the HV grid. This electricity is produced by PV plants, when the PV generation level on LV grid covers all demand and the surplus energy can nether be consumed nor stored in the MV and LV grid. The energy flows back to the HV grid level and affects the electricity generation in the transmission network: thus, electricity generation by other power plants can be replaced.

The network simulation focused on the technical effects in the distribution grid. Which electricity generation units are influenced by surplus PV electricity was not investigated in the simulation. Therefore, in the LCA different standard options for the replaced and consumed grid electricity were assumed in order to represent different power system preconditions (Table 7):

- Option 1: For the consumed and replaced grid electricity, the Belgian electricity mix is used. To assess the environmental impact of electricity generation LCA studies often use country specific electricity mixes, depending on the location of the investigated system. As the network development scenarios are representative for different European countries and

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

several demonstration cases in project are in Belgium, we chose the Belgian electricity mix, representing an example for a country specific electricity mix.[2]

- Option 2: For the consumed grid electricity, the Belgian electricity mix is used. For surplus PV electricity, it is assumed that the electricity generation in a natural gas power plant can be replaced, since natural gas power plants as flexible electricity generation units are high on the merit order curve of the day-ahead electricity market.
- Option 3: For surplus PV electricity, it is assumed that this electricity is stored in a pumped storage power plant connected at the HV grid level. For the consumed grid electricity, the Belgian electricity mix is used plus the share of electricity stored in the pumped storage power plant – reduced by storage losses.
- Option 4: For the consumed and replaced grid, electricity generation with a natural gas power plant is assumed.

The amount of replaced electricity is reduced by grid transmission losses in all options.

Table 7: Investigated Options for the generation of consumed and replaced grid electricity

	Option 1	Option 2	Option 3	Option 4
Consumption of grid electricity	Belgian electricity mix	Belgian electricity mix	Belgian electricity mix + Pumped storage power plant	Natural gas CC power plant
Surplus PV into HV	Replacement: Belgian electricity mix	Replacement: Natural gas CC power plant	Pumped storage power plant	Replacement: Natural gas CC power plant

3.3 Functional unit

The environmental impacts of the investigated scenarios are compared by using their functional unit. Since the primary function of the investigated scenarios is to cover the electricity consumption of household and EV on an annual basis, MWh electricity consumption per year has been chosen as the functional unit.

[2] For the demo specific LCA calculations, which were performed in WP6 the corresponding country specific electricity mix was used (e.g. for “Demonstration 3 – Storage in a factory”, which is located in Navarra (Spain) the Spanish mix was used; for “Demonstration 5 – Demonstration of flexibility and robustness of a large scale storage unit”, which is located in Slovenia, the Slovenian mix was used.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

For each scenario, the environmental impacts are calculated for the yearly electricity consumption (68,350 MWh/a for scenarios with low EV installed capacity and 75,620 MWh/a for scenarios with high EV installed capacity). Results are presented in this format:

- t CO_2-eq/a
- MWh/a

Also, specific emissions and cumulative energy demand per MWh consumed electricity are presented indicating the environmental impact of 1 MWh consumed electricity in the investigated set-up.

3.4 System boundaries

For the environmental assessment we defined technical, geographic, and temporal system boundaries:

Technical system boundary

The technical system boundary covers the manufacturing and the operation phase of the investigated systems (Figure 3).

In the manufacturing phase, the production of raw materials (primary and secondary) and the energy demand for the manufacturing and construction of the investigated components (PV plant, battery system, power plants, power grid) are included.

In the operation phase the generation of the consumed electricity is included, as well as electricity storage losses and transmission losses (losses in the power lines and the transformer).

At the end of its lifetime the battery system is dismantled and the used materials as far as possible separated. These materials are either recycled or landfilled. As battery systems are rather new technologies it turned out that the existing data base for recycling of batteries is not detailed enough to include it into the LCA. Therefore, the dismantling phase is not included in this environmental assessment.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

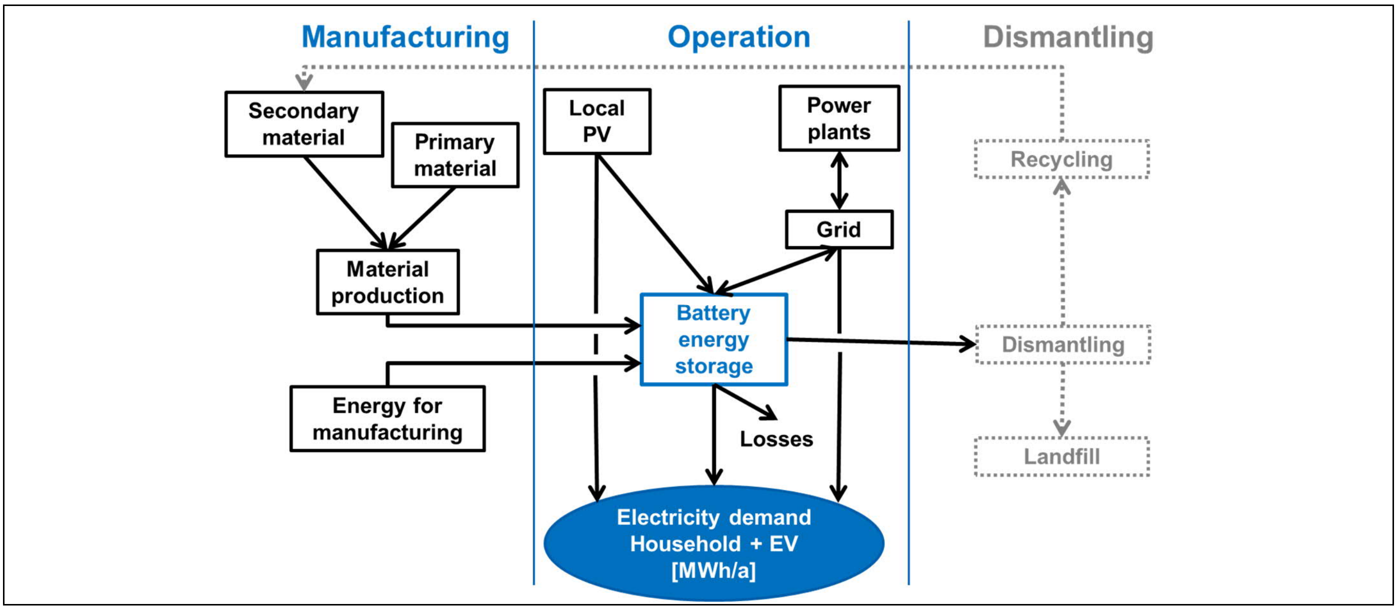


Figure 3: Simplified scheme of the investigated system showing manufacturing, operation, and dismantling phase

Geographic system boundary

For the operation phase the geographic system boundary is Europe. The investigated network development scenarios were modelled for central Europe. For the electricity generation typical European data sets are used.

For the production of system components (battery system, PV plant, etc.) the geographic system boundary is defined by the source of the raw materials and the production location, which for - some materials - (e.g. Lithium) lies outside of Europe.

Temporal system boundary

The temporal system boundary for the operation phase is one year. The environmental impact of the construction phase is allocated to one year by dividing it by the life time of the system components (e.g. 10 years for the battery, 20 years for the PV plant, 100 years for the pumped storage power plant).

3.5 Basic data

Two types of basic data were used in the LCA calculation: (1) Foreground data, and (2) Background data.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

3.5.1 Foreground data

Foreground data are project specific data, collected for the investigated scenarios. If possible, monitoring data from the "Suha" demonstration were used (e.g. battery efficiency, auxiliary energy demand of the battery system, electricity demand of households, electricity generation from PV) and implemented in the grid simulation or directly used in the LCA calculation.

Table 8 and Table 9 provide basic parameters for the substation and household batteries. Table 10 lists basic data on the PV units.

Table 8: Data on MV/LV substation battery

MV/LV substation battery		
Type		Li-Ion NCM
Capacity (used)	[kWh]	320
Rated Power	[kW]	170
Roundtrip efficiency		88.36
Lifetime	[a]	10
Auxiliary power[1)]	[kW]	4 kW, constant load during BESS operation

1) For heating and cooling of the battery system

Table 9: Data on LV household battery

LV household battery		
Type		Li-Ion NCM
Capacity	[kWh]	16
Rated Power	[kW]	15
Roundtrip efficiency		66.88
Lifetime	[a]	10

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Table 10: Data on PV units

Scenarios	PV peak power [kWp]	PV area [m²] [1)]	Lifetime [a]
40% RES	12 000	90 909	10
110% RES	33 000	250 000	10

[1)] Calculated using a nominal conversion efficiency of 13.2% for a multi-crystalline silicone module [NREL, 2018]

Consumption of grid electricity and replacement of grid electricity occurs at different times during the day in all scenarios. An example is shown Figure 4 for “Large-scale scenario 6” on a summer day. During the night and in the evening hours the electricity demand is covered with HV grid-supplied electricity (positive values for energy flowing through HV/MV transformer). From 4:00 – 6:00 and 16:00 – 19:00, the electricity demand is covered by electricity from the PV plant and the grid. Between 6:00 and 16:00, PV generation is higher than electricity demand and the electricity is injected into the higher grid level (negative values for energy flowing through HV/MV transformer).

Depending on the electricity generation technologies, the generation mix changes over the year and during daytime. Therefore, the calculation of GHG emissions of consumed and replaced grid electricity was performed using hourly GHG emission factors.

For the large-scale integration scenarios, historic data on the hourly Belgian electricity generation mix was taken from (Elia, 2019) for the period between 11/2017 and 12/2018. To correspond with the grid simulation the hourly electricity generation was needed for a typical day per season. An autoregressive integrated moving average (ARIMA) model and for wind generation a Markov chain was used to simulate the hourly electricity generation mix for a typical day per season.

This calculation procedure leads to different emission factors per season and scenario ranging from 107 to 167 kg CO_2-eq/MWh for the Belgian electricity mix.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

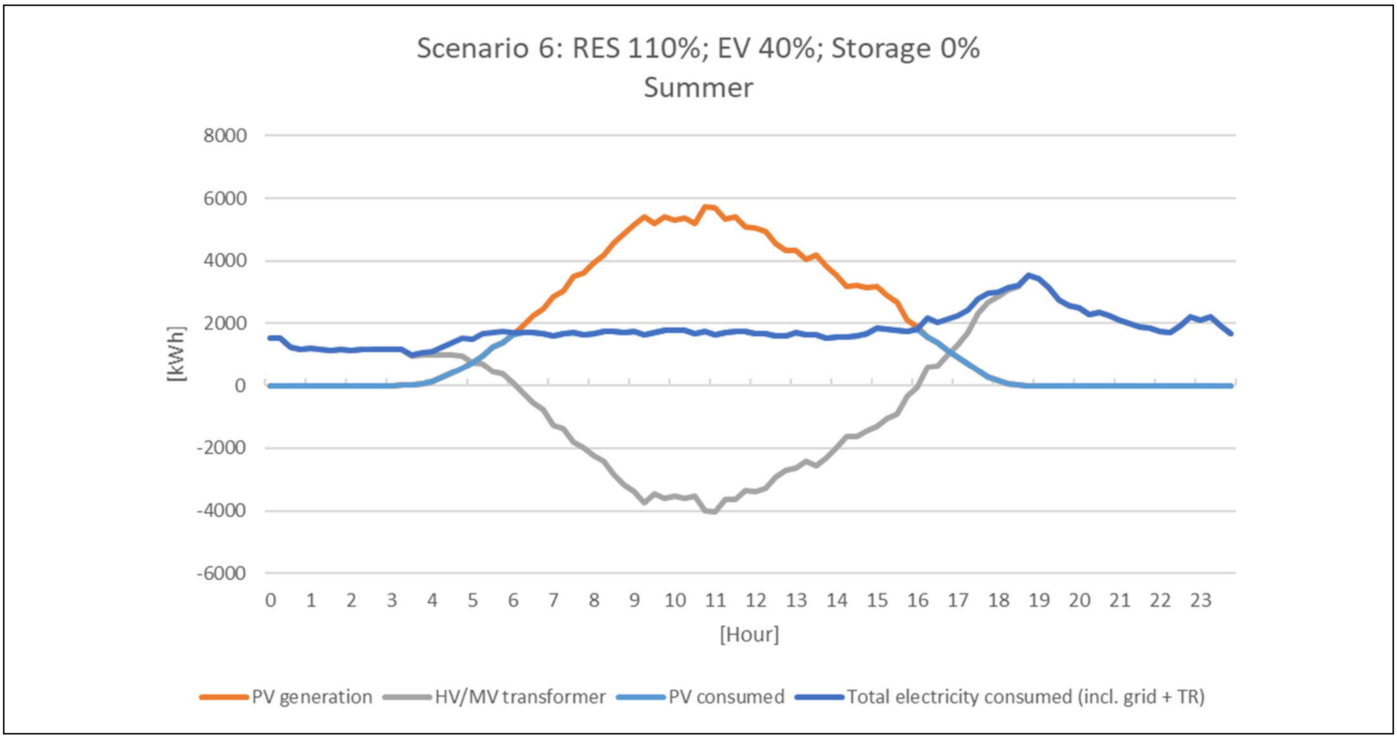


Figure 4: Electricity flow during a summer day in Scenario 6_110% RES_40%EV_0%Batt

3.5.2 Background data

Additional background data is needed to calculate the environmental impacts of the investigated scenarios. These are mainly specific emission factors for energy processes, transport processes and materials. The main sources for background data were LCA databases GEMIS (IINAS, 2017) and ecoinvent (Wernet, 2016).

The following tables summarise selected data on the GHG emissions to produce the PV units and batteries and electricity generation technologies. LCA calculation was performed using one selected value (expert estimation) and a range (min-value, max-value).

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Table 11: GHG emission factors for electricity generation technologies (IINAS, 2017 & Wernet, 2016)

Electricity generation from	GHG emissions Expert estimate [kg CO_2-eq/kWh]	Min [kg CO_2-eq/kWh]	Max [kg CO_2-eq/kWh]
Solid biomass[1)]	36	36	36
Biogas[1)]	252	252	252
Brown coal/lignite	1 064	982	1 092
Coal	960	895	1 087
Fossil gas	412	400	447
Fossil oil	799	797	869
Hydro Pumped storage[2)]	43	12	83
Hydro Run-of-river	4	1	10
Nuclear	33	8	67
Solar/PV[3)]	52	42	57
Waste	996	448	1 710
Wind onshore	13	9	28

[1)] no Min/Max value considered, as share in investigated electricity mix is below 1%

[2)] storage of electricity from nuclear power plants assumed

[3)] for Slovenian solar radiation data

Table 12: GHG emission for production of multi-crystalline silicone PV plant (Wernet, 2016)

	GHG emissions Expert estimate [kg CO_2-eq/m²]	Min [kg CO_2-eq/m²]	Max [kg CO_2-eq/m²]
Production of PV plant	270	220	300

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Table 13: GHG emission for production of Li-Ion NCM battery (Peters, 2018 & Aichberger, 2019)

	GHG emissions		
	Expert estimate [kg CO_2-eq/kWh]	Min [kg CO_2-eq/kWh]	Max [kg CO_2-eq/kWh]
Production of Li-Ion NCM	124	68	186

3.6 Results and discussion

3.6.1 Greenhouse gas emissions

Figure 5 to Figure 12 show the results on the GHG emissions of the investigated network development scenarios for different grid electricity generation Options.

In Figure 5 the annual GHG emissions for scenarios with high amount of PV share and high amount of EVs are shown for Option 1, where the Belgian electricity mix is used for consumed and replaced grid electricity. The figure shows the total annual GHG emissions and contributions from PV plant production, battery production, electricity received from the HV grid and electricity supplied to the HV grid. Electricity supply into the HV grid replaces electricity generation, therefore the GHG emissions are negative.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

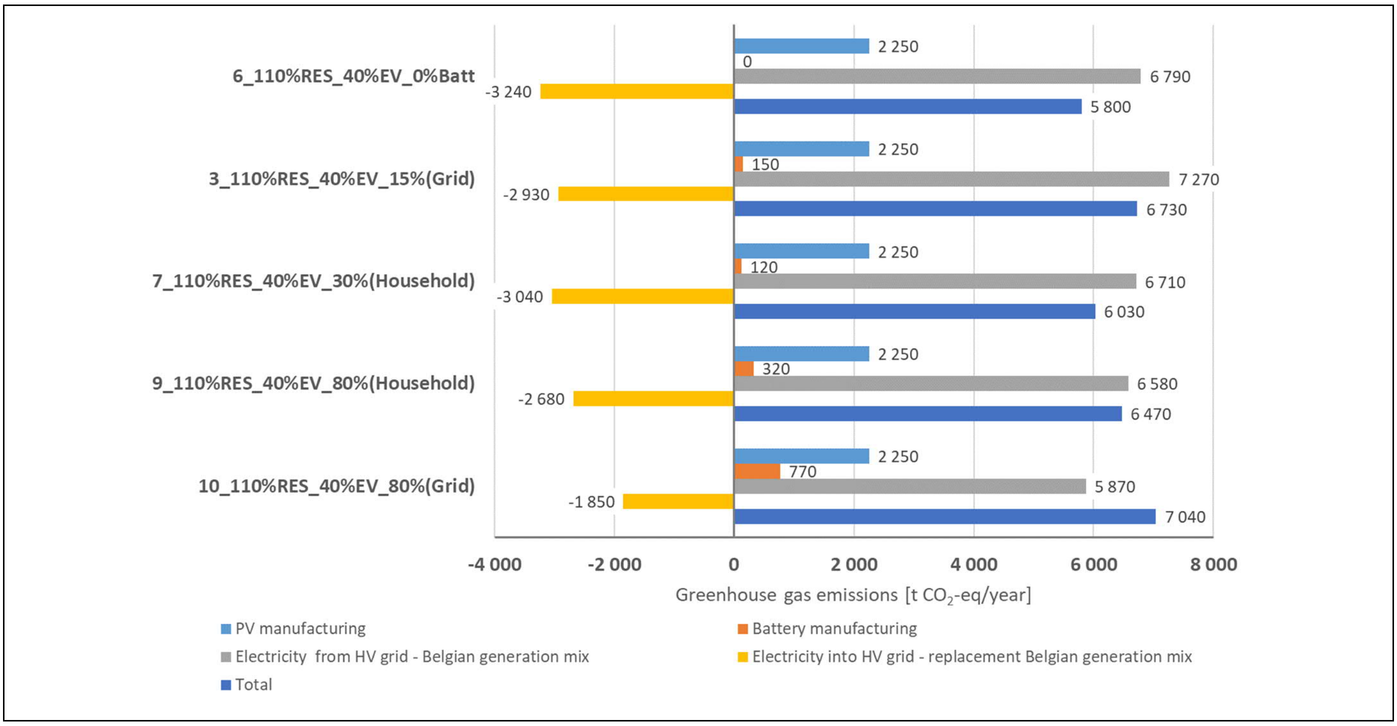


Figure 5: Annual GHG emissions for large-scale storage implementation scenarios with high PV and high EV for Option 1-Belgian electricity mix

We can summarize the results as follows:

- GHG emissions of PV production are in all scenarios 2 250 t CO_2-eq/year, as all shown scenarios have the same amount of installed PV power.
- GHG emissions of battery manufacturing range from 120 to 770 t CO_2-eq/year, depending on the size of the batteries installed in the scenarios.
- Scenario “9_110%RES_40%EV_80%(Household)” has lower GHG emissions for battery production compared to scenario “10_110%RES_40%EV_80%(Grid)” (320 versus 770 t CO_2-eq/year) although the installed battery charging/discharging power is 24 MW in both scenarios.
- However, household batteries and grid batteries have different ratios between storage power and storage capacity. Scenario 10 has a total storage capacity of 45.2 MWh, whereas Scenario 9 has a total storage capacity of 25.6 MWh.
- In all scenarios with batteries, the contribution of battery production to the total GHG emissions is rather low, ranging from 2% to 11%.

Of stronger influence on the total GHG emissions is the contribution of the consumed and replaced grid electricity.

- In scenario “6_110%RES_40%EV_0%Batt”, without batteries, the total amount of surplus electricity from PV is injected into the HV grid and the amount of saved GHG emissions is highest.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

- The scenarios with batteries use more of the PV electricity in the investigated MV and LV grid sections and therefore saved GHG emissions are lower.
- In three of the four scenarios with batteries, the GHG emissions of consumed grid electricity are lower compared to GHG emissions of consumed grid electricity in scenario “6_110%RES_40%EV_0%Batt”, as less grid electricity is needed due to the battery systems.
- However, scenario “3_110%RES_40%EV_15%(Grid)” has higher GHG emissions for consumed grid electricity compared to scenario “6_110%RES_40%EV_0%Batt”. This is explained due to losses of the MV/LV substation battery system. The system needs auxiliary energy for cooling and heating of the container, where the battery system is located. This leads to relatively high overall system losses of 11% in consumed electricity (see Table 6).

Summarising the results in Figure 5 we see that the scenarios with batteries have less GHG emissions for electricity consumption from the HV grid compared to the scenario without batteries. This small advantage cannot compensate the lower amount of saved GHG emissions from replaced grid electricity and additional GHG emissions for battery manufacturing in scenarios with batteries. Therefore, scenario “6_110%RES_40%EV_0%Batt” without the battery, has the lowest GHG emissions.

Figure 6 depict the same result for specific GHG emissions per MWh electricity demand. Scenarios without battery have lower specific GHG emissions as scenarios with batteries.

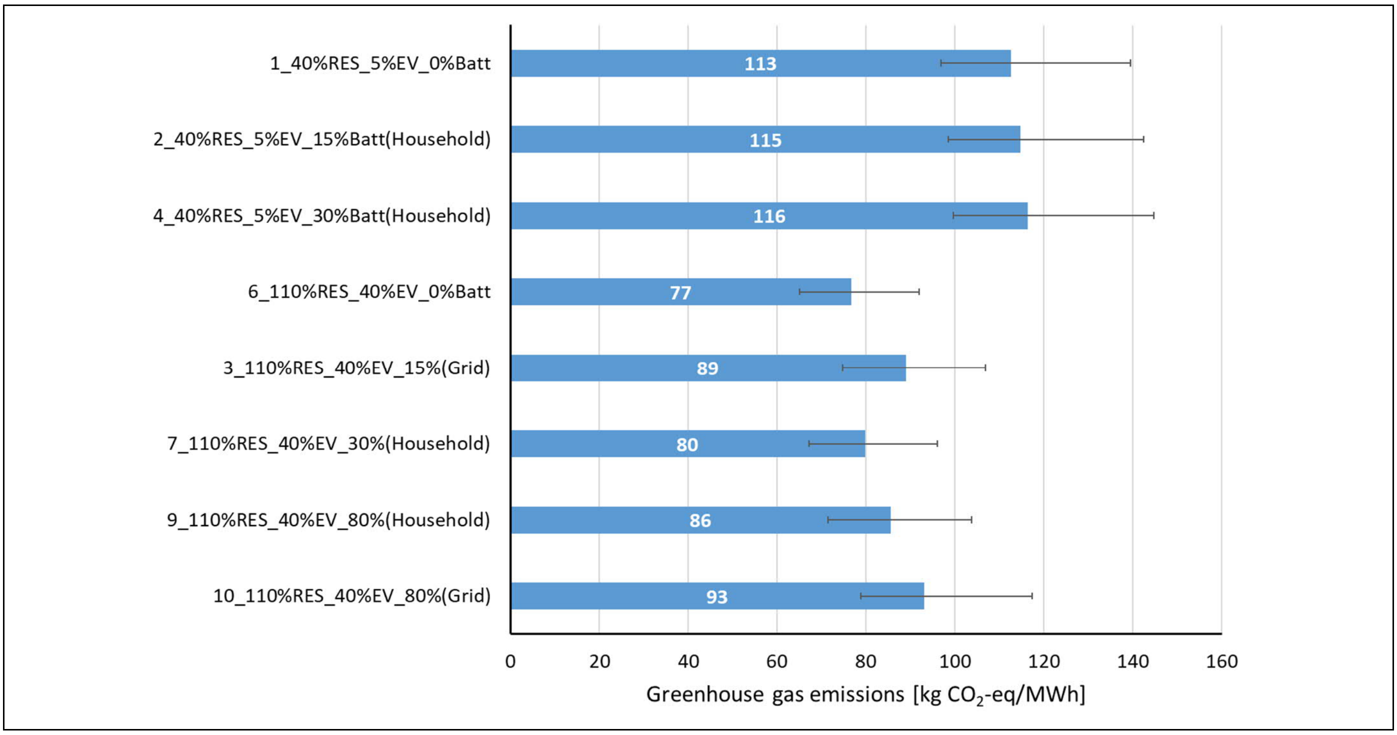


Figure 6: GHG emissions per MWh electricity demand for Option 1 – Belgian electricity mix

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Figure 7 and Figure 8 show the GHG emissions for "Option 2 – Belgian electricity mix + natural gas CC power plant". In this Option, we assumed that surplus electricity replaces electricity produced in a natural gas CC power plant, as natural gas CC power plants are flexible generation units.

- Scenario 6 and Scenario 7 have negative total GHG emissions. This is explained by the different GHG emission factors for consumed and replaced grid electricity.
- The GHG emission factor for electricity produced in a natural gas CC power plants (412 kg CO_2-eq/MWh) exceeds the GHG emissions factor of the Belgian electricity (107 – 167[3] kg CO_2-eq/MWh), which leads to a higher value for saved GHG emissions than for consumed GHG emissions in Scenario 6 and Scenario 7.

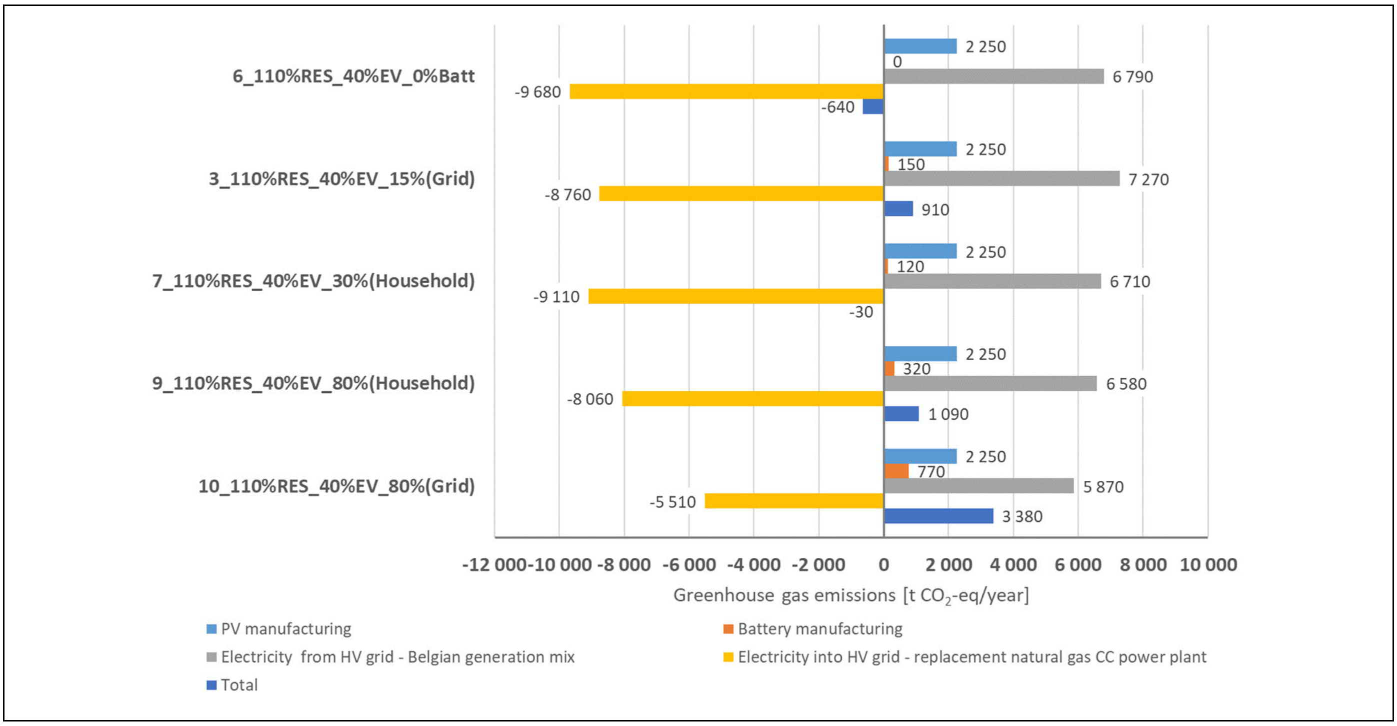


Figure 7: Annual GHG emissions for large-scale storage implementation scenarios with high PV and high EV for Option 2 – Belgian electricity mix + Natural gas CC power plant

[3] Using hourly emission factors for the electricity generation mix leads to different emission factors per scenario and season, see 3.5.1 Foreground data for details

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

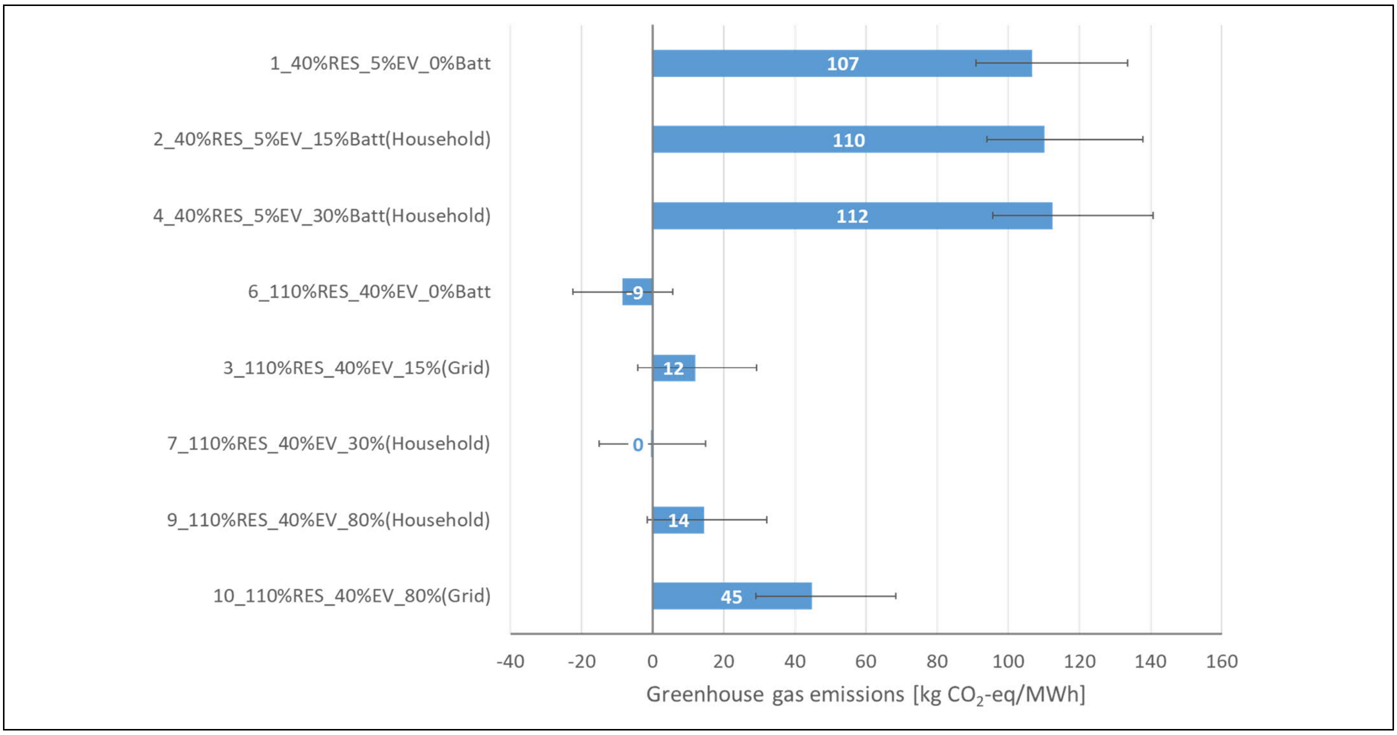


Figure 8: GHG emissions per MWh electricity demand for Option 2 – Belgian electricity mix + Natural gas CC power plant

Figure 9 and Figure 10 provide an overview of the results in terms of GHG emissions for "Option 3 - Belgian electricity mix + pumped storage". In this Option, we assumed that surplus electricity is stored in a pumped storage power plant. Therefore, Figure 9 shows no saved GHG emissions.

The bar "electricity into HV grid -…- pumped storage)" represents the GHG emissions for storing the electricity in a pumped storage power plant. It includes emissions from the construction of the pumped storage power plant (only 3 g CO_2-eq / MWh electricity). The pumped storage power plant operation is included in the GHG emissions of "Electricity from HV grid".

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

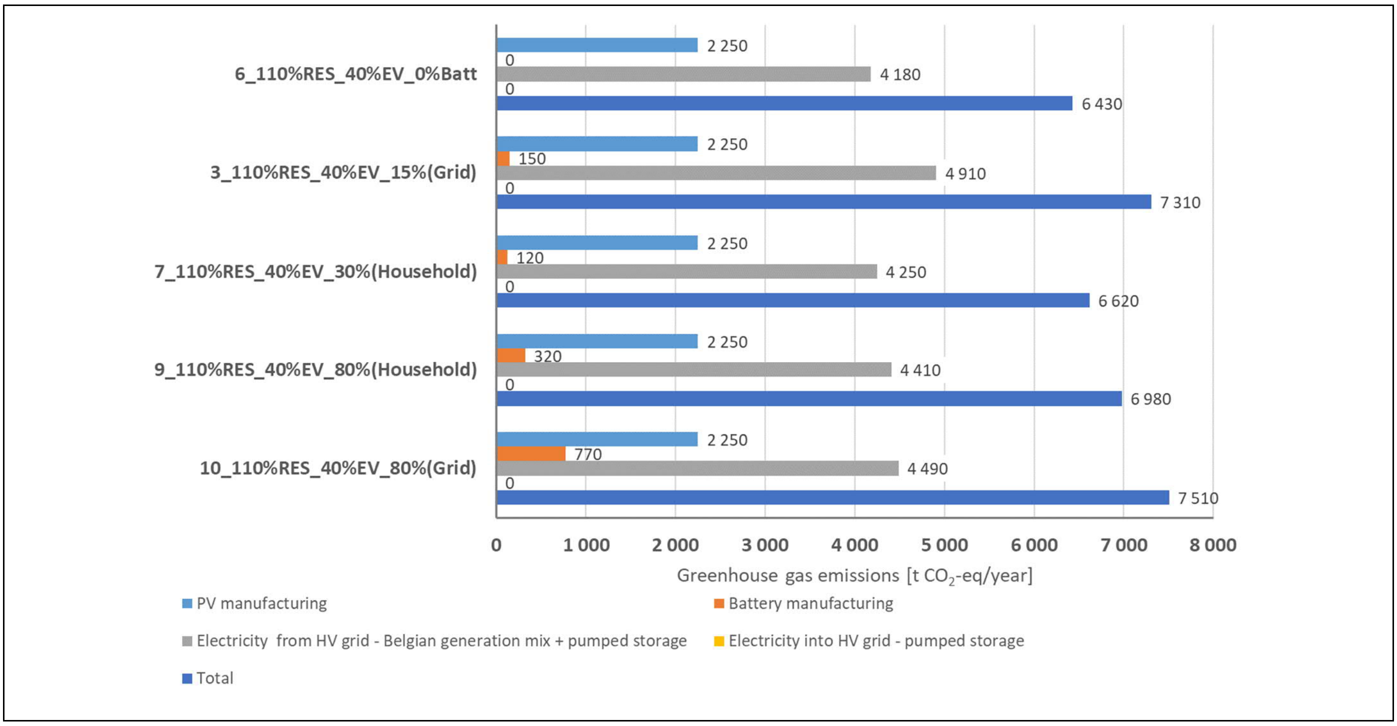


Figure 9: Annual GHG emissions for large-scale storage implementation scenarios with high PV and high EV for Option 3 - Belgian electricity mix + pumped storage

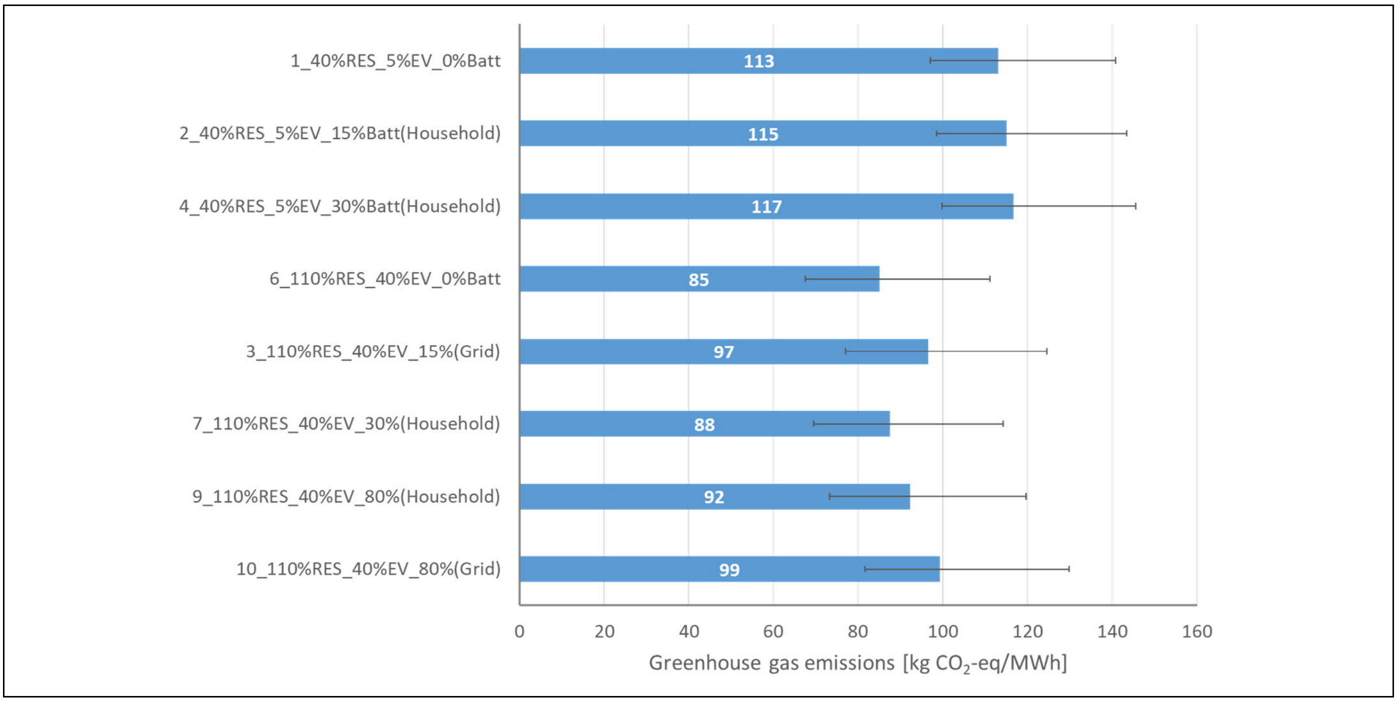


Figure 10: GHG emissions per MWh electricity demand for Option 3 – Belgian electricity mix + pumped storage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Figure 11 and Figure 12 show the GHG emissions for “Option 4 – Natural gas CC power plant”.

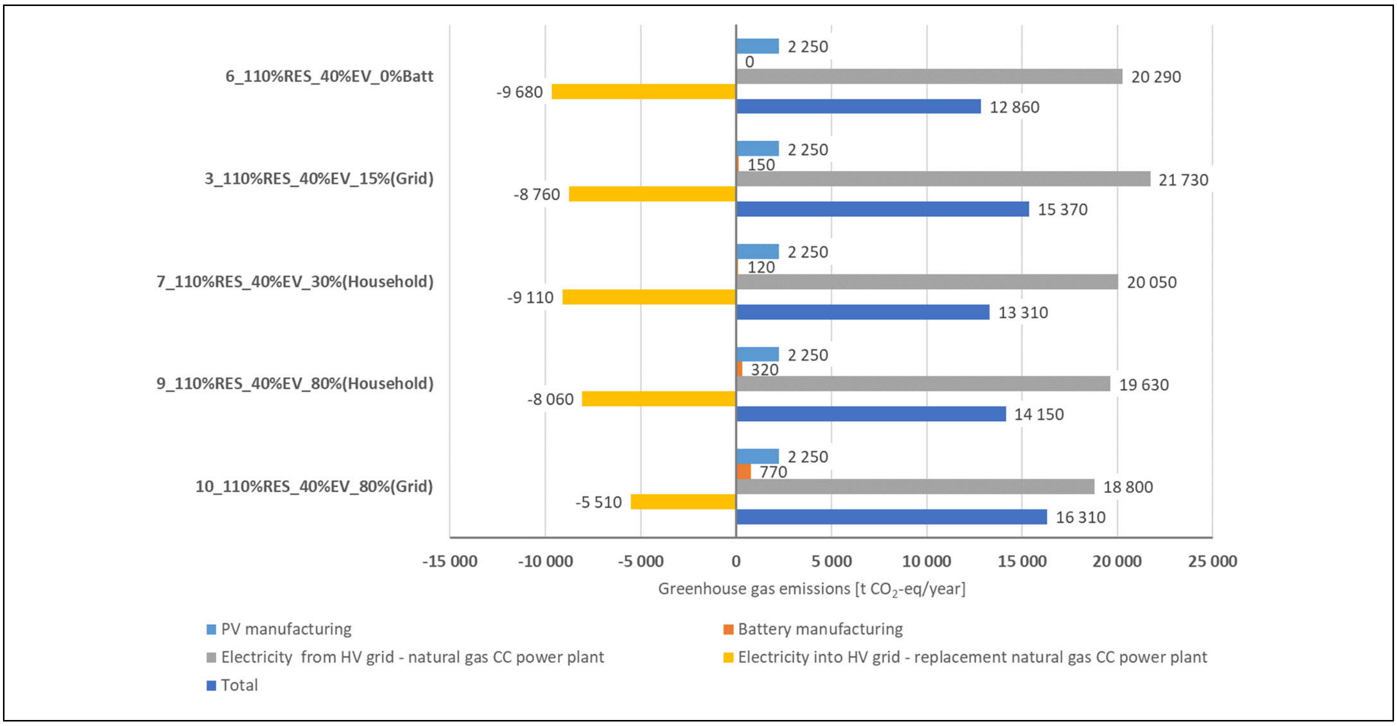


Figure 11: Annual GHG emissions for large-scale storage implementation scenarios with high PV and high EV for Option 4 – Natural gas CC power plant

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

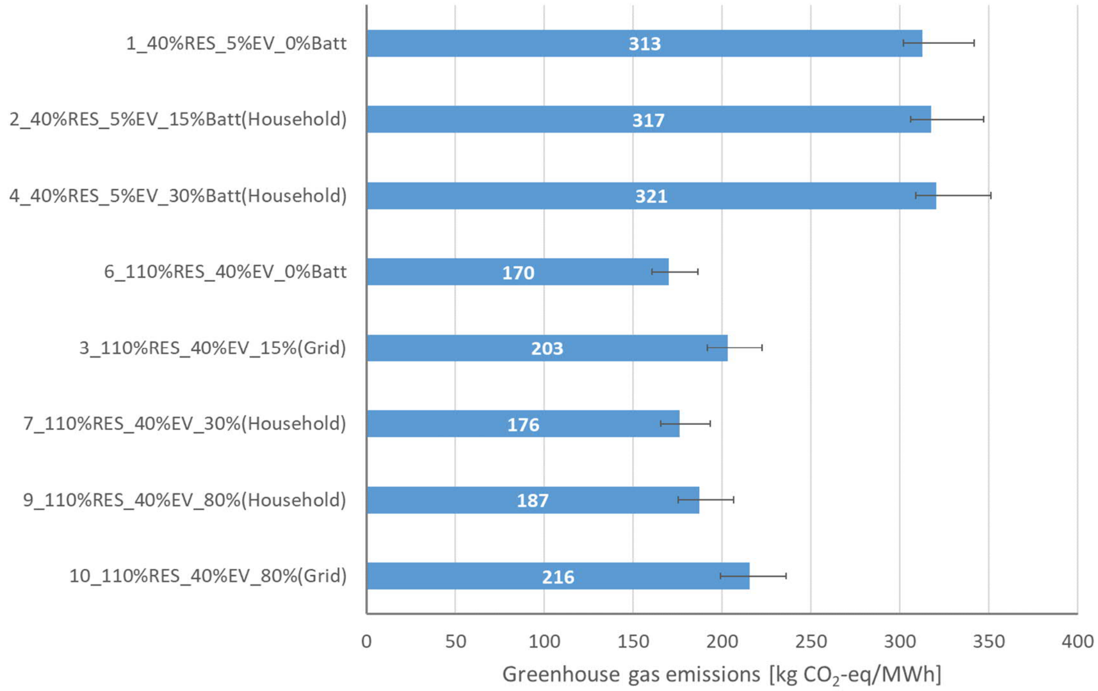


Figure 12: GHG emissions per MWh electricity demand for Option 4 – Natural gas CC power plant

When interpreting the results, the following aspects need to be considered:

- Firstly, we must point out, that for the considered amount of PV power in the investigated LV grid section the grid model showed no limitation in technical parameters. So up to the assumed amount of PV power curtailment is not needed in any of the scenarios. Transporting the electricity to another place in the network ("grid as a storage") shows smaller losses than storing the electricity in the battery system.
- Secondly, data for LV/MV substation battery are mostly based on real-world data from the Suha demonstration case, whereas data on the household batteries are from literature only. In both cases Li-Ion NCM technology is used. However, in the demonstration case, the battery storage capacity was oversized, leading to higher GHG emissions for the battery production. Data for auxiliary energy demand for cooling and heating of the battery system installed in a container at a transformer station is from "a first of a kind solution", which will be improved in the future. Literature data on the Tesla power wall battery used, which was used for the household batteries, does not include performance losses due to changing temperatures, which might take place although the batteries are installed indoor.

The total GHG emissions of the investigated system with PV and storage depend on the electricity system into which it is included, and which source is replaced by surplus electricity and which

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

source provides the consumed electricity. From the investigated standardized options on consumed and replaced grid electricity, "Option 2 – Belgian electricity mix + Natural gas CC power plant had the lowest absolute GHG emissions". However, the goal of the LCA was to investigate the influence of the battery. Here we see, that in all options scenarios without battery systems have the lowest total GHG emissions under the investigated circumstances.

3.6.2 Cumulative primary energy demand

Figure 13 to Figure 19 show the results on the cumulative primary energy demand of the investigated network development scenarios for large-scale storage implementation.

The figures show:

- Annual primary energy demand for scenarios with high amount of PV installations and high amount of EVs, and
- Specific primary energy demand per MWh electricity demand for all investigated scenarios

for four Options for consumed and replaced grid electricity.

For example, Figure 13 demonstrate the annual primary energy demand for Option 1, where the Belgian electricity mix was used for consumed and replaced grid electricity. It shows the total cumulative primary energy demand and contribution from PV operation, PV production, battery production, electricity received from HV grid and electricity supplied to the HV grid. Electricity supply to the HV grid replaces electricity generation, therefore the primary energy demand is negative.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

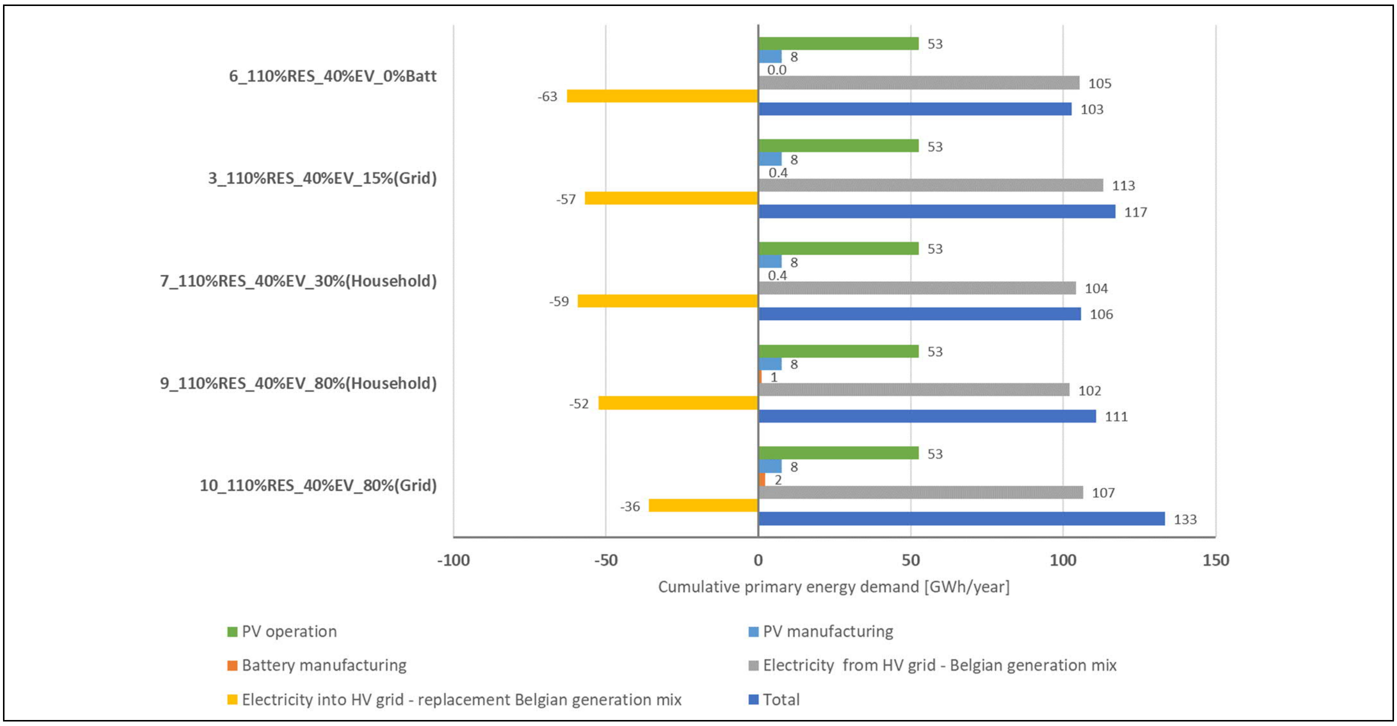


Figure 13: Annual primary energy demand for large-scale storage implementation scenarios with high PV and high EV for Option 1 – Belgian electricity mix

The results are summarized as:

- The primary energy demand for PV operation (53 GWh/year)[4] and PV plant production (8 GWh/year) is the same in all scenarios, as all shown scenarios have the same amount of installed PV power.
- The contribution of the production of the battery to the total primary energy demand is rather small with 0.4 to 2 GWh/year, depending on the installed battery capacity in the scenarios.
- The amount of electricity supplied to the HV grid decreases in scenarios with batteries and therefore the amount of replaced primary energy is smaller compared to the scenario “6_110%RES_40%EV_0%Batt”, without a battery.
- In the scenarios 7 and 9 with household batteries, the primary energy demand for consumed grid electricity decreases compared to the scenario without a battery.
- In the scenarios 3 and 10 with the MV/LV substation battery system, the primary energy demand for consumed grid electricity increases. This is again explained by the auxiliary energy needed in the MV/LV substation battery for heating and cooling of the container.

[4] Different possibilities to assess the primary energy demand of PV, wind power and water power exist (Klöpffer & Grahl, 2009). Here, primary energy demand of PV operation was assumed to equal PV electricity generation, which complies with calculation methods used in energy statistics.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

- Summarising all different contributions in Figure 13, we see that scenarios with a battery have in total a higher annual primary energy demand compared to the scenario without a battery.

Figure 14 shows the results for the specific primary energy demand for Option 1.

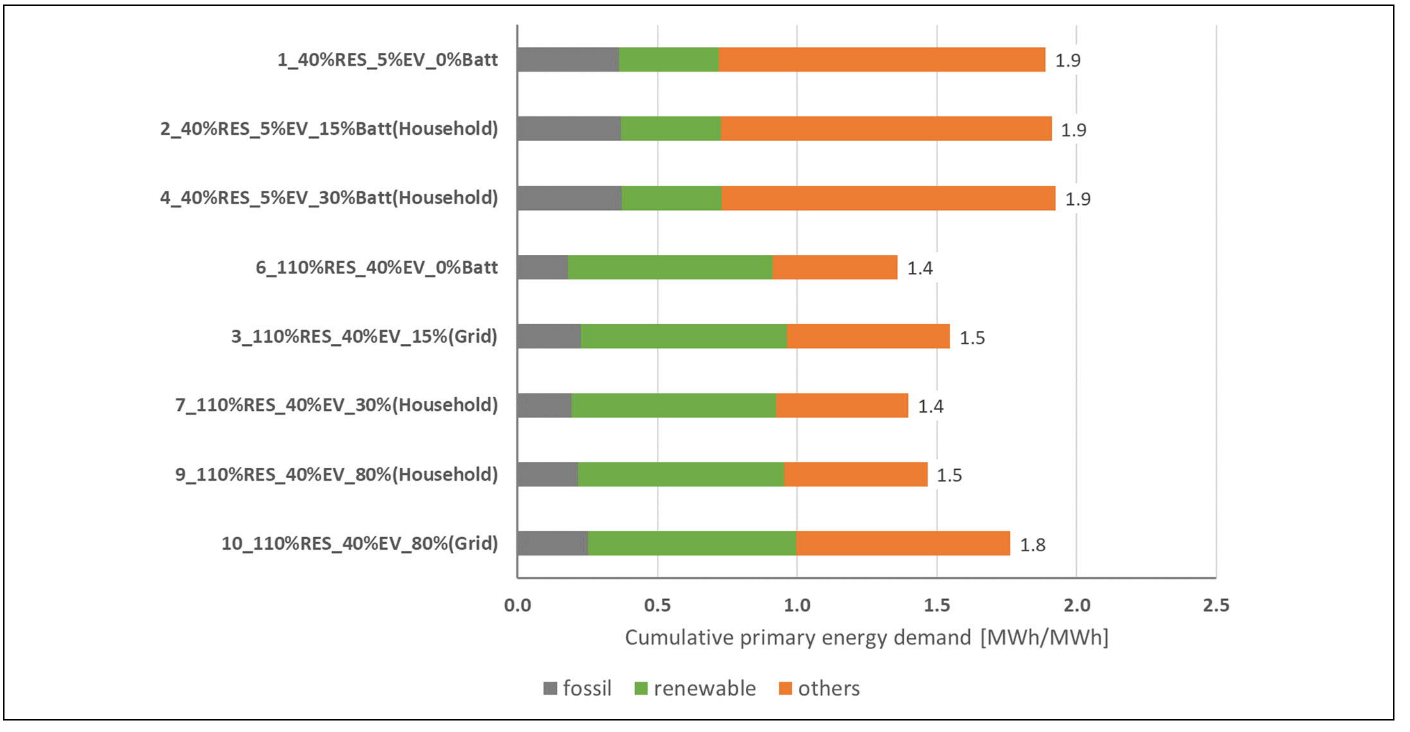


Figure 14: Primary energy demand per MWh electricity demand for Option 1 – Belgian electricity mix

Here the primary energy demand is split up into fossil, renewable and other sources.

- In scenarios with a low amount of PV installations and a low amount of EVs (scenario 1, 2, 4) the influence of the battery is rather small, and all scenarios have a primary energy demand of 1.9 MWh/MWh.
- In the second set of scenarios with a high amount of PV installation and high amount of EVs the specific primary energy demand is somewhat higher in the scenarios with a battery. As these scenarios have more PV electricity the share of renewable sources is higher compared to the first set of scenarios.
- All scenarios have a relative higher share of other sources. This is explained by the higher share of nuclear energy in the Belgian electricity mix (between 50%-70% depending on the season).

Figure 15 to Figure 18 give the results for Options 2 and 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

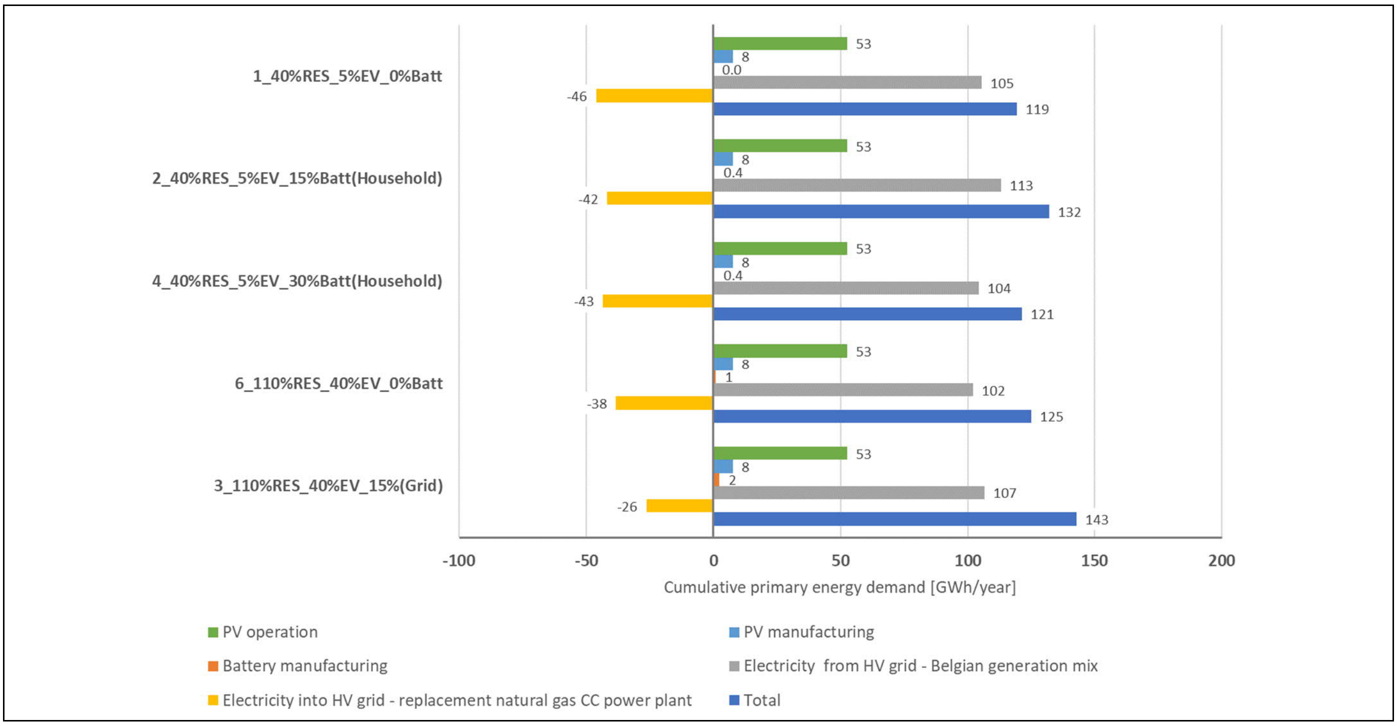


Figure 15: Annual primary energy demand for large-scale storage implementation scenarios with high PV and high EV for Option 2 – Belgian electricity mix + natural gas CC power plant

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Figure 16 shows negative values for fossil primary energy demand for some scenarios with a high amount of PV installation. These negative values occur because different technologies for consumed and replaced grid electricity are considered in Option 2. For the replaced grid electricity, electricity generation with a natural gas CC power plant was considered. For the consumed grid electricity, the Belgium electricity mix. Electricity generation with a natural gas CC power plant has a higher fossil primary energy factor as the Belgium electricity mix, which has a higher share of other sources due to nuclear power plants being part of the mix. As replaced grid electricity is considered negative in the calculation, negative values for the fossil primary energy demand occur in scenarios where a higher amount of PV electricity is injected into the HV grid.

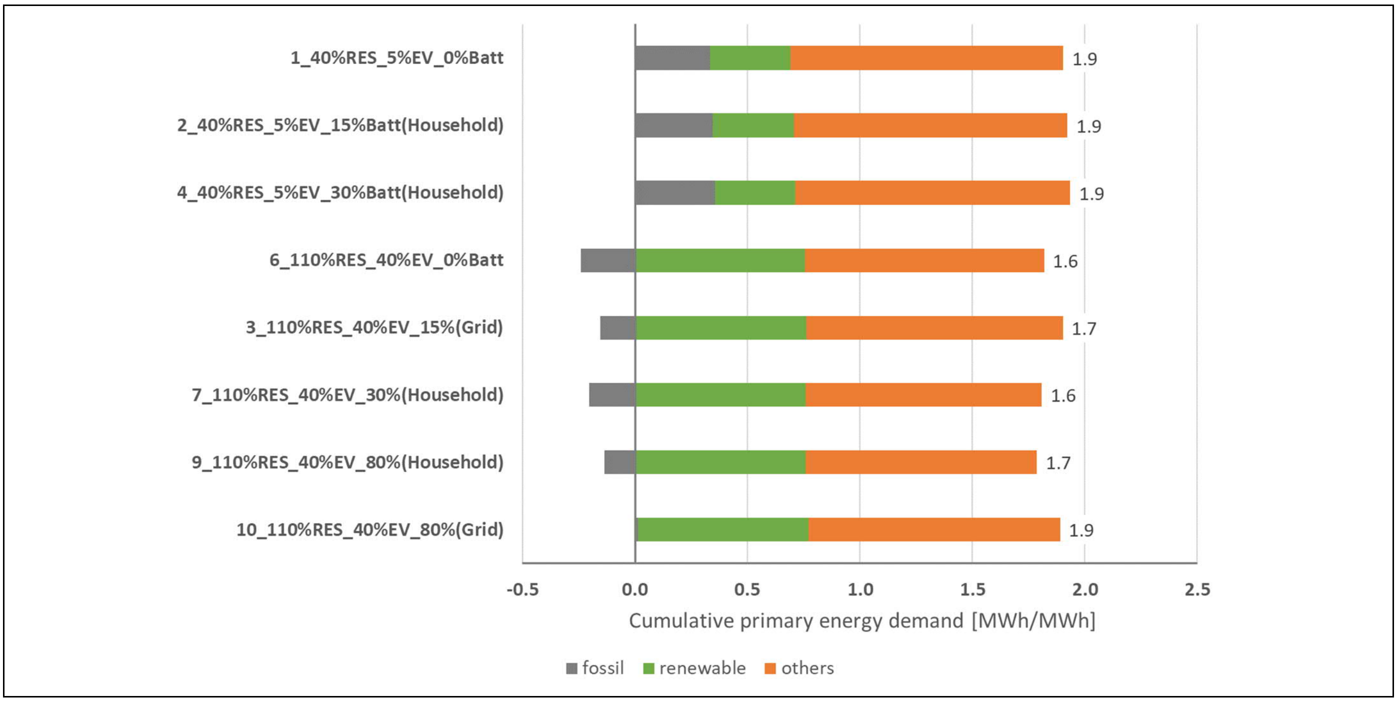


Figure 16: Primary energy demand per MWh electricity demand for Option 2 – Belgian electricity mix + natural gas CC power plant

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

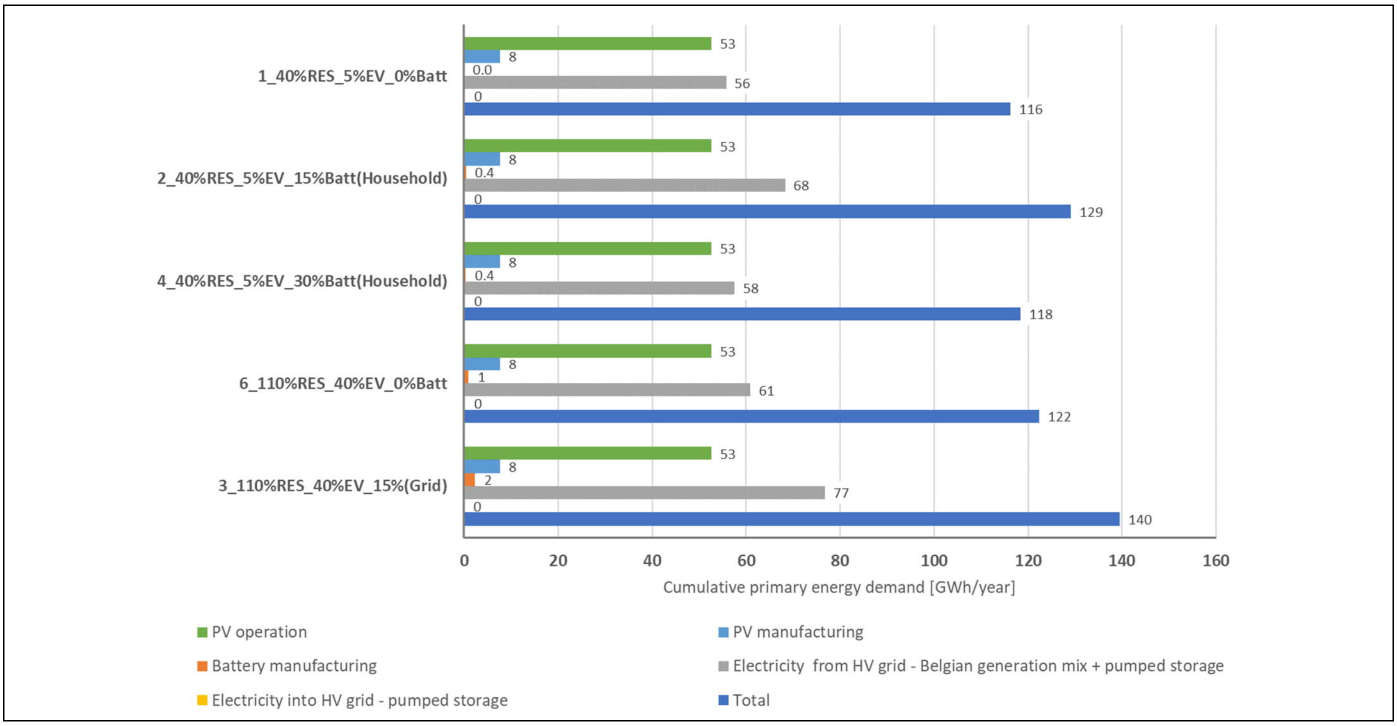


Figure 17: Annual primary energy demand for large-scale storage implementation scenarios with high PV and high EV for Option 3 – Belgian electricity mix + pumped storage

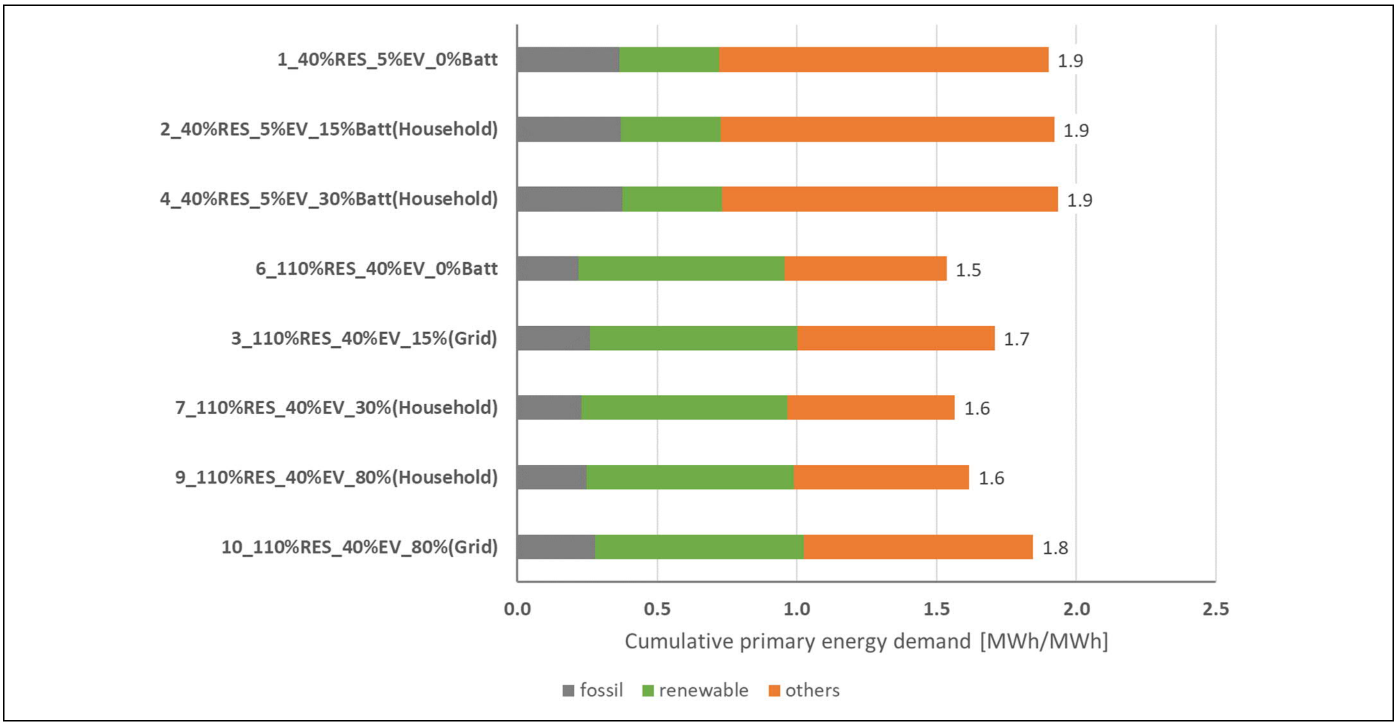


Figure 18: Primary energy demand per MWh electricity demand for Option 3 – Belgian electricity mix + pumped storage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

In Figure 19, where for the consumed and replaced grid electricity generation with a natural CC power plant was assumed, the contribution of other sources is significantly lower and the contribution of fossil sources significantly higher.

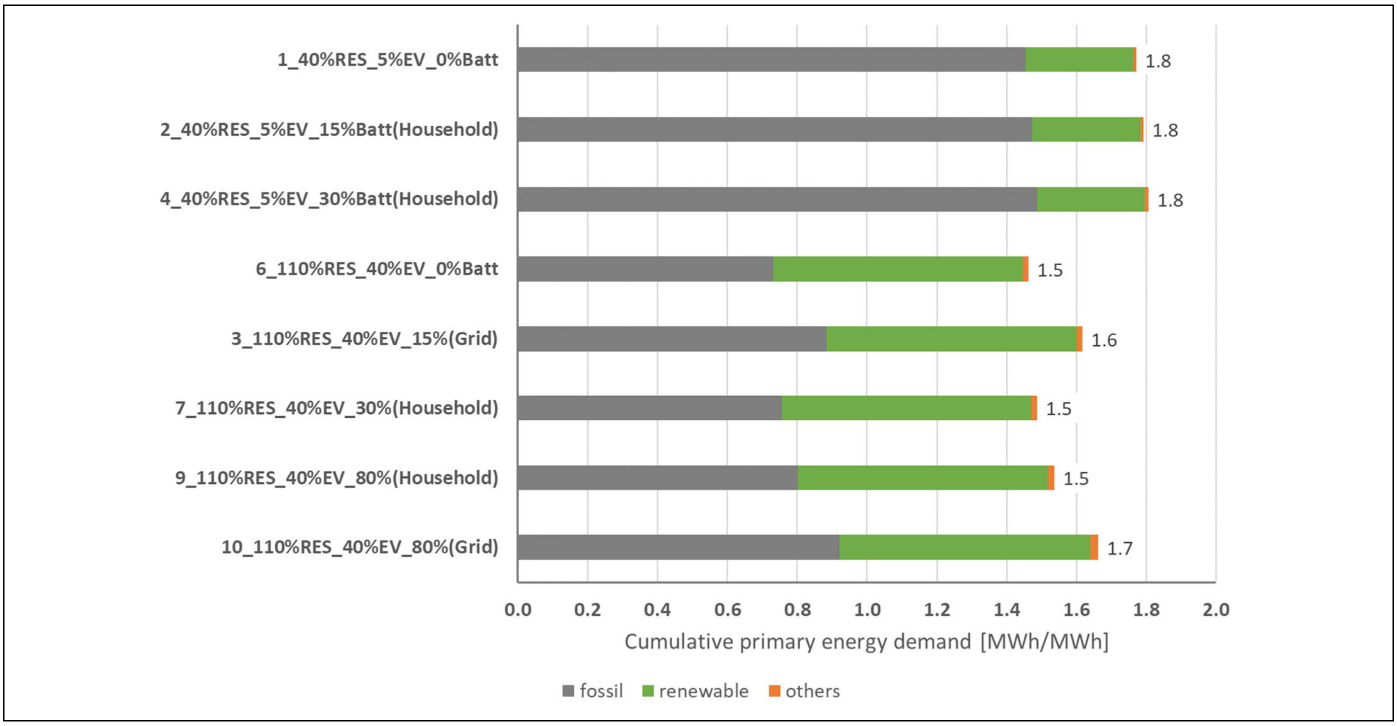


Figure 19: Primary energy demand per MWh electricity demand for Option 4 – natural gas CC power plant

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

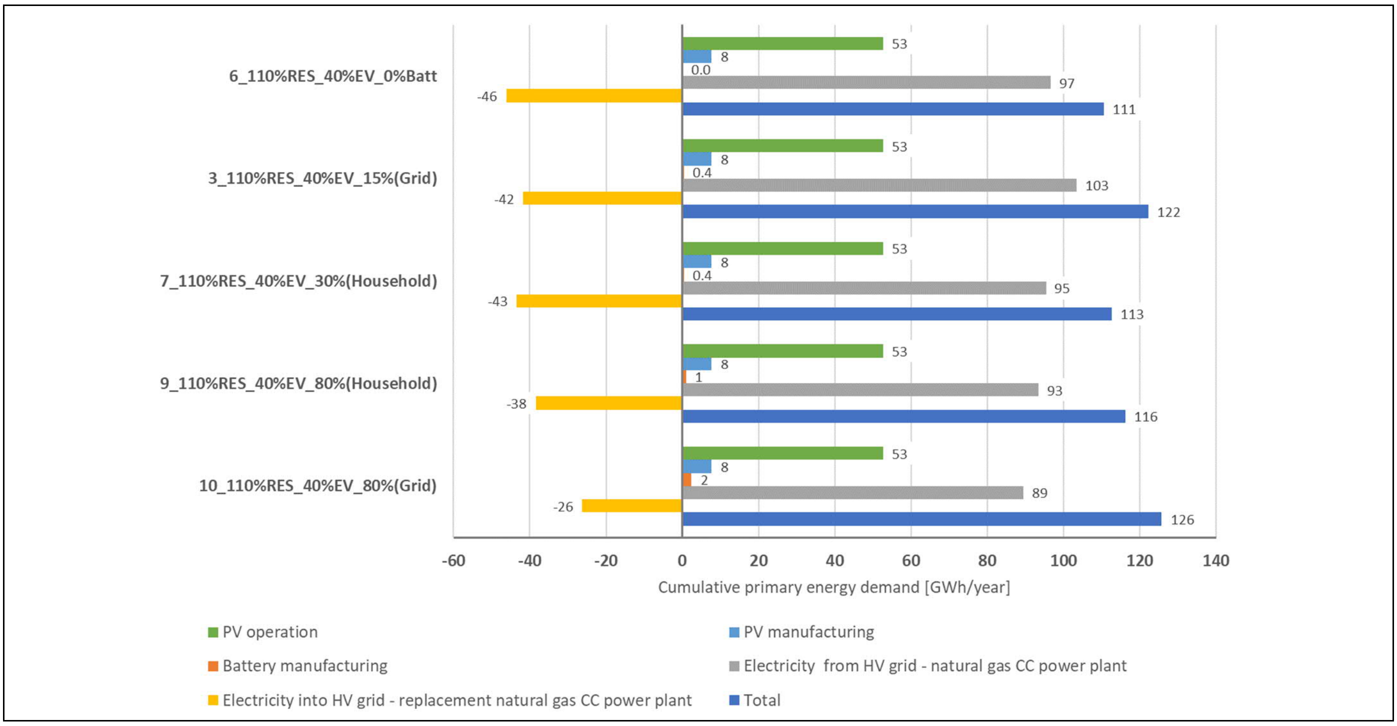


Figure 20: Annual primary energy demand for large-scale storage implementation scenarios with high PV and high EV for Option 4 – natural gas CC power plant

3.6.3 Air pollutants

The focus of the LCA was on GHG emissions and cumulative primary energy demand. However, impacts on acidification potential, ozone creation potential and particulate matter were also investigated. The complete results on these impact categories are depicted in “Appendices 1 - Life cycle assessment”.

Figure 21 and Figure 22 show selected results on the acidification potential. Figure 21 shows the annual acidification potential for scenarios with a high amount of PV installations and a high amount of EVs. The figure provides an overview of the total annual acidification potential and contributions from PV plan production, battery production, electricity received from HV grid and electricity supplied to the HV. In contrast to the previous results on GHG emissions and cumulative primary energy demand, battery production has a relevant share in the total acidification potential. For example, in scenario “10_110%RES_40%EV_80%(Grid)” battery production accounts for 40% of the total acidification potential.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

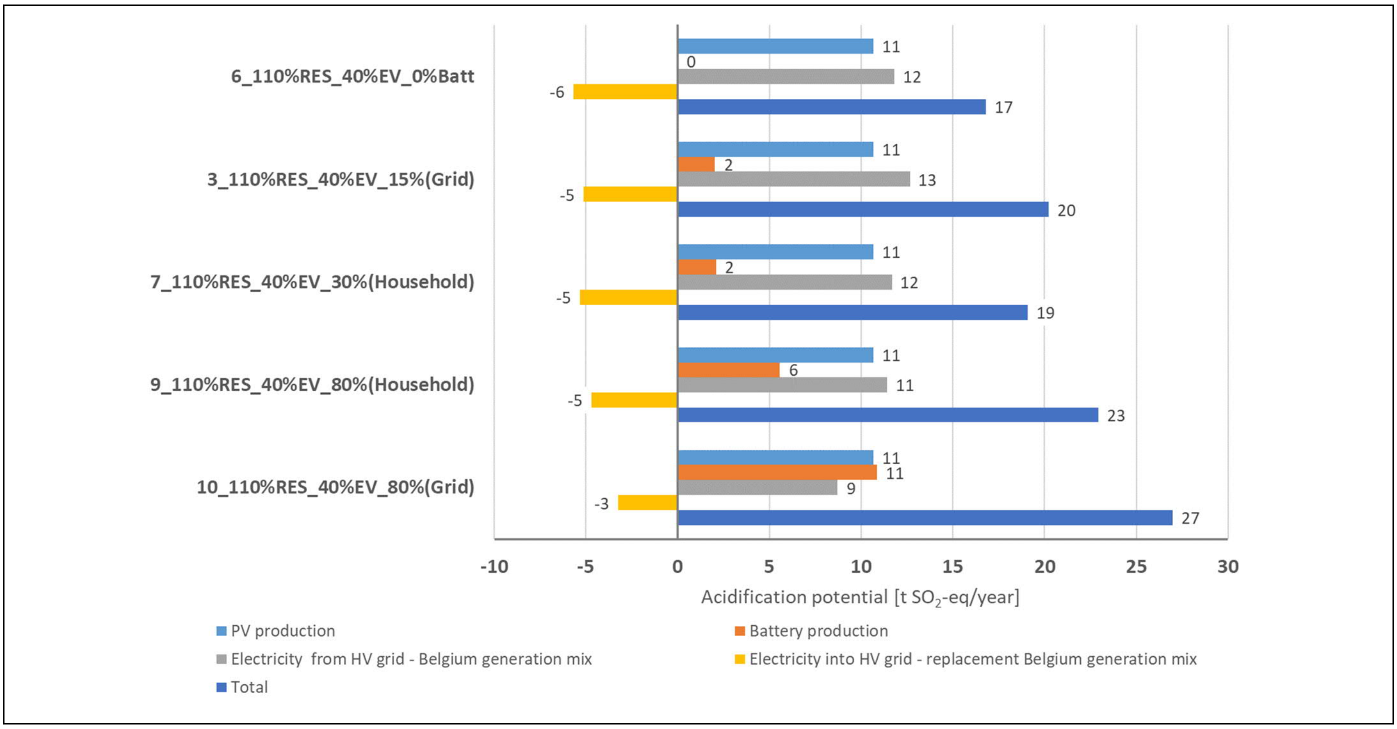


Figure 21: Annual acidification potential for large-scale storage implementation scenarios with high PV and high EV for Option 1 – Belgian electricity mix

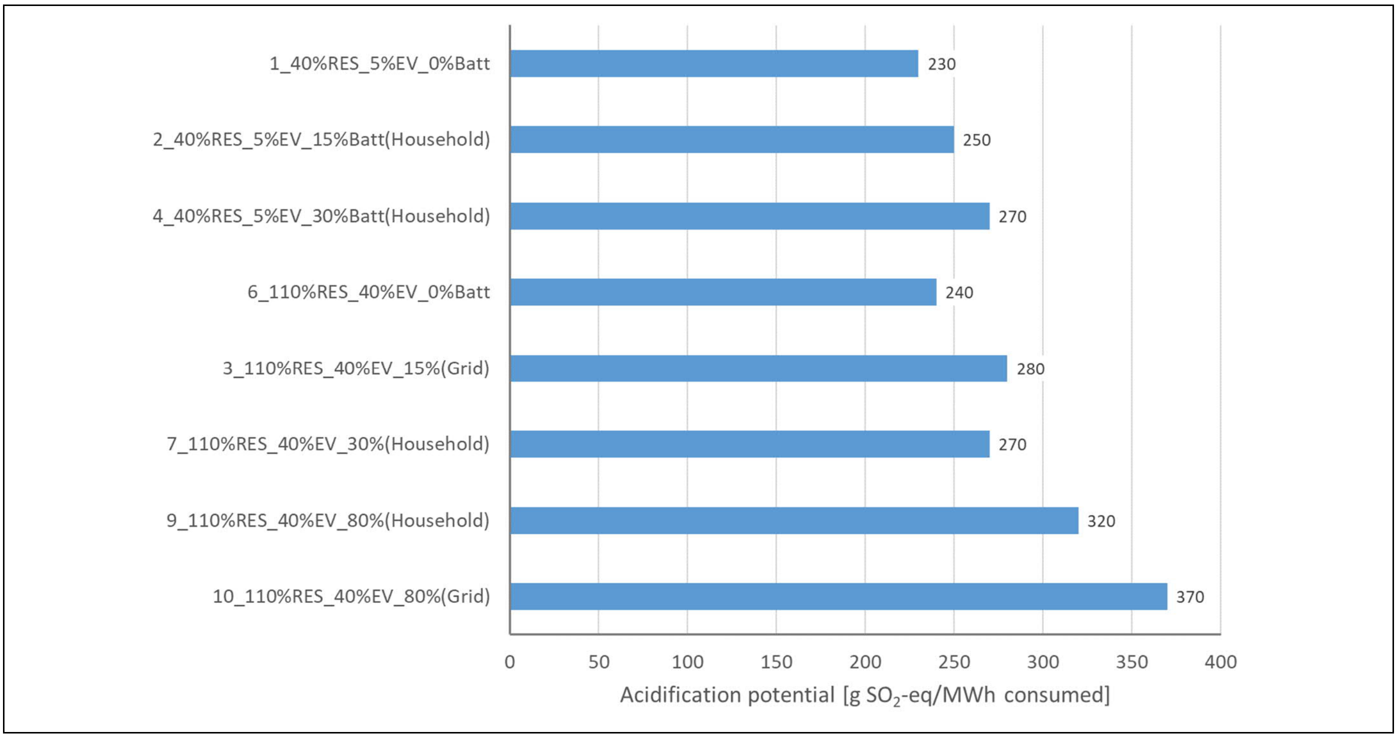


Figure 22: Acidification potential per MWh electricity demand for Option 1 – Belgian electricity mix

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

4 Social life cycle assessment

To get a holistic picture of the environmental impacts of a product, life cycle assessment methods are being used. But consumers and enterprises are also more and more interested in the economic and social circumstances under which a product is produced. While the use of LCA is quite widespread, similar approaches for the economic and social dimensions of sustainability are still limited in their application.

The challenge to include a social assessment in a LCA approach is that the social dimension is determined by factors like personal behaviour, general moral values, interaction with other social groups, etc. and besides that, has a very strong regional character and differs from case to case.

Like LCA, Social Life Cycle Assessment (sLCA) integrates traditional life cycle assessment methodological steps while having social impacts as focus. UNEP defines social impacts as “the consequences of interactions in the context of an activity (production, consumption or disposal) and/or endangered by it and /or preventive or reinforcing actions taken by stakeholders (e.g. enforcing safety measures in a plant)”. The sLCA in principle follows the ISO 14040 framework and complements the environmental LCA. It is used to assess the social and sociological aspects of products, their actual and potential positive as well as negative impacts along the life cycle, from the extraction of raw materials, till the final disposal.

The main questions at the starting point of a social assessment are “why should we measure the social aspects” and “how shall we do this”? For the “why” there are several good reasons: no company for example wants to be linked with child labour or corruption but, on the other side, wants to avoid protests and objections to new technologies from the local community and the society up-front. Therefore, it is necessary to find a way on how to consider and assess social effects of products along their whole life cycle, to get

- an improved social performance;
- a better risk assessment;
- a better image;
- have information for reporting and labelling.

For the “how” there already exist some methods, tools, and indicators for collecting and assessing social indicators (UNEP, 2009):

Analytical tools: Social Impact Assessment (SIA), Technology Assessment (TA)

Procedures and Management tools: Standards and Certifications: (SA8000); Guidelines (ISO26000); performance measures (Sustainability Balanced Scorecard)

Monitoring tools: Social Audits

Communication tools: Sustainable Development Reports; Labelling; Sustainable/Social indexes

Reporting tools: GRI guidelines; social reporting indicators

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426

All these tools have a different focus on different objectives and cannot easily replace each other. To be able to consider all dimensions of sustainability (economic, environmental, and social), it would be good to have a method that is complementary to Life Cycle Costing (LCC) and to Life Cycle Assessment (LCA). Whereas the environmental LCA has its standards, it is still hard to get a holistic picture of the social impacts of a product over its entire life cycle. In recent years, the UNEP/SETAC Working Group developed guidelines on how to conduct an sLCA and there is high interest from policy and industry already, but still there is no software and no databases available at present. Some of the above-mentioned tools are also complementary to an sLCA approach and in 2009, a guideline was developed by the UNEP/SETAC Working Group, which aims at providing a general guidance on the use of sLCA, facilitating a more uniform performance of this technique.

The challenges with social categories and indicators are that

- they are very complex as they are the result of relationships and a function of politics, economy, ethics, legal issues, culture, etc.,
- they are complex cause-effect chains,
- social indicators are subjectively perceived and hard to evaluate,
- it is hard to find appropriate indicators, there are hardly any generic databases,
- reliable data are difficult to find for some aspects as child labour, discrimination, etc.,
- data are needed at different levels: country level, regional level, sector level, company level and site level,
- they are a mixture of quantitative, semi-quantitative and qualitative data and
- it is hard to compare between companies, processes, and products.

A sLCA has 2 main objectives:

- to enable a comparison of products/services and processes for decision making
- to attempt to identify improvements potentials within the system to slash social impacts

The attempt of a sLCA is to get a complete picture of the situation, meaning

- which stakeholders are relevant,
- which topics are of interest (definition of subcategories),
- define indicators to describe these topics, and
- assessing these indicators.

Starting back in the 1990’s, when discussions started on how sLCA should be integrated or aligned with the environmental LCA methodology, different social indicators have been proposed, such as additional employment, Quality Adjusted Life Years (QALY) and health impacts (positive and negative). Site-specific assessments have also been argued for, as the impacts relate to company conduct and should therefore be assessed on-site.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

An important achievement in the on-going development of sLCA was the issuing of the UNEP/SETAC S-LCA Guidelines in 2009. The Guidelines are the outcome of a broad, global, transparent and open process involving many relevant stakeholders from the public, academic and business sectors and aiming at providing a general guidance on the use of sLCA, facilitating a more uniform performance of this technique.

The methodology suggests setting the following steps:

- Definition of the goal and the scope of the assessment
- Definition of the product system
- Identification of Social Hotspots
- Indicator selection and Data collection
- Assessment and Weighting

As already mentioned before, a sLCA assesses the social impacts along the whole lifecycle of a product. The different stages of a product's lifecycle can be seen in Figure 23:

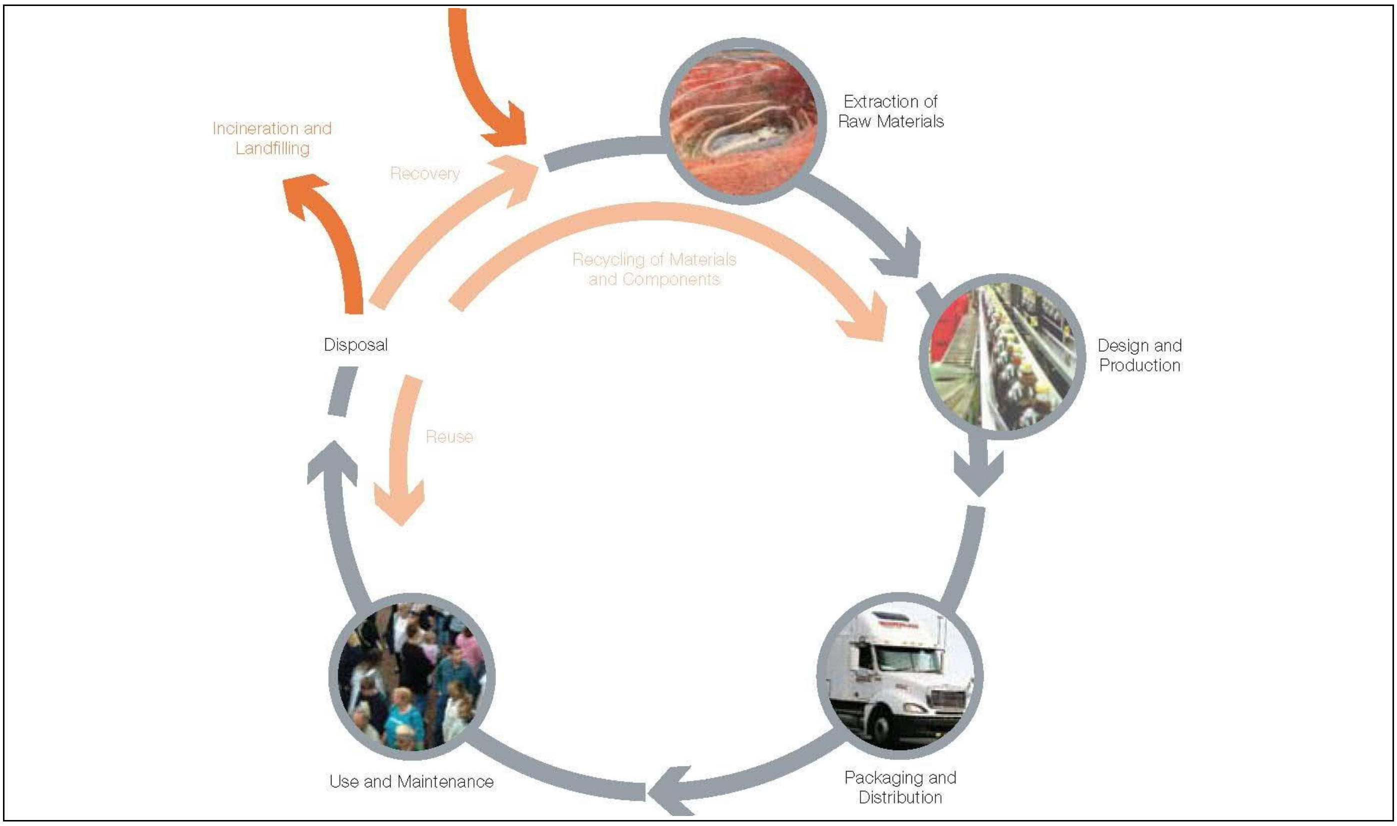


Figure 23: Product lifecycle (UNEP, 2009)

Each of these life cycle stages are connected to a geographic location, where the processes are carried out (e.g. mines, fields, factories, offices, disposal-sites).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

At all these sites, social impacts may be observed in five main **stakeholder categories:**

- workers/employees,
- local community,
- society (national and global),
- consumers and
- value chain actors (which are not consumers).

Each of these stakeholder categories consists of a cluster of stakeholders that are expected to have shared interests due to their similar relationship to the investigated product systems. The stakeholder categories provide a comprehensive basis for the articulation of the subcategories. The proposed stakeholder categories are deemed to be the main group categories potentially impacted by the life cycle of a product (UNEP, 2009).

Subcategories

If we follow the UNEP/SETAC guidelines for a sLCA, the next thing to do is to define subcategories. In a first step, social subcategories have been defined according to international agreements (conventions, treaties, etc.). In a next step, best practices at the international level have been considered: international instruments, CSR initiatives, model legal framework, social impacts assessment literature UNEP, 2009). The international conventions on “Human Rights and Workers Rights” are a good basis for a sLCA indicators framework. International conventions are valuable instruments that have been negotiated by countries, they are the best example of a universal set of social criteria. Additional international instruments, initiatives, best practices, model legal framework, etc., guide the development of additional categories and indicators that go beyond minimal compliance and assess additional and complementary social impacts.

Here, to consider different contexts is of great importance: as, for example, in a developed country, many “Human Rights and Workers Rights” may already be covered by legislation, this might not be the case in developing countries and it is important to emphasize that this should not be taken for granted. As it is put in the UNEP Guidelines, “international standards tend to define floors rather than ceilings”. Therefore, as part of the assessment, screening for minimum compliance when thresholds exist, and possibly also to assess performance beyond compliance thresholds is suggested (UNEP, 2009).

Taking all this into account, a comprehensive set of subcategories was formulated under the five stakeholder categories (UNEP, 2009):

Stakeholder “worker”

- Freedom of Association and Collective Bargaining
- Child Labour
- Fair Salary
- Working Hours

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

- Forced Labour
- Equal opportunities/Discrimination
- Health and Safety
- Social Benefits/Social Security

Stakeholder "consumer"

- Health and Safety
- Feedback Mechanism
- Consumer Privacy
- Transparency
- End of life responsibility

Stakeholder "local community"

- Access to material resources A
- Access to immaterial resources D
- Delocalization and Migration Cultural Heritage
- Safe and healthy living conditions
- Respect of indigenous rights
- Community engagement
- Local employment
- Secure living conditions

Stakeholder "society"

- Public commitments to sustainability issues
- Contribution to economic development
- Prevention and mitigation of armed conflicts
- Technology development
- Corruption

Value chain actors, not including consumers

- Fair competition
- Promoting social responsibility
- Supplier relationships
- Respect of intellectual property rights

Subcategories are the basis of a sLCA assessment; they are the socially significant themes or attributes. Subcategories are not only classified according to stakeholder categories but also according to impact categories and are assessed by using indicators. These indicators may vary,

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

depending on the context of an assessment.

The purpose of the classification into impact categories is to support the identification of stakeholders. The impact categories should preferably reflect internationally recognized categorizations/standards (like the UN declaration on economic, social, and cultural rights - ECOSOC, standards for multinationals) and/or result from a multi-stakeholder process (UNEP, 2009).

Impact categories are logical groupings of sLCA results, related to social issues of interest to stakeholders and decision makers (see Figure 24). A final set of accepted impact categories still needs to be defined.

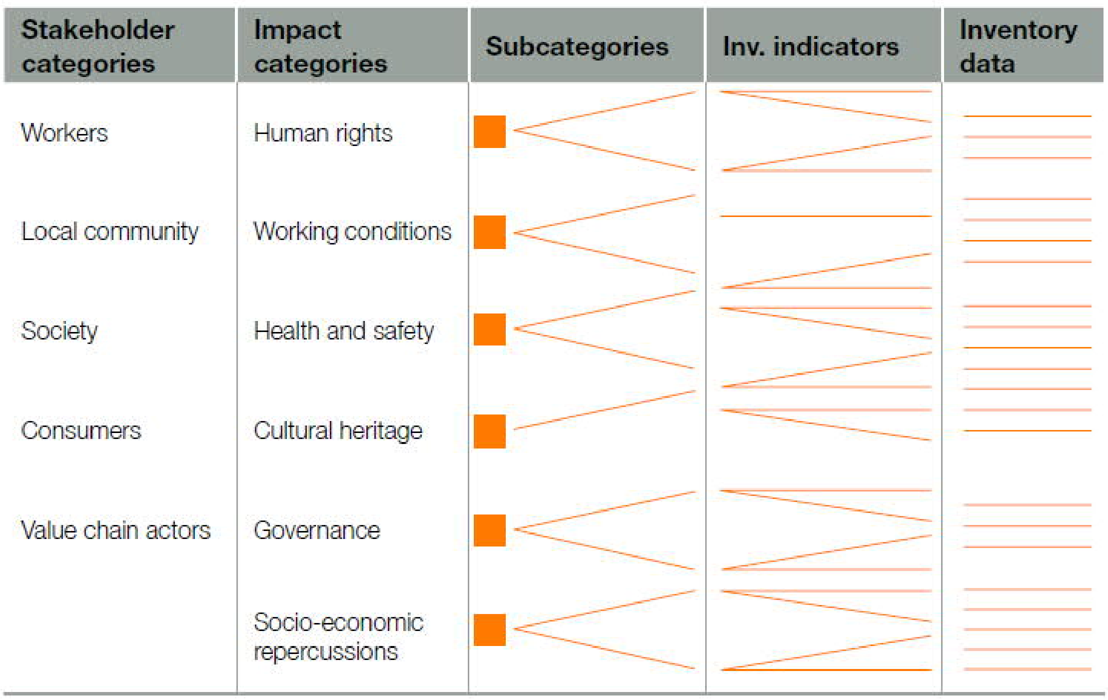


Figure 24: Assessment system from categories to unit of measurement (adapted from Benoît et al., 2007, UNEP, 2009).

The social dimension of a product is a very complex task to do and many aspects have to be considered, among them the selection of social impact categories, the determination of appropriate indicators and affected stakeholder groups as well as the type of data that is required for an assessment like this.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

4.1 Methodology

Following the DoA of STORY, within a social analysis, social indicators (e.g. employment, health and safety, prevention of forced and compulsory labour) shall be identified and assessed for the large-scale storage implementation.

To assess the social aspects within the STORY project, the process for conducting a sLCA as described in UNEP, 2009 was followed:

1. Definition of the goal and the scope of the assessment
2. Definition of the product system/system boundaries
3. Identification of Social Hotspots
4. Indicator selection and data collection/input data
5. Assessment

From the process steps for conducting a sLCA listed above, step (1) to (4) are described in this chapter. The results of the assessment (step 5) are described in chapter “4.2 Results and discussion”.

4.1.1 Goal and scope

The goal of the sLCA is to assess the possible positive or negative social impacts occurring for large-scale storage implementation in STORY. Within this, several social indicators are to be identified and assessed. From the analysis, recommendations to further reduce negative social impact and elevate positive social impact can be derived.

The scope of the sLCA is the analysis of battery storage systems, starting with the analysis of the source and extraction of the raw materials and ending with its purchase by the battery supplier within STORY. This approach was chosen after a survey among the partner responsible for the batteries.

4.1.2 System boundaries

In the project STORY, the focus in the life cycle lies on the manufacturing and the operation of the battery energy storage. The dismantling, including recycling and going into landfill will not be part of this report (see Figure 3). In the manufacturing phase the production of raw materials (primary and secondary) for the social assessment is included. The operation phase was not assessed within the sLCA, but this phase includes other social issues as the inclusion of different stakeholders, e.g. users and occupants or people responsible for maintenance of the batteries as well as the acceptability of new technologies like battery storage. These topics are covered firstly in the appendices of this report for the acceptability and secondly in WP6, D6.2 on the stakeholders and will not be further elaborated in this Deliverable 7.4.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

Geographically, for the sLCA, only the extraction and production sites for the system components were taken into consideration, which are outside of Europe for all demos with batteries.

4.1.3 Identification of social hotspots/social indicators

Using the definition of the UNEP-SETAC guidelines (2009), social hotspots are “unit processes located in a region where a situation occurs that may be considered a problem, a risk or an opportunity, in relation to a social theme of interest”. Social Hotspots are identified based on country or sector specific databases and based on desk research dealing with the questions:

- Does the process occur in a country with known international human right violations or social risks?
- Is the process known to present social risks to stakeholders due to the nature of the activity in this step?

Therefore, the aim in STORY was to find out which parts of the supply chain of these batteries present a high risk concerning social issues. So, it was relatively clear from the beginning that the main issues which will be assessed within STORY are dealing with the following questions:

- Where do the raw materials for the batteries come from?
- Are they “critical minerals and/or minerals of concern”? (from conflict-affected and high-risk regions)?
- Where and how are the batteries assembled?
- Which issues are connected to these raw materials and processes?

4.1.4 Indicator selection and data collection

In STORY, 4 out of 6 batteries that are used as storage devices are Lithium-based batteries, so the focus or the assessment lies here. Lithium-ion batteries are considered a key component in all kinds of energy storage applications. However, the currently used technology is based on several critical materials, such as lithium, cobalt, nickel, manganese, and graphite. These main raw materials can be found in different locations worldwide:

- the largest producer of lithium is Australia, other important producers are Chile and, to some extent, Argentina (see also Table 14)
- Nickel is produced mainly in three countries: Indonesia, the Philippines, and Canada whereas
- Cobalt production is mainly based in the DR Congo.
- Manganese production mainly takes place in South Africa, China, and Australia (Thies at al., 2019).
- China is the main producer of aluminium and graphite, followed by Russia and Canada for aluminium, and India and Brazil for graphite.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

Table 14: Main producers, main source of import into EU, substitutability index and recycling rate of cobalt, natural graphite, silicon metal and lithium (Lebedova et al., 2017)

Raw material	Main producers (2014-2015)	Main sources of imports into the EU (mainly 2012)	Substitutability index	End-of-life recycling input rate
Critical raw materials used in Li-ion batteries				
Cobalt	Democratic Republic of Congo: 51 % China: 6 % Russia: 5 % Canada: 5 % Australia: 5 %	Russia: 96 % (cobalt ores and concentrates) USA: 3 % (cobalt ores and concentrates)	0.71	16 %
Natural graphite	China: 66 % India: 14 % Brazil: 7 %	China: 57 % Brazil: 15 % Norway: 9 %	0.72	0 %
Silicon metal	China: 68 % Russia: 8 % USA: 5 % Norway: 4 %	Norway: 38 % Brazil: 24 % China: 8 % Russia: 7 %	0.81	0 %
Non-critical raw material used in Li-ion batteries				
Lithium	Australia: 41 % Chile: 36 % Argentina: 12 % China: 7 %		n.a.	n.a.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

These raw materials are used to produce intermediates such as the positive and negative electrodes and electrolyte which is usually done by specialty chemicals companies located in China (Ahmed et al., 2017). After that, the batteries are being assembled by battery producers. Table 15 shows the Top 10 Li-ion battery producers worldwide.

Table 15: Top 10 Li-ion battery producers worldwide (Aug. 2018) (ELE times, 2018)

Top 10 Lithium ionic battery producer		Country
1	Panasonic	Japan
2	Toshiba	Japan
3	LG Chem	Süd Korea
4	Tesla	US
5	A123 System	US
6	eCobaltSolutions	Canada
7	BYD	China
8	Contemporary Amperex Technology	China
9	Johnson Control	Irland
10	Samsung SDI	Süd Korea

But, lithium, cobalt, nickel, manganese, and graphite are also **classified critical**, as they have

(I) a significant economic importance for key sectors in the European economy, they have
(II) a high-supply risk due to the very-high import dependence and high level of concentration of set critical raw materials in particular countries and there is
(III) a lack of (viable) substitutes, due to the very unique and reliable properties of these materials for existing, as well as future applications (http://criticalrawmaterials.org/critical-raw-materials/). Finally, they are associated with environmental and social impacts in their supply chain, where the social impacts have been neglected so far to a wide extent.

Box 1: Critical raw materials

According to critical raw materials.org (http://criticalrawmaterials.org/critical-raw-materials/), Critical Raw Materials (CRMs) are those raw materials which are economically and strategically important for the European economy, but have a high-risk associated with their supply. Used in environmental technologies, consumer electronics, health, steelmaking, defence, space exploration, and aviation, these materials are not only 'critical' for key industry sectors and future applications, but also for the sustainable functioning of the European economy. Examples of CRMs include rare earth elements, cobalt, and niobium.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

It is important to note that these materials *are not classified as 'critical' because these materials are considered scarce*, rather they are classified as 'critical' because:

they have a significant economic importance for key sectors in the European economy, such as consumer electronics, environmental technologies, automotive, aerospace, defence, health, and steel.
they have a high-supply risk due to the very-high import dependence and high level of concentration of set critical raw materials in particular countries
there is a lack of (viable) substitutes, due to the unique and reliable properties of these materials for existing, as well as future applications

Already in 2008 and 2011 in its two Communications COM (2008)699 'The Raw Materials Initiative' (EC, 2008) and COM (2011)25 'Tackling The Challenges in Commodity Markets and on Raw Materials' (EC, 2011), the European Commission had put forward the regular identification of CRMs and the improvement of resource efficiency and of conditions for recycling as crucial components of its raw materials policy. The importance of these two components and their close interrelation was recently reinforced in the Communication COM (2015) 614 on the 'EU action plan for the Circular Economy' (EC, 2015a) where critical raw materials are identified as one of the five priority areas where actions should be taken. The action plan identified several actions in this area, including the commitment to issue a report on critical raw materials and the circular economy in 2017, 'in order to ensure a coherent and effective approach, to provide key data sources and to identify [best practices and] Options for further action'.

In November 2018, the European Commission also issued a "Commission Staff Working Document", Report on Raw Materials for Battery Applications". The report focuses on four essential raw materials for batteries production namely: cobalt, lithium, graphite, and nickel. Other important raw materials for battery applications such as manganese, aluminium, copper, tin, silicon, magnesium, germanium, indium, antimony and rare earth elements (REEs) are briefly mentioned but they would require a more in-depth analysis as outlined in the relevant paragraph on Alternative Materials. REEs are also materials of relevance to electro-mobility, for electric traction motors. Some of these materials have a high economic importance while at the same time have a high supply-risk. Among the materials used in Li-ion cells, three are listed as critical raw materials (CRMs)[1] by the European Commission namely, cobalt, natural graphite, and silicon (metal). Lithium is not a CRM but has an increasing relevancy for the Li-ion battery industry.

This report identifies the need to improve the knowledge on battery raw materials. Data regarding minor metals, as cobalt or lithium, is either unavailable, scattered, confidential or of low quality. Data in the EU is also reported under different standards, which makes their comparison and integration difficult.

It confirms that the EU is sourcing primary battery raw materials like cobalt, lithium, graphite, and nickel mostly from third countries such as Democratic Republic of Congo, Russia, Chile and Brazil, and that there is a potential for boosting primary and secondary battery materials production in the EU. It also shows that there are few obstacles to using the EU potential such as: the lack of geological data necessary to discover deeper deposits; the difficulty to access to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

known deposits; a weak integration of land use planning and mining and finally diverse regulatory conditions across the EU and low public awareness of raw materials and acceptance of production operations.

--

[1] The 2017 list of Critical Raw Materials for the EU: COM (2017) 490 final:
https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF

Table 16: The 2017 List of Critical Raw Materials to the EU (EC, 2017a).

Critical raw materials			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

(HREEs = heavy rare earth elements (1), LREEs = light rare earth elements (2), PGMs = platinum group metals (3))

This brings us to a next critical issue, the so-called conflict minerals.

Box 2: Conflict minerals

Conflict minerals (CM) are termed “conflict” as profits arising from the sales of these minerals contribute to the financing of armed forces in conflict-prone areas, which are often connected to social and human rights issues such as forced labour (European Commission, 2017; Islam and van Staden, 2018). Some of the materials used for storage production are not conflict minerals as such but come from countries that are known for being the source of conflict minerals, as the Democratic Republic of Congo (the main producer of Cobalt).

An obstacle to preventing such problems is that global sourcing and complex supply chains have led to a non-transparent procurement market. The lack of transparency may be going along with

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

a lack of awareness of or at least knowledge about human rights abuses and other social injustice Inflicted upon workers in supply chains.

The first attribute of a CM is that it originates from a conflict-affected and high-risk region (European Commission, 2017), with the Dodd-Frank Act specifying the Democratic Republic of the Congo or an adjoining country (USA Congress, 2010).

The second attribute is that the mineral's extraction and further manufacturing is connected to financing conflict linked to social and human rights abuses, such as forced labour (European Commission, 2017). While some authors claim that any mineral from those conflict regions are CM (Hofmann et al., 2015), this paper argues that the second necessary attribute is that social and human rights abuses are connected to its exploitation. For example, the Responsible Minerals Initiative (2018) highlights the need to use minerals from the Democratic Republic of the Congo (DRC) to create positive change resulting in a reduction of conflict and the accompanying social and human rights abuses.

"Conflict minerals," as defined by the US legislation, currently include the metals tantalum, tin, tungsten, and gold, which are the derivatives of the minerals cassiterite, columbite-tantalite and wolframite, respectively. All these Downstream companies often refer to the derivatives of these minerals as 3TG. Note: Conflict minerals can be extracted at many different locations around the world including the Democratic Republic of Congo (DRC). The SEC rules define conflict minerals as 3TG metals, wherever extracted. For example, tin extracted in Canada, Russia or Argentina is considered a conflict mineral by definition. In the SEC rule, "DRC conflict-free" is defined as minerals that were extracted and did not directly or indirectly benefit armed groups in the covered countries. Therefore, tin extracted from Canada is considered "DRC conflict-free" under the definitions of the SEC rule. The internationally recognized OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas has a broader scope and covers all minerals, not only 3TG. http://www.responsiblemineralsinitiative.org/about/faq/general-questions/what-are-conflict-minerals/

After this first step to identify the main social themes, the task within STORY was to conduct a first assessment of the social impacts of batteries used in the different demos.

Two introductory remarks:

- It clearly must be distinguished that the extraction of raw materials, the production of intermediates and the assembly of the batteries in most cases are done by different companies in different countries.
- It also has to be noted that the buyers and users of the batteries are not the manufacturers of the batteries in STORY, only in one case study, the supplier and the producer of the battery are the same (SAFT in the case study of Spain).

Despite the considerable benefits that are related to the use phase of lithium-ion batteries, there are significant impacts related to their production as we have seen in the previous chapters. The

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

materials mentioned above are not only associated with environmental but also with several social impacts. So far, the social impacts have not been investigated to a very high extent and only little material is available.

In contrast to an LCA which focuses on quantities of resources and emissions, an sLCA focuses on socio-economic interactions and analyses their organizational and societal context in the supply chain.

The main challenges for a sLCA are

- determination of appropriate indicators to measure the status of a specific theme
- data collection
- evaluation and interpretation of data

So, after the desktop research to gain an overview of the batteries and the raw materials used in the different demos within STORY, a survey among the partners in the project also showed that only little information on social issues can be gained from the information that are supplied with the Safety Data Sheets and other information provided by the battery producer.

As already said in 4.1.1. and 4.1.2, the goal of this sLCA is to identify social hotspots in the supply chain of lithium-ion batteries used in STORY and the scope is to have a look at the extraction and processing of raw materials, the production of intermediates and the assembly of the battery pack as the final product. As the batteries used in the demo cases are very different it was not possible to have ONE representative state-of-the art battery to be considered. Instead, a general assessment was done, trying to catch the most pressing issues as good as possible.

Firstly, the different stakeholder categories were analysed with regards to their possible social implications in our scope, also in accordance with literature (e.g. Thies et al., 2019). In a first assessment on social hot spots, two main subcategories have been identified with the help of the UNEP/SETAC methodological sheets (UNEP, 2013) which have the highest relevance in the countries where raw materials are being extracted and processes and the batteries and their components are being produced and assembled: unsafe working conditions (working conditions in general) and child labour.

In sLCA, one often combines a generic assessment with data from different official sources like the International Labour Organisation (ILO), the World Bank, etc. with a specific assessment where data is gained “on-site” from data published by the producers themselves and from interviews with stakeholders to include the specific context of the supply chain where social impacts depend upon. So, this would mean to conduct interviews e.g. with workers, governmental agencies, management, non-governmental organizations, and certification bodies, which was not possible for the variety of different batteries used in STORY.

For the identification of Social Hotspots data based on international institutions like the World Bank, the existing databases of the International Labour Organisation or the World Health Organisation have been used (https://ilostat.ilo.org/topics/child-labour/,

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

https://ilostat.ilo.org/topics/safety-and-health-at-work/): to get an overview on the topics of child labour and unsafe working conditions in the countries:

- China
- DR of Congo
- Brazil
- Chile
- Russia
- Indonesia
- South Africa

The data bases show that only little information is available and almost no reports on the situation in the respective countries are available.

4.2 Results and discussion

Due to the complex situation with different battery types in STORY, no comprehensive sLCA could be conducted, but several social themes could be assessed. This assessment showed that the most interesting questions are the ones concerning the raw materials of the batteries used, their origin and the circumstances under which the raw materials are extracted. Due to a lack of information, only a rough assessment could be made during the STORY project, with a need for further research in the future.

Social implications are more complex, dynamic, and regionally fragmented than most environmental impacts. To get a better insight, not only information from available data bases is needed but also on-site data would be necessary to include the specific context of the supply chain where social impacts depend upon to conduct a full social assessment. This was not possible due to several factors described in the previous chapters.

Nevertheless, some issues could be raised:

Firstly, there is certain dependency of Europe from critical raw materials and their (few) producers. For example, a look at the situation with rare earth elements (REE) shows that, although they are not rare at all and although the deposits are widely scattered around the globe, they are currently obtained almost exclusively from China because it is not economically viable for other countries.

A second issue is the fact that some raw materials are considered conflict materials, as they come from conflict-prone areas, which are often connected to social and human rights issues such as forced labour. But conflict minerals are only one area where social problems occur in supply chains (Silva & Schaltegger, 2019). Social problems are not limited to countries like the DR of Congo and they are also not limited to conflict minerals. This discussion suggests that it is necessary to better include social rights and environmental issues in the supply chain and for industry specific regulations. Conflict mineral regulations like the Dodd-Frank Wall Street Reform and Consumer Protection Act have already shown impacts on the textile and apparel industry

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

(Silva & Schaltegger, 2019) and from success and failures new approaches can be derived, not only for critical minerals but also for topics like health and safety or better working conditions.

A third issue is the research for new materials for large-scale storage devices to replace materials and processes with high (negative) social impacts. Research is being done on so called flow batteries which can store and discharge larger amounts of energy, in a safer and more durable way than their lithium-ion counterparts. Finally, organic flow batteries would even do away with the metal-containing electrolytes. Ongoing research is looking into quinones, organic compounds, as an alternative (see also STORY Highlight, May 2019).

In general, materials, such as lithium, cobalt, nickel, manganese, and graphite are mostly extracted and further processed in countries where social issues are not on top of the agenda.

A more comprehensive sLCA with data also gained on site could be useful for companies to select production locations, processes, and suppliers. But as we also know from literature (e.g. Zimmerman et al., 2015): “in an early design phase production location and even some materials are unknown and local social impacts are typically not considered.”

5 Employment creation

This chapter gives an overview of the current employment situation due to storage and PV implementation and introduced a European employment factor for the calculation of created jobs by PV.

The basis of the methodology is a combination of literature research as well as expert interviews and industry data. For an adequate analysis of future employment creation, the exact capacities of the investigated scenarios are needed as well as their different technology mixes. As the results should not depend on specific geographical areas, a European Employment Factor was created and used. This employment factor is defined by jobs per installed MW and is an overall average of employment factors across Europe. The idea behind the employment factor approach is simple: showing job effects with jobs per installed capacity times the planned size of the scenario. The basis of the analysis in STORY is Rutovitz et al. (2015), where global employment factors with two scenarios regarding electricity production are analysed.

5.1 PV

Although PV production is mainly located in Asia, PV expansion in Europe has also positive effects on the European economy as system planning and the installation of PVs are done on a local level, creating jobs regionally. These local jobs can be divided into direct jobs (installation and maintenance of the PV systems) and indirect jobs (transport, manufacturing of certain materials or services). In 2018 the number of jobs regarding PV systems (in FTE) in the EU 28 was over 117,600 and until 2021, an increase up to 174,000 is expected (SolarPOwer Europe, 2017).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

5.1.1 Employment factor

For the qualitative assessment of the job creation by PV production the concept of an employment factors is used. The focus of the method is to look at different phases of a RES and how labour intensive these phases are. The phases are manufacturing, construction/installation, and operation and maintenance. The data source for the analysis is a mixture of literature review as well as surveys and expert interviews about the current market situation in Europe. The structure of the employment factor approach is described in Figure 25.

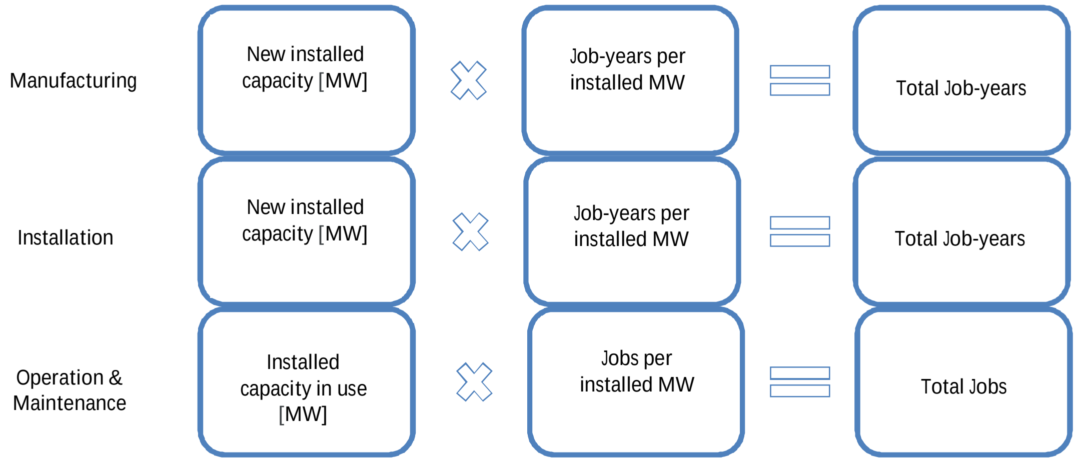


Figure 25: Employment factor approach

For the calculations, two components are important. First, scenarios with capacity values are necessary to make predictions regarding employment creation. Second, the employment factors for the three phases are required. In the table below two scenarios of Deliverable 7.3, which are also summarized in section 3.2 of this report, are presented with the respective installed power for the PV systems.

Table 17: PV scenarios for employment creation

Medium Voltage Network Scenarios	PV	
	Installed Power	Installed area
	[MW]	m^2
1) 40%RES, 5%EV, 0%Batt	12	90910
6) 110%RES, 5%EV, 0%Batt	33	250000

In Table 18 the employment factors used in the analysis are presented. Based on a literature research such as Rutowitz 2015 we present an upper and lower boundary, for further information

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

see Appendix A-5. This is necessary as many different results of research across Europe indicate different employment factors.

Table 18: PV employment factors

PV	Employment per Production Step		
	Construction in Py[5]/MW	Manufacturing in Py/MW	O&M in Jobs/MW
Lower bound	10,9	6.7	0.6
Upper bound	16,7	15.7	1.5

5.1.2 Results

The results of the employment factor approach for PV are presented in Table 19. The upper and lower bound of possible employment created for the selected scenarios can be seen.

Table 19: Employment creation due to PV implementation

PV	Manufacturing	Construction	O&M	Total jobs created	Jobs created without Manufacturing in Europe
Scenario	Jobs	Jobs	Jobs	Jobs	Jobs
1	3 - 6	4 - 7	7 - 18	14 – 31	11 – 25
6	7 - 17	12 - 18	20 – 49	39 – 84	32 – 67

In Scenario 1 an employment creation of around 14 to 31 jobs is possible for 12 MW installed. For Scenario 6 with 33 MW installed a potential job creation of 39 to 84 jobs can be expected. The last column shows all scenarios without the assumption, that the manufacturing process takes place in Europe. This represents the current situation where nearly all cells and modules are produced in Asia. With this assumption, the expected European employment creation drops to level between 11 and 25 jobs for Scenario 1 and between 32 and 67 jobs for Scenario 6.

[5] Py/MW = person years per MW

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

5.2 Storage

Currently, the biggest market share of lithium-ion batteries belongs to Asian companies, however it is expected that Europe may face the steepest growth in the coming years. In the JRC report of 2018 it is mentioned that Europe's share of the global cell manufacturing was 3% in 2018 and is expected to increase up to 7 – 25% until 2028.

The employment creation by storage is not calculated via employment factors but rather an overview of current literature estimations is given. A study from the JRC estimates the job creation potential from the production of Lithium-Ion batteries based on different previously conducted studies (Table 15). It is expected that with a competitive lithium-ion battery capability the EU could create 90 to 180 direct jobs/GWh. Along the full value chain, many more jobs are created, with an approximate ratio of 3.7 to 7.5 compared to the direct jobs (JRC, 2017).

Table 20: Job creation potential of lithium-ion cell manufacturing plants (JRC, 2017)

LIB cell production plant	Capacity (GWh/y)	Expected job creation
NPE	13	1300 direct, 3000 indirect
Tesla (Nevada)	35	6500
Panasonic (China)	2.5	500
Northvolt (SE)	32	2500-3000 direct, 20 000+ indirect
TerraE (DE)	8	400 direct
Boston Energy and Innovation (Australia)	15	1000 in manufacturing, 1000 direct support, 5000 indirect
VW (DE)	150	9000

https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108043/kjna28837enn.pdf

The NPE study[6] describes the job creation potential as follows: For a cell production of approximately 13 GWh/a, 1050-1300 jobs are created directly within the plant (production, R&D, sales, and distribution). Additionally, up to 3100 indirect jobs could be created. The number of jobs depends on the structure of the region. In structural weak areas up to 3100 jobs could be created, while in well-structured areas 1400 to 1800 additional jobs are expected (JRC, 2017).

[6] Nationale Plattform Elektromobilität: Roadmap integrierte Zell-und Batterieproduktion Deutschland, Jan. 2016

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table 21: Direct and indirect jobs in a cell manufacturing plant of 13 GWh/a (NPE, 2016)

Employees 1.050-1.300			**Indirect employees**	
Direct/indirect **production staff**	Indirect employees in **administration, purchasing, sales**	Indirect employees in **Research and Development**	Around **structurally strong regions**	Around **structurally weak regions**
Direct employees, including • Plant operators • Logistics providers • Stand-ins Indirect employees including: • Maintenance technicians • Process technicians • Shift supervisors	• Commercial staff • Technical jobs	• Engineers • Technicians • Other technical professions	• Logistics • Supplier industry • Mechanical and plant engineering	• Logistics • Supplier industry • Mechanical and plant engineering
750-900 jobs	**150-200 jobs**	**150-200 jobs**	**1.400 -1.800 jobs**	**2.100-3.100 jobs**

If the assembling of systems and modules is also taken into consideration the total number of jobs created is further increased. It is expected that in cell manufacturing the ratio of the preparatory effort is comparable to the automotive branch at around 70%. In this study, it is further assumed that the imported part is around 40% (NPE, 2016).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

6 Conclusions

This report presented an environmental and socioeconomic evaluation of large-scale network simulations including storage, PV and EVs.

Based on the presented results we draw the following conclusions for the three investigated aspects (1) life cycle assessment, (2) social life cycle assessment and (3) employment creation.

6.1 Life cycle assessment

The LCA was the most comprehensive assessment performed in this task. We investigated 8 large-scale scenarios and 4 options for generated and replaced grid electricity leading to 32 investigated cases.

The results show that different factors influence the GHG emissions of network development scenarios with PV and battery storage:

The most important factor is the amount of PV power installed in the distribution grid and the ability of the grid to transport the PV electricity. In the investigated scenarios the grid model showed no limitation in technical parameters for the LV grid. So up to the assumed amount of PV power (33 MW, in a grid model with 30 MV HV/MV transformer) curtailment is not needed in any of the scenarios. Transporting the electricity to another place in the network (“grid as a storage”) has less losses than storing the electricity in the battery system.

Also, additional GHG emissions from the manufacturing of the batteries arise, although the contribution of battery manufacturing on the total GHG emissions of the scenarios was rather low (2-11% of total GHG emissions).

The total GHG emissions of the investigated system with PV and batteries depend on the electricity system into which it is included, and which source is replaced by surplus electricity and which source provides the consumed electricity. From the investigated standardized options on consumed and replaced grid electricity, the option with the Belgian electricity mix for consumed and a natural gas CC power plant for replaced grid electricity (Option 2) had the lowest total GHG emissions.

However, the goal of the LCA was to investigate the influence of the battery. Here we saw, that in all options scenarios without battery systems have lower total GHG emissions under the investigated circumstances.

6.2 Social life cycle assessment and employment creation

The sLCA on the battery systems installed in the STORY demonstration cases, indicated that the most interesting social questions are the ones concerning the raw materials of the batteries used, their origin and the circumstances under which the raw materials are extracted.

The assessment on employment creation showed that the implementation of PV and storage can lead to significant employment opportunities on a global and European level.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

PV manufacturing is mostly located in Asia, however, jobs for construction and O&M are created in Europe. For scenario 2 (12 MW PV) this would mean on average 23 jobs created in total and 18 in Europe. For scenario 6 (33 MW PV) this corresponds to 62 jobs on average created, 49 assuming the manufacturing takes place outside of Europe.

The production of batteries is mostly located in Asia. However, it is expected that the share of lithium-ion batteries produced in Europe could increase significantly until 2030. It is estimated that 90-180 direct jobs/GWh will be created in Europe and approximately 6 times this number for indirect jobs.

6.3 Outlook

Within the STORY project additional work is performed on LCA for the demonstration cases. Here we will focus in more detail on the network penetration from PV, also showing that in grid situations, where PV curtailment is needed systems with battery storage have less GHG emissions compared to systems without battery.

The results obtained from the environmental and social analysis on large-scale storage integration fed into Task 7.5., where an overall assessment of storage integration is performed. It brings together the technical, economic, environmental, and social aspects and draws a holistic picture of storage integration into the distribution grid.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

7 Acronyms and terms

ARIMA	Autoregressive integrated moving average
Batt	Battery
CC	Combined cycle
CO_2-eq	Carbon dioxide equivalent
DoA	Description of Action, part of the project contractual obligations
EV	Electric vehicle
GHG	Greenhouse gas emissions
GWP	Global warming potential
HV	High voltage
IPCC	International panel on climate change
LCA	Life cycle assessment
LCC	Life cycle costing
LV	Low voltage
MV	Medium voltage
PV	Photovoltaics
RES	Renewable sources
RP	Report
SHDB	Social hot spot database
sLCA	Social life cycle assessment

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

8 References

Ahmed S, Nelson PA, Gallagher KG, Susarla N, Dees DW. Cost and energy demand of producing nickel manganese cobalt cathode material for lithium ion batteries. Journal of Power Sources 342: 733–740, US, 2017

Aichberger, 2019: C. Aichberger, "LCA of Automotive Batteries for Electric Vehicles – A Literature Review", Master Thesis, FH Joanneum – Energy and Transport Management, Kapfenberg, 2019.

EHPA, 2019: European heat pump association database. Available at: http://www.stats.ehpa.org/hp_sales/story_sales/ [accessed: May 20th, 2020].

ELIA, 2019: ELIA group - Belgium's transmission system operator, Data Download, 2019. [Online] Available: http://www.elia.be/en/grid-data/data-download [Accessed April, 11, 2019]

Entsoe, 2019: Entsoe Transparency Platform, Central collection and publication of electricity generation, transportation and consumption data and information for the pan-European market, 2019 [Online] Available: https://transparency.entsoe.eu/ [Accessed December, 10, 2019]

EurObserv'er, 2019a: EurObserv'ER online database. Available at: https://www.eurobserv-er.org/online-database/#, [accessed May 19th 2020].

EurObserv'er, 2019b: The state of renewable energies in Europe; edition 2019. 19th EurObserv'ER Report. Available at: https://www.eurobserv-er.org/pdf/19th-annual-overview-barometer/ [accessed May 20, 2019]

European Commission. Commission Staff Working Document, Report on Raw Materials for Battery Applications. Brussels, 2018

European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the 2017 list of Critical Raw Materials for the EU. COM (2017) 490 final. Brussels, 2017. Available at: file:///G:/STORY/papers%20on%20raw%20materials%20and%20employment/COM-2017-490-F1-EN-MAIN-PART-1.PDF

European Commission. The EU's new conflict minerals regulation, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2017:130:FULL&from=EN, Brussels, 2017 (accessed 21 December 2018).

European Union. Regulation (EU) 2017/821 of the European parliament and of the council of 17 may 2017 laying down supply chain due diligence obligations for union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas: EU, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2017: 130:FULL&from=EN Brussels, 2017 (accessed 21 December 2018).

Fischer, W., Schumann, D. Große Stromspeicher aus Sicht der Bevölkerung. Energiewirtschaftliche Tagesfragen 66. Jg. (2016) Heft 9, 2016

GRI – GLOBAL REPORTING INITATIVE. G4 Sustainability Reporting Guidelines, Reporting Principles and Standard Disclosures, Available online: https://www.globalreporting.org/resourcelibrary/GRIG4-Part1-Reporting-Principles-and-Standard-Disclosures.pdf, 2013a

GRI – GLOBAL REPORTING INITATIVE. G4 Sustainability Reporting Guidelines, Implementation Manual. 2013b. Available online: https://www.globalreporting.org/resourcelibrary/GRIG4-Part2-Implementation-Manual.pdf,

Hofmann, H., Schleper, M.C. and Blome, C. Conflict minerals and supply chain due diligence: An exploratory study of multi-tier supply chains, Journal of Business Ethics, Vol. 147, pp. 1-27, 2015

IINAS, 2017: Global Emission Model of Integrated Systems (GEMIS), Version 4.95, Internationales Institut für Nachhaltigkeitsanalysen und –strategien (IINAS). 2017. [Online] Available: http://www.iinas.org/gemis-de.html

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

IPCC, 2013: G. Myhre, D. Shindell, F.-M. Bréon, W. Collins,J. Fuglestvedt, J. Huang,D. Koch,J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, "Anthropogenic and Natural Radiative Forcing" in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Islam, M.A., Haque, S. and Roberts, R. Human rights performance disclosure by companies with operations in high risk countries: evidence from the Australian minerals sector", Australian Accounting Review, Vol. 27 No. 1, pp. 34-51, 2017

ISO 14040: EN ISO 14040 Environmental management – Life cycle assessment – Principles and framework (ISO14040:2009), 2009.

JRC, 2017: Steen, M., Lebedeva, N., Die Persio, F., Boon-Brett, L. (JRC) 2017: EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions. Available at https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108043/kjna28837enn.pdf, [accessed 15.04.2019]

Lebedova, N., Di Persio, F., Boon-Brett, L. Lithium ion battery value chain and related opportunities for Europe. JRC Science for Policy Reports, 2017

Mathieux, F. et al.Critical Raw Material and the Circular Economy, JRC Science for Policy Reports, 2017

NREL, 2018: NREL National Renewable Energy Laborators, Life Cycle GHG Emissions from Solar Photovoltaics, 2018. [Online] Available: www.nrel.gov/harmonization [Accessed December, 06, 2018].

Nowak, T. 2018 Heat Pumps: Integrating technologies to decarbonise heating and cooling. Available at: https://www.ehpa.org/fileadmin/user_upload/White_Paper_Heat_pumps.pdf, [accessed: 19.04.2019].

Peters, 2018: J. F. Peters, M. Weil, "Providing a common base for life cycle assessment of Li-Ion batteries", *Journal of Cleaner Production*, Online Supplementary Information, vol. 171, pp. 704 – 713, 2018.

Responsible Minerals Initiative. Conflict-Free sourcing initiative statement on sourcing from the Democratic Republic of the Congo and adjoining countries", 2018. available at: www.responsiblemineralsinitiative.org/about/media-news/news/in-region-sourcing/ (accessed 2 February 2018).

Rutovitz, 2015: Rutovitz, J., Dominish, E., Downes, J. Calculating global energy sector jobs: 2015 methodology update. Available at: https://opus.lib.uts.edu.au/bitstream/10453/43718/1/Rutovitzetal2015Calculatingglobalen ergysectorjob smethodology.pdf , [accessed April 20th,2019]

Silva, S., Schaltegger, St. Social assessment and management of conflict minerals: a systematic literature review", Sustainability Accounting, Management and Policy Journal, 2019. Available at: https://doi.org/10.1108/SAMPJ-02-2018-00

SolarPower Europe, 2017: Solar PV jobs & value added in Europe. Available at: https://www.solarpowereurope.org/wp-content/uploads/2018/08/Solar-PV-Jobs-Value-Added-in-Europe-November-2017.pdf [accessed April, 20, 2019].

NPE, 2016: The German National Platform for Electric Mobility (NPE). Roadmap for an Integrated Cell and Battery Production in Germany, 2016. Available at: http://nationale-plattform-elektromobilitaet.de/fileadmin/user_upload/Redaktion/Publikationen/AG2_Roadmap_Zellfertigung_eng_bf.pdf (accessed 2 February 2018).

Thies, C., Kieckhäfer, K., Spengler, T.S., Sodhi, M.S. Assessment of social sustainability hotspots in the supply chain of lithium-ion batteries, 26th CIRP Life Cycle Engineering (LCE) Conference, 2019

UNEP. Guidelines for Social Life Cycle Assessment of products, 2009, available online: http://www.unep.fr/shared/publications/pdf/DTIx1164xPA-guidelines_sLCA.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

UNEP. The Methodological Sheets for Subcategories in Social life cycle assessment (sLCA), 2013. Available at: https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/SLCA_methodological_sheets_11.11.13.pdf

UNEP. Towards a Life Cycle Sustainability Assessment: Making informed choices on products, 2011, available online: http://www.unep.org/pdf/UNEP_LifecycleInit_Dec_FINAL.pdf

US Congress. Dodd-Frank Wall Street Reform and Consumer Protection Act: U.S, US Congress, Washington, DC., 2010

Wernet, 2016: G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, „The ecoinvent database version 3 (part I): overview and methodology", *The International Journal of Life Cycle Assessment*, vol. 21, pp. 1218–1230, 2016.

Zimmermann, B., Baumann, M., Reiß, J., Rodriguez-Garcia, G., Weil, M. Social Life Cycle Assessment as a pillar of sustainability analysis of batteries: the case of LiFePO4. SETAC Europe 25th Annual Meeting, Barcelona, 2015

Zupančič, 2018: J. Zupančič, A.F. Gubina, M. Antončič and A. Tuerk, "Deliverable 7.3: Report on large scale impact simulations" STORY – added value of STORage in distribution sYstems, European Union's Horizon 2020 research and innovation programm, grant agreement No 646426, 2018. [Online] Available: http://horizon2020-story.eu/wp-content/uploads/d73_20181031.pdf [Accessed November, 19, 2018].

Important websites for chapter 4 – Social life cycle assessment

Critical Raw materials: http://criticalrawmaterials.org/critical-raw-materials/

Fair Labour Association: http://www.fairlabor.org

Global Reporting Initiative (GRI): www.globalreporting.org

International Labour Organisation (ILO): http://www.ilo.org/global/about-the-ilo/lang--en/index.htm

ISO 26000: http://www.iso.org/iso/socialresponsibility.pdf

SA 8000: www.sa8000.org

Social Hot Spots: http://socialhotspot.org

UNEP- DITE- Life Cycle and Resource Management: http://www.unep.fr/scp/lifecycle/

UNEP/SETAC Life Cycle Initiative: http://www.lifecycleinitiative.org

UN Global Compact: www.unglobalcompact.org

Universal Declaration of Human Rights (1948): http://www.ohchr.org/EN/UDHR/Documents/UDHR_Translations/eng.pdf

World Business Council for Sustainable Development (WBCSD): www.wbcsd.org/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

9 Appendices

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

A-1. Life cycle assessment: Result tables

The following tables show the results of the environmental assessment of the investigated large-scale storage implementation scenarios. In the environmental assessment GHG emissions, cumulative primary energy demand, acidification potential, ozone creation potential and particulate matter were investigated using life cycle assessment. The results were calculated on an annual basis (e.g. t CO_2-eq/year) and on a specific basis per MWh electricity demand (e.g. g CO_2-eq/MWh).

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

Greenhous gas emissions

Table-A 1: Annual GHG emissions for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement Belgian generation mix	Total
			[t CO2-eq/year]		
1_40%RES_5%EV_0%Batt	820	0	7 070	-200	7 700
2_40%RES_5%EV_15%Batt(Household)	820	60	7 110	-150	7 840
4_40%RES_5%EV_30%Batt(Household)	820	120	7 150	-130	7 960
6_110%RES_40%EV_0%Batt	2 250	0	6 790	-3 240	5 800
3_110%RES_40%EV_15%(Grid)	2 250	150	7 270	-2 930	6 730
7_110%RES_40%EV_30%(Household)	2 250	120	6 710	-3 040	6 030
9_110%RES_40%EV_80%(Household)	2 250	320	6 580	-2 680	6 470
10_110%RES_40%EV_80%(Grid)	2 250	770	5 870	-1 850	7 040

Table-A 2: Specific GHG emissions for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenarios	Total [kg CO2-eq/MWh] Expert estimate	Min	Max
1_40%RES_5%EV_0%Batt	113	97	140
2_40%RES_5%EV_15%Batt(Household)	115	98	142
4_40%RES_5%EV_30%Batt(Household)	116	100	145
6_110%RES_40%EV_0%Batt	77	65	92
3_110%RES_40%EV_15%(Grid)	89	75	107
7_110%RES_40%EV_30%(Household)	80	67	96
9_110%RES_40%EV_80%(Household)	86	71	104
10_110%RES_40%EV_80%(Grid)	93	79	117

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table-A 3: Annual GHG emissions for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement natural gas CC power plant	Total
			[t CO2-eq/year]		
1_40%RES_5%EV_0%Batt	820	0	7 070	-600	7 290
2_40%RES_5%EV_15%Batt(Household)	820	60	7 110	-460	7 530
4_40%RES_5%EV_30%Batt(Household)	820	120	7 150	-410	7 680
6_110%RES_40%EV_0%Batt	2 250	0	6 790	-9 680	-640
3_110%RES_40%EV_15%(Grid)	2 250	150	7 270	-8 760	910
7_110%RES_40%EV_30%(Household)	2 250	120	6 710	-9 110	-30
9_110%RES_40%EV_80%(Household)	2 250	320	6 580	-8 060	1 090
10_110%RES_40%EV_80%(Grid)	2 250	770	5 870	-5 510	3 380

Table-A 4: Specific GHG emissions for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + natural gas CC power plant

Scenarios	Total [kg CO2-eq/MWh]		
	Expert estimate	Min	Max
1_40%RES_5%EV_0%Batt	107	91	134
2_40%RES_5%EV_15%Batt(Household)	110	94	138
4_40%RES_5%EV_30%Batt(Household)	112	96	141
6_110%RES_40%EV_0%Batt	-9	-22	6
3_110%RES_40%EV_15%(Grid)	12	-4	29
7_110%RES_40%EV_30%(Household)	0	-15	15
9_110%RES_40%EV_80%(Household)	14	-1	32
10_110%RES_40%EV_80%(Grid)	45	29	68

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table-A 5: Annual GHG emissions for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix pumped storage power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix + pumped storage	Electricity into HV grid - pumped storage	Total
			[t CO2-eq/year]		
1_40%RES_5%EV_0%Batt	820	0	6 910	0	7 730
2_40%RES_5%EV_15%Batt(Household)	820	60	6 990	0	7 870
4_40%RES_5%EV_30%Batt(Household)	820	120	7 040	0	7 980
6_110%RES_40%EV_0%Batt	2 250	0	4 180	0	6 430
3_110%RES_40%EV_15%(Grid)	2 250	150	4 910	0	7 310
7_110%RES_40%EV_30%(Household)	2 250	120	4 250	0	6 620
9_110%RES_40%EV_80%(Household)	2 250	320	4 410	0	6 980
10_110%RES_40%EV_80%(Grid)	2 250	770	4 490	0	7 510

Table-A 6: Specific GHG emissions for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix pumped storage power plant

Scenarios	Total [kg CO2-eq/MWh]		
	Expert estimate	Min	Max
1_40%RES_5%EV_0%Batt	113	97	141
2_40%RES_5%EV_15%Batt(Household)	115	99	143
4_40%RES_5%EV_30%Batt(Household)	117	100	146
6_110%RES_40%EV_0%Batt	85	67	111
3_110%RES_40%EV_15%(Grid)	97	77	125
7_110%RES_40%EV_30%(Household)	88	69	114
9_110%RES_40%EV_80%(Household)	92	73	120
10_110%RES_40%EV_80%(Grid)	99	82	130

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table-A 7: Annual GHG emissions for large-scale storage implementation scenarios for Option 4 – Natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - natural gas CC power plant	Electricity into HV grid - replacement natural gas CC power plant	Total
	[t CO2-eq/year]				
1_40%RES_5%EV_0%Batt	820	0	21 160	-600	21 380
2_40%RES_5%EV_15%Batt(Household)	820	60	21 270	-460	21 690
4_40%RES_5%EV_30%Batt(Household)	820	120	21 380	-410	21 910
6_110%RES_40%EV_0%Batt	2 250	0	20 290	-9 680	12 860
3_110%RES_40%EV_15%(Grid)	2 250	150	21 730	-8 760	15 370
7_110%RES_40%EV_30%(Household)	2 250	120	20 050	-9 110	13 310
9_110%RES_40%EV_80%(Household)	2 250	320	19 630	-8 060	14 150
10_110%RES_40%EV_80%(Grid)	2 250	770	18 800	-5 510	16 310

Table-A 8: Specific GHG emissions for large-scale storage implementation scenarios for Option 4 – Natural gas CC power plant

Scenario	GWP [kg CO2-eq/MWh]		
	Expert estimate	Min	Max
1_40%RES_5%EV_0%Batt	313	302	342
2_40%RES_5%EV_15%Batt(Household)	317	306	347
4_40%RES_5%EV_30%Batt(Household)	321	309	351
6_110%RES_40%EV_0%Batt	170	161	186
3_110%RES_40%EV_15%(Grid)	203	192	223
7_110%RES_40%EV_30%(Household)	176	166	193
9_110%RES_40%EV_80%(Household)	187	175	207
10_110%RES_40%EV_80%(Grid)	216	199	236

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Cumulative primary energy demand

Table-A 9: Annual cumulative primary energy demand for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	PV manufacturing				Battery manufacturing				PV operation	Electricity from HV grid - Belgian electricity mix				Electricity into HV grid - replacement Belgian generation mix				Total			
	fossil	renewable	others	total	fossil	renewable	others	total	renewable	fossil	renewable	others	total	fossil	renewable	others	total	fossil	renewable	others	total
	[MWh/a]				[MWh/a]				[MWh/a]	[MWh/a]				[MWh/a]				[MWh/a]			
1_40%RES_5%EV_0%Batt	1 854	519	394	2 768	0	0	0	0	20 527	23 810	3 381	82 507	109 698	-860	-122	-2898	-3880	24 804	24 306	80 003	129 113
2_40%RES_5%EV_15%Batt(Household)	1 854	519	394	2 768	117	22	46	186	20 527	23 909	3 477	82 716	110 101	-652	-91	-2227	-2969	25 228	24 455	80 929	130 613
4_40%RES_5%EV_30%Batt(Household)	1 854	519	394	2 768	234	45	92	371	20 527	24 006	3 408	83 181	110 595	-586	-81	-2006	-2673	25 508	24 419	81 661	131 588
6_110%RES_40%EV_0%Batt	5 099	1 428	1 084	7 612	0	0	0	0	52 621	22 885	3 234	79 262	105 382	-14304	-1962	-46545	-62811	13 681	55 322	33 801	102 804
3_110%RES_40%EV_15%(Grid)	5 099	1 428	1 084	7 612	288	59	92	439	52 621	24 590	3 437	85 178	113 206	-12939	-1764	-42114	-56817	17 038	55 782	44 241	117 060
7_110%RES_40%EV_30%(Household)	5 099	1 428	1 084	7 612	234	45	92	371	52 621	22 662	3 200	78 405	104 267	-13436	-1849	-43837	-59121	14 559	55 446	35 745	105 750
9_110%RES_40%EV_80%(Household)	5 099	1 428	1 084	7 612	624	120	246	990	52 621	22 375	3 271	76 478	102 124	-11791	-1560	-39126	-52478	16 307	55 880	38 682	110 869
10_110%RES_40%EV_80%(Grid)	5 099	1 428	1 084	7 612	1 537	314	489	2 340	52 621	20 611	3 038	82 970	106 619	-8177	-1077	-26565	-35819	19 070	56 324	57 978	133 372

Table-A 10: Specific cumulative primary energy demand for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	Total			
	fossil	renewable	others	total
	[MWh/MWh]			
1_40%RES_5%EV_0%Batt	0.36	0.36	1.17	1.89
2_40%RES_5%EV_15%Batt(Household)	0.37	0.36	1.18	1.91
4_40%RES_5%EV_30%Batt(Household)	0.37	0.36	1.19	1.93
6_110%RES_40%EV_0%Batt	0.18	0.73	0.45	1.36
3_110%RES_40%EV_15%(Grid)	0.23	0.74	0.59	1.55
7_110%RES_40%EV_30%(Household)	0.19	0.73	0.47	1.40
9_110%RES_40%EV_80%(Household)	0.22	0.74	0.51	1.47
10_110%RES_40%EV_80%(Grid)	0.25	0.74	0.77	1.76

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table-A 11: Annual cumulative primary energy demand for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + natural gas CC power plant

Scenario	PV manufacturing				Battery manufacturing				PV operation	Electricity from HV grid - Belgian electricity mix				Electricity into HV grid - replacement natural gas CC power plant				Total			
	fossil	renewable	others	total	fossil	renewable	others	total	renewable	fossil	renewable	others	total	fossil	renewable	others	total	fossil	renewable	others	total
	[MWh/a]				[MWh/a]				[MWh/a]	[MWh/a]				[MWh/a]				[MWh/a]			
1_40%RES_5%EV_0%Batt	1 854	519	394	2 768	0	0	0	0	20 527	23 810	3 381	82 507	109 698	-2 839	-2	-5	-2 845	22 826	24 426	82 896	130 148
2_40%RES_5%EV_15%Batt(Household)	1 854	519	394	2 768	117	22	46	186	20 527	23 909	3 477	82 716	110 101	-2 166	-1	-4	-2 171	23 714	24 545	83 152	131 411
4_40%RES_5%EV_30%Batt(Household)	1 854	519	394	2 768	234	45	92	371	20 527	24 006	3 408	83 181	110 595	-1 949	-1	-3	-1 953	24 145	24 499	83 664	132 308
6_110%RES_40%EV_0%Batt	5 099	1 428	1 084	7 612	0	0	0	0	52 621	22 885	3 234	79 262	105 382	-46 079	-25	-77	-46 180	-18 094	57 259	80 270	119 434
3_110%RES_40%EV_15%(Grid)	5 099	1 428	1 084	7 612	288	59	92	439	52 621	24 590	3 437	85 178	113 206	-41 672	-22	-69	-41 763	-11 695	57 523	86 285	132 114
7_110%RES_40%EV_30%(Household)	5 099	1 428	1 084	7 612	234	45	92	371	52 621	22 662	3 200	78 405	104 267	-43 367	-23	-72	-43 463	-15 373	57 271	79 510	121 408
9_110%RES_40%EV_80%(Household)	5 099	1 428	1 084	7 612	624	120	246	990	52 621	22 375	3 271	76 478	102 124	-38 337	-21	-64	-38 421	-10 239	57 420	77 745	124 925
10_110%RES_40%EV_80%(Grid)	5 099	1 428	1 084	7 612	1 537	314	489	2 340	52 621	20 611	3 038	82 970	106 619	-26 232	-14	-44	-26 290	1 015	57 387	84 500	142 901

Table-A 12: Specific cumulative primary energy demand for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + natural gas CC power plant

Scenario	Total			
	fossil	renewable	others	total
	[MWh/MWh]			
1_40%RES_5%EV_0%Batt	0.33	0.36	1.21	1.90
2_40%RES_5%EV_15%Batt(Household)	0.35	0.36	1.22	1.92
4_40%RES_5%EV_30%Batt(Household)	0.35	0.36	1.22	1.94
6_110%RES_40%EV_0%Batt	-0.24	0.76	1.06	1.58
3_110%RES_40%EV_15%(Grid)	-0.15	0.76	1.14	1.75
7_110%RES_40%EV_30%(Household)	-0.20	0.76	1.05	1.61
9_110%RES_40%EV_80%(Household)	-0.14	0.76	1.03	1.65
10_110%RES_40%EV_80%(Grid)	0.01	0.76	1.12	1.89

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table-A 13: Annual cumulative primary energy demand for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix + pumped storage power plant

Scenario	PV manufacturing				Battery manufacturing				PV operation	Electricity from HV grid - Belgian generation mix + pumped storage				Electricity into HV grid - pumped storage				Total			
	fossil	renewable [MWh/a]	others	total	fossil	renewable [MWh/a]	others	total	renewable [MWh/a]	fossil	renewable [MWh/a]	others	total	fossil	renewable [MWh/a]	others	total	fossil	renewable [MWh/a]	others	total
1_40%RES_5%EV_0%Batt	1 854	519	394	2 768	0	0	0	0	20 527	23 100	3 287	80 253	106 639	9	1	1	12	24 963	24 335	80 648	129 946
2_40%RES_5%EV_15%Batt(Household)	1 854	519	394	2 768	117	22	46	186	20 527	23 366	3 276	81 188	107 830	7	1	1	9	25 345	24 346	81 629	131 320
4_40%RES_5%EV_30%Batt(Household)	1 854	519	394	2 768	234	45	92	371	20 527	23 517	3 344	81 634	108 495	6	1	1	8	25 612	24 436	82 121	132 169
6_110%RES_40%EV_0%Batt	5 099	1 428	1 084	7 612	0	0	0	0	52 621	11 349	1 694	42 704	55 747	152	20	16	188	16 600	55 763	43 805	116 168
3_110%RES_40%EV_15%(Grid)	5 099	1 428	1 084	7 612	288	59	92	439	52 621	14 159	2 058	52 070	68 287	138	18	15	170	19 684	56 184	53 260	129 128
7_110%RES_40%EV_30%(Household)	5 099	1 428	1 084	7 612	234	45	92	371	52 621	11 804	1 752	43 993	57 549	143	18	15	177	17 281	55 865	45 185	118 330
9_110%RES_40%EV_80%(Household)	5 099	1 428	1 084	7 612	624	120	246	990	52 621	12 750	1 949	46 232	60 931	127	16	13	156	18 600	56 135	47 576	122 310
10_110%RES_40%EV_80%(Grid)	5 099	1 428	1 084	7 612	1 537	314	489	2 340	52 621	14 349	2 178	60 305	76 832	87	11	9	107	21 072	56 553	61 887	139 511

Table-A 14: Specific cumulative primary energy demand for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix + pumped storage power plant

Scenario	Total			
	fossil	renewable [MWh/MWh]	others	total
1_40%RES_5%EV_0%Batt	0.37	0.36	1.18	1.90
2_40%RES_5%EV_15%Batt(Household)	0.37	0.36	1.19	1.92
4_40%RES_5%EV_30%Batt(Household)	0.37	0.36	1.20	1.93
6_110%RES_40%EV_0%Batt	0.22	0.74	0.58	1.54
3_110%RES_40%EV_15%(Grid)	0.26	0.74	0.70	1.71
7_110%RES_40%EV_30%(Household)	0.23	0.74	0.60	1.56
9_110%RES_40%EV_80%(Household)	0.25	0.74	0.63	1.62
10_110%RES_40%EV_80%(Grid)	0.28	0.75	0.82	1.84

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Table-A 15: Annual cumulative primary energy demand for large-scale storage implementation scenarios for Option 4 – Natural gas CC power plant

Scenario	PV manufacturing [MWh/a]				Battery manufacturing [MWh/a]				PV operation [MWh/a]	Electricity from HV grid - natural gas CC power plant [MWh/a]				Electricity into HV grid - replacement natural gas CC power plant [MWh/a]				Total [MWh/a]			
	fossil	renewable	others	total	fossil	renewable	others	total	renewable	fossil	renewable	others	total	fossil	renewable	others	total	fossil	renewable	others	total
1_40%RES_5%EV_0%Batt	1 854	519	394	2 768	0	0	0	0	20 527	100 403	80	185	100 668	-2 839	-2	-5	-2 845	99 418	21 126	574	121 118
2_40%RES_5%EV_15%Batt(Household)	1 854	519	394	2 768	117	22	46	186	20 527	100 930	81	186	101 196	-2 166	-1	-4	-2 171	100 735	21 149	623	122 507
4_40%RES_5%EV_30%Batt(Household)	1 854	519	394	2 768	234	45	92	371	20 527	101 464	81	187	101 732	-1 949	-1	-3	-1 953	101 603	21 172	670	123 445
6_110%RES_40%EV_0%Batt	5 099	1 428	1 084	7 612	0	0	0	0	52 621	96 294	77	177	96 548	-46 079	-25	-77	-46 180	55 314	54 102	1 185	110 601
3_110%RES_40%EV_15%(Grid)	5 099	1 428	1 084	7 612	288	59	92	439	52 621	103 110	83	190	103 383	-41 672	-22	-69	-41 763	66 826	54 169	1 297	122 291
7_110%RES_40%EV_30%(Household)	5 099	1 428	1 084	7 612	234	45	92	371	52 621	95 134	76	175	95 385	-43 367	-23	-72	-43 463	57 099	54 147	1 280	112 527
9_110%RES_40%EV_80%(Household)	5 099	1 428	1 084	7 612	624	120	246	990	52 621	93 160	75	171	93 406	-38 337	-21	-64	-38 421	60 546	54 223	1 438	116 207
10_110%RES_40%EV_80%(Grid)	5 099	1 428	1 084	7 612	1 537	314	489	2 340	52 621	89 187	71	164	89 423	-26 232	-14	-44	-26 290	69 591	54 421	1 694	125 705

Table-A 16: Specific cumulative primary energy demand for large-scale storage implementation scenarios for Option 4 – Natural gas CC power plant

Scenario	Total [MWh/MWh]			
	fossil	renewable	others	total
1_40%RES_5%EV_0%Batt	1.45	0.31	0.01	1.77
2_40%RES_5%EV_15%Batt(Household)	1.47	0.31	0.01	1.79
4_40%RES_5%EV_30%Batt(Household)	1.49	0.31	0.01	1.81
6_110%RES_40%EV_0%Batt	0.73	0.72	0.02	1.46
3_110%RES_40%EV_15%(Grid)	0.88	0.72	0.02	1.62
7_110%RES_40%EV_30%(Household)	0.76	0.72	0.02	1.49
9_110%RES_40%EV_80%(Household)	0.80	0.72	0.02	1.54
10_110%RES_40%EV_80%(Grid)	0.92	0.72	0.02	1.66

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Acidification potential

Table-A 17: Acidification potential for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement Belgian generation mix	Total	Total
	[t SO2-eq/year]					[g SO2-eq/MWh]
1_40%RES_5%EV_0%Batt	4	0	12	0	16	230
2_40%RES_5%EV_15%Batt(Household)	4	1	12	0	17	250
4_40%RES_5%EV_30%Batt(Household)	4	2	12	0	18	270
6_110%RES_40%EV_0%Batt	11	0	12	-6	17	220
3_110%RES_40%EV_15%(Grid)	11	2	13	-5	20	270
7_110%RES_40%EV_30%(Household)	11	2	12	-5	19	250
9_110%RES_40%EV_80%(Household)	11	6	11	-5	23	300
10_110%RES_40%EV_80%(Grid)	11	11	9	-3	27	360

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Table-A 18: Acidification potential for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + Natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
			[t SO2-eq/year]			[g SO2-eq/MWh]
1_40%RES_5%EV_0%Batt	4	0	12	0	16	230
2_40%RES_5%EV_15%Batt(Household)	4	1	12	0	17	250
4_40%RES_5%EV_30%Batt(Household)	4	2	12	0	18	270
6_110%RES_40%EV_0%Batt	11	0	12	-7	16	210
3_110%RES_40%EV_15%(Grid)	11	2	13	-6	19	250
7_110%RES_40%EV_30%(Household)	11	2	12	-7	18	240
9_110%RES_40%EV_80%(Household)	11	6	11	-6	22	290
10_110%RES_40%EV_80%(Grid)	11	11	9	-4	26	350

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Table-A 19: Acidification potential for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix + pumped storage power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix + pumped storage	Electricity into HV grid - pumped storage	Total	Total
	[t SO2-eq/year]					[g SO2-eq/MWh]
1_40%RES_5%EV_0%Batt	4	0	12	0	16	230
2_40%RES_5%EV_15%Batt(Household)	4	1	12	0	17	250
4_40%RES_5%EV_30%Batt(Household)	4	2	12	0	18	270
6_110%RES_40%EV_0%Batt	11	0	7	0	18	240
3_110%RES_40%EV_15%(Grid)	11	2	9	0	21	280
7_110%RES_40%EV_30%(Household)	11	2	7	0	20	270
9_110%RES_40%EV_80%(Household)	11	6	8	0	24	320
10_110%RES_40%EV_80%(Grid)	11	11	7	0	28	370

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Table-A 20: Acidification potential for large-scale storage implementation scenarios for Option 4 – natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - natural gas CC power plant	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
			[t SO2-eq/year]			[g SO2-eq/MWh]
1_40%RES_5%EV_0%Batt	4	0	16	0	19	280
2_40%RES_5%EV_15%Batt(Household)	4	1	16	0	20	300
4_40%RES_5%EV_30%Batt(Household)	4	2	16	0	21	310
6_110%RES_40%EV_0%Batt	11	0	15	-7	19	250
3_110%RES_40%EV_15%(Grid)	11	2	16	-6	22	300
7_110%RES_40%EV_30%(Household)	11	2	15	-7	21	280
9_110%RES_40%EV_80%(Household)	11	6	14	-6	25	330
10_110%RES_40%EV_80%(Grid)	11	11	14	-4	31	420

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Ozone creation potential

Table-A 21: Ozone creation potential for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement Belgian generation mix	Total	Total
			[t C2H4-eq/year]			[g C2H4-eq/MWh]
1_40%RES_5%EV_0%Batt	2.9	0.0	17.0	-0.4	19.5	290
2_40%RES_5%EV_15%Batt(Household)	2.9	0.2	17.1	-0.3	19.9	290
4_40%RES_5%EV_30%Batt(Household)	2.9	0.4	17.2	-0.3	20.2	300
6_110%RES_40%EV_0%Batt	8.0	0.0	16.3	-5.1	19.2	250
3_110%RES_40%EV_15%(Grid)	8.0	0.5	17.5	-4.6	21.3	280
7_110%RES_40%EV_30%(Household)	8.0	0.4	16.1	-4.8	19.7	260
9_110%RES_40%EV_80%(Household)	8.0	1.1	15.8	-4.2	20.6	270
10_110%RES_40%EV_80%(Grid)	8.0	2.6	13.0	-2.9	20.7	270

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table-A 22: Ozone creation potential for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + Natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
			[t C2H4-eq/year]			[g C2H4-eq/MWh]
1_40%RES_5%EV_0%Batt	2.9	0.0	17.0	-0.9	19.0	280
2_40%RES_5%EV_15%Batt(Household)	2.9	0.2	17.1	-0.7	19.5	290
4_40%RES_5%EV_30%Batt(Household)	2.9	0.4	17.2	-0.6	19.9	290
6_110%RES_40%EV_0%Batt	8.0	0.0	16.3	-14.0	10.3	140
3_110%RES_40%EV_15%(Grid)	8.0	0.5	17.5	-12.6	13.3	180
7_110%RES_40%EV_30%(Household)	8.0	0.4	16.1	-13.1	11.3	150
9_110%RES_40%EV_80%(Household)	8.0	1.1	15.8	-11.6	13.2	170
10_110%RES_40%EV_80%(Grid)	8.0	2.6	13.0	-7.9	15.6	210

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Table-A 23: Ozone creation potential for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix + pumped storage power plant

Scenario	PV manufacturing	Battery manufacturing	from HV grid - Belgian generation	Electricity into HV grid - pumped storage	Total	Total
			[t C2H4-eq/year]			[g C2H4-eq/MWh]
1_40%RES_5%EV_0%Batt	2.9	0.0	16.6	0.0	19.5	290
2_40%RES_5%EV_15%Batt(Household)	2.9	0.2	16.8	0.0	19.9	290
4_40%RES_5%EV_30%Batt(Household)	2.9	0.4	16.9	0.0	20.2	300
6_110%RES_40%EV_0%Batt	8.0	0.0	10.0	0.0	18.0	240
3_110%RES_40%EV_15%(Grid)	8.0	0.5	11.8	0.0	20.2	270
7_110%RES_40%EV_30%(Household)	8.0	0.4	10.2	0.0	18.6	250
9_110%RES_40%EV_80%(Household)	8.0	1.1	10.6	0.0	19.6	260
10_110%RES_40%EV_80%(Grid)	8.0	2.6	9.9	0.0	20.5	270

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Table-A 24: Ozone creation potential for large-scale storage implementation scenarios for Option 4 – natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - natural gas CC power plant	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
	[t C2H4-eq/year]					[g C2H4-eq/MWh]
1_40%RES_5%EV_0%Batt	2.9	0.0	30.7	-0.9	32.8	480
2_40%RES_5%EV_15%Batt(Household)	2.9	0.2	30.9	-0.7	33.3	490
4_40%RES_5%EV_30%Batt(Household)	2.9	0.4	31.1	-0.6	33.8	490
6_110%RES_40%EV_0%Batt	8.0	0.0	29.5	-14.0	23.5	310
3_110%RES_40%EV_15%(Grid)	8.0	0.5	31.6	-12.6	27.4	360
7_110%RES_40%EV_30%(Household)	8.0	0.4	29.1	-13.1	24.4	320
9_110%RES_40%EV_80%(Household)	8.0	1.1	28.5	-11.6	25.9	340
10_110%RES_40%EV_80%(Grid)	8.0	2.6	27.3	-7.9	29.9	400

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Particulate matter

Table-A 25: Particulate matter for large-scale storage implementation scenarios for Option 1 – Belgian electricity mix

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement Belgian generation mix	Total	Total
			[t/year]			[g/MWh]
1_40%RES_5%EV_0%Batt	1.9	0.0	1.7	0.0	3.5	50
2_40%RES_5%EV_15%Batt(Household)	1.9	0.1	1.7	0.0	3.6	50
4_40%RES_5%EV_30%Batt(Household)	1.9	0.2	1.7	0.0	3.8	60
6_110%RES_40%EV_0%Batt	5.2	0.0	1.6	-0.8	6.0	80
3_110%RES_40%EV_15%(Grid)	5.2	0.3	1.7	-0.7	6.5	90
7_110%RES_40%EV_30%(Household)	5.2	0.2	1.6	-0.7	6.3	80
9_110%RES_40%EV_80%(Household)	5.2	0.6	1.6	-0.7	6.7	90
10_110%RES_40%EV_80%(Grid)	5.2	1.8	0.9	-0.4	7.4	100

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Table-A 26: Particulate matter for large-scale storage implementation scenarios for Option 2 – Belgian electricity mix + Natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - Belgian generation mix	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
			[t/year]			[g/MWh]
1_40%RES_5%EV_0%Batt	1.9	0.0	1.7	0.0	3.6	50
2_40%RES_5%EV_15%Batt(Household)	1.9	0.1	1.7	0.0	3.7	50
4_40%RES_5%EV_30%Batt(Household)	1.9	0.2	1.7	0.0	3.8	60
6_110%RES_40%EV_0%Batt	5.2	0.0	1.6	-0.1	6.7	90
3_110%RES_40%EV_15%(Grid)	5.2	0.3	1.7	-0.1	7.1	90
7_110%RES_40%EV_30%(Household)	5.2	0.2	1.6	-0.1	6.9	90
9_110%RES_40%EV_80%(Household)	5.2	0.6	1.6	-0.1	7.2	100
10_110%RES_40%EV_80%(Grid)	5.2	1.8	0.9	-0.1	7.8	100

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Table-A 27: Particulate matter for large-scale storage implementation scenarios for Option 3 – Belgian electricity mix + pumped storage power plant

Scenario	PV manufacturing	Battery manufacturing	from HV grid - Belgian generation	Electricity into HV grid - pumped storage	Total	Total
			[t/year]			[g/MWh]
1_40%RES_5%EV_0%Batt	1.9	0.0	1.6	0.0	3.5	50
2_40%RES_5%EV_15%Batt(Household)	1.9	0.1	1.7	0.0	3.7	50
4_40%RES_5%EV_30%Batt(Household)	1.9	0.2	1.7	0.0	3.8	60
6_110%RES_40%EV_0%Batt	5.2	0.0	1.0	0.0	6.2	80
3_110%RES_40%EV_15%(Grid)	5.2	0.3	1.2	0.0	6.7	90
7_110%RES_40%EV_30%(Household)	5.2	0.2	1.0	0.0	6.4	80
9_110%RES_40%EV_80%(Household)	5.2	0.6	1.0	0.0	6.8	90
10_110%RES_40%EV_80%(Grid)	5.2	1.8	0.7	0.0	7.7	100

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

Table-A 28: Particulate matter for large-scale storage implementation scenarios for Option 4 – natural gas CC power plant

Scenario	PV manufacturing	Battery manufacturing	Electricity from HV grid - natural gas CC power plant	Electricity into HV grid - replacement natural gas CC power plant	Total	Total
			[t/year]			[g/MWh]
1_40%RES_5%EV_0%Batt	1.9	0.0	0.7	0.0	2.6	40
2_40%RES_5%EV_15%Batt(Household)	1.9	0.1	0.7	0.0	2.7	40
4_40%RES_5%EV_30%Batt(Household)	1.9	0.2	0.7	0.0	2.8	40
6_110%RES_40%EV_0%Batt	5.2	0.0	0.7	-0.1	5.8	80
3_110%RES_40%EV_15%(Grid)	5.2	0.3	0.8	-0.1	6.2	80
7_110%RES_40%EV_30%(Household)	5.2	0.2	0.7	-0.1	6.0	80
9_110%RES_40%EV_80%(Household)	5.2	0.6	0.7	-0.1	6.4	80
10_110%RES_40%EV_80%(Grid)	5.2	1.8	0.7	-0.1	7.5	100

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

A-2. Overview on battery installations in STORY demonstration sites

The following table gives an overview on the battery installation in STORY demonstration sites including type of battery, supplier, and producer.

Table-A 29: Overview on battery installations in STORY demonstration sites

	Demo 1	Demo 2		Demo 3	Demo 5	Demo 6
	Demonstration in residential building	Demonstrating roll out of a neighbourhood		Demonstration of storage in a factory	Demonstration of flexibility and robustness of large scale storage unit	Demonstration of roll out of private multi energy grid in industrial area
Location	Oud-Heverlee, Belgium	Oud-Heverlee, Belgium		Navarra, Spain	Suha (+ EG Headquarters), Slovenia	Olen, Belgium
Battery type	Lead-Acid AGM EnerSys PowerSafe SBS 480 46 kWh	Lithium-Ion Polymer LG JH3 90 kWh	Lithium-Iron Phosphate 5x BYD B-BOX 10.0 50 kWh	Li-Ion NCA (VL45E cells) Graphite-based anode Nickel oxide-based cathode Electrolyte: blend of carbonates solvents+LiPF6 50 kW, 222 kWh	Li-Ion, NMC 170 kW, 365 kWh	24 Rolls batteries, lead-acid, total 101 kWh (60% dischargeable, 60.7 kWh useful capacity)
Supplier	Enion	ABB	Th!nk E	SAFT	ABB	Enion
Producer	EnerSys	LG-Chem	BYD		LG-Chem Korea	Surrette Battery Company (Rolls Battery Engineering)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

A-3. Survey on battery and energy storage system data

For the work on the environmental and social analysis in the STORY project (Subtask 6.2.8., Task 7.4.) data on the batteries involved in the demonstration projects and used in Task 7.3. Large scale impact simulation was collected.

Therefore a survey was conducted.

This Appendices shows the survey, and collected data for the STORY demonstration case in Navarra, Spain and for a Tesla power wall, which was used in the large-scale impact assessment.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Survey on battery and energy storage system data

Dear STORY partners!

For our work on the environmental and social analysis in the STORY project (Subtask 6.2.8., Task 7.4.) we collect data on the batteries involved in the demonstration projects and used in Task 7.3. Large scale impact simulation.

Please fill out the tables below and send the document back to Johanna.pucker@joanneum.at

Thank you.

General data

Demo site	
Battery type (e.g. Li-Ion, Lead-Acid,…)	
Cell chemistry (e.g. LFP, LTO, NCM, NCA, LMO,…)	
Which other parts are included in your energy storage system beside the battery? (E.g. BMS, container, control unit,…)	

Technical battery parameters

Technical parameters	**Unit**		**Source[1)]**
Charging/discharging power	[kW]		
Storage capacity	[kWh]		
Storage volume	[m^3]		
Volumetric energy density	[Wh/m^3]		
Gravimetric energy density	[Wh/kg]		
Efficiency factor per cycle	[-]		
Lifetime	[cycles]		
Lifetime	[years]		

[1)] especially, if literature data is used (e.g. for the Tesla-Power Wall)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

Project STORY - H2020-LCE-2014-3

Materials

- Which (raw) materials does the battery contain? Can you provide the material composition in mass-%?
- Where do the raw materials come from?
- Are there any materials of concern involved (e.g. raw material from a conflict-affected and high-risk region or materials that might be linked to social and human rights abuse)?

Battery purchasing

- Who was the supplier of the battery?
- Who is the battery producer?

Employment

- Are any data regarding employment available? E.g. How many employees worked on the different stages (production, installation, and maintenance)?

Abbreviations

LFP	Lithium-Iron-Phosphate with graphite anode
LTO	Lithium-Iron-Phosphate with lithium-titanate anode
NCM	Lithium-Nickel-Cobalt Manganese Oxide with graphite anode
NCA	Lithium-Nickel-Cobalt-Aluminium-Oxide with graphite anode
LMO	Lithium-Manganese Oxide with graphite anode

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426

Survey results for the demonstration case in Navarra, Spain

General data

Demo site	Exkal Factory
Battery type (e.g. Li-Ion, Lead-Acid,…)	Li-ion (SAFT battery indoor)
Cell chemistry (e.g. LFP, LTO, NCM, NCA, LMO,…)	NCA (VL45E cells) Graphite-based anode Nickel oxide-based cathode Electrolyte: blend of carbonates solvents+$LiPF_6$
Which other parts are included in your energy storage system beside the battery? (E.g. BMS, container, control unit,…)	BMS (by SAFT) Power Converter Unit (by Cinergia) Control Unit based on Siemens PLC (developed by CENER for STORY) Cabinet

Technical battery parameters

Technical parameters	**Unit**		**Source**
Charging/discharging power	[kW]	Approx. 50 kW	
Storage capacity	[kWh]	222	
Storage volume	[m^3]	0.018 m3	Based on size of Synerion 24E module
Volumetric energy density	[Wh/m^3]	313 Wh/dm^3	VL45E cell
Gravimetric energy density	[Wh/kg]	149	VL45E cell
Efficiency factor per cycle	[-]	97%	DC Roundtrip Efficiency
Lifetime	[cycles]	>4.000	
Lifetime	[years]	>15 years	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

Materials

- Which (raw) materials does the battery contain? Can you provide the material composition in mass-%?
  Usually cathode basic composition is $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ (Li 7.22%, Ni 48.88%, Co 9.2%, Al 1.4%, O 33.3%)
  The anode is made of graphite which is basically C but the contribution to the overall battery composition is unknown.

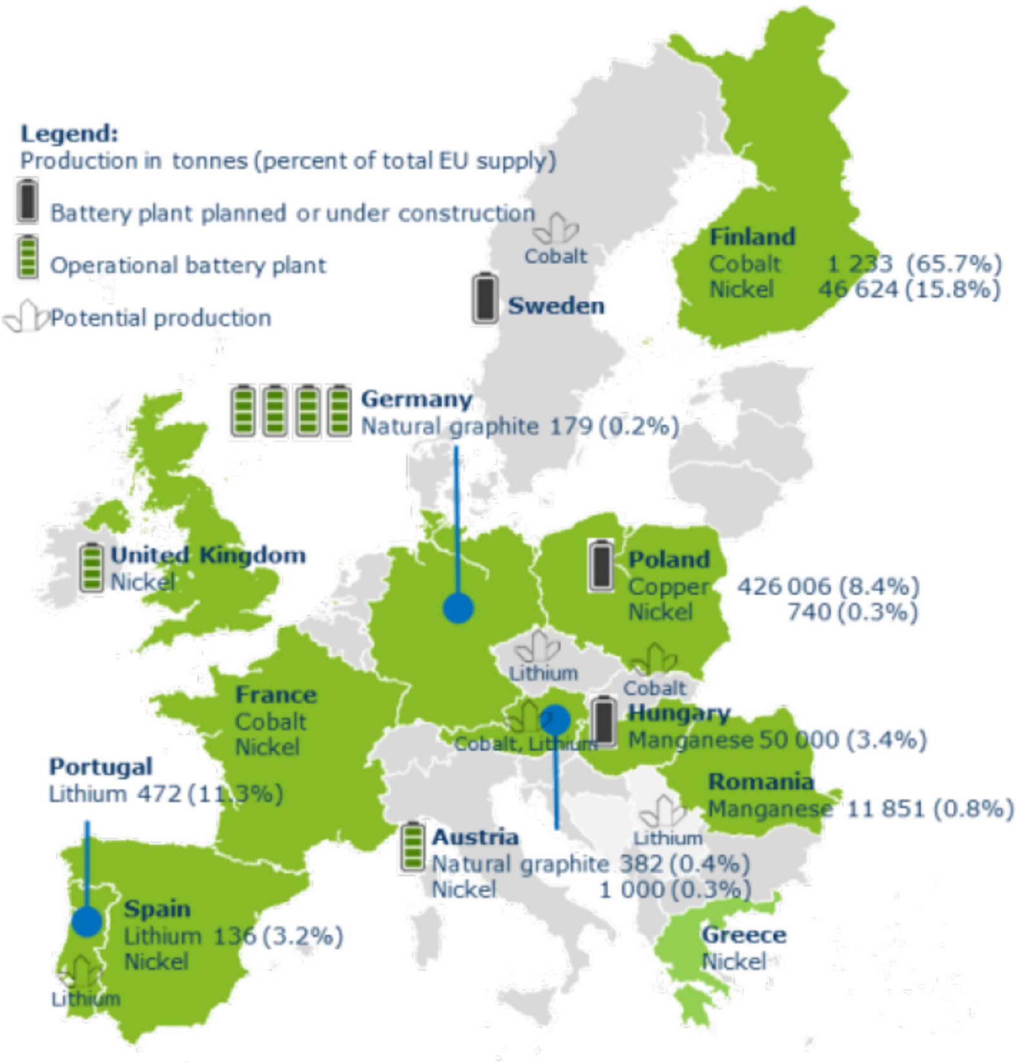
- Where do the raw materials come from?
  A majority of the raw materials in EU come from Democratic Republic of Congo, Russia, Chile and Brazil but the demand increase for EV Li-ion batteries is increasing the prices of Li and Co salts and there is no price transparency in those markets. In the last year new production sites are being explored to respond to the expected demand according to the article:

https://www.metalbulletin.com/Article/3825438/The-lithium-ion-battery-boom-and-its-impact-on-raw-material-markets.html

- Are there any materials of concern involved (e.g. raw material from a conflict-affected and high-risk region or materials that might be linked to social and human rights abuse)?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

There are 4 main raw materials Li, Co, Ni, and graphite. Among the materials used in Li-ion cells, three are listed as critical raw materials (CRMs) by the European Commission namely, cobalt, natural graphite, and silicon (metal). Lithium is not a CRM but has an increasing relevancy for the Li-ion battery industry.
Main concerns are natural graphite with 69% of the global supply from China and cobalt with 64% of global supply from Democratic Republic of Congo.



Source: EU Criticality assessment 2017

Ref. COMMISSION STAFF WORKING DOCUMENT Report on Raw Materials for Battery Applications

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

The cobalt supply chain is at risk because of political instability and concentration in the Democratic Republic of Congo. But other factors such as the capacity to produce the battery-grade materials can be a risk.

Battery purchasing

- Who was the supplier of the battery?
  SAFT, a wholly owned subsidiary of Total
- Who is the battery producer?
  SAFT

Employment

- Are any data regarding employment available? E.g. How many employees worked on the different stages (production, installation, and maintenance)?

4300 people worldwide from 49 countries, 1.5% PhDs. 14 manufacturing sites

Abbreviations

LFP	Lithium-Iron-Phosphate with graphite anode
LTO	Lithium-Iron-Phosphate with lithium-titanate anode
NCM	Lithium-Nickel-Cobalt Manganese Oxide with graphite anode
NCA	Lithium-Nickel-Cobalt-Aluminium-Oxide with graphite anode
LMO	Lithium-Manganese Oxide with graphite anode

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

Survey results for the Tesla power wall

General data

Demo site	
Battery type (e.g. Li-Ion, Lead-Acid,…)	Li-ion
Cell chemistry (e.g. LFP, LTO, NCM, NCA, LMO,…)	NCM
Which other parts are included in your energy storage system beside the battery? (E.g. BMS, container, control unit,…)	BMS, cabinet, converter, programmable control

Technical battery parameters

Technical parameters	**Unit**		**Source**
Charging/discharging power	[kW]	5 kW	Reference 1, Reference 2
Storage capacity	[kWh]	14 kWh (13.5 kWh useful)	
Storage volume	[m³]	0.134 (Total volume)	
Volumetric energy density	[Wh/m³]	104 Wh/dm³	Based on system dimensions
Gravimetric energy density	[Wh/kg]	112	Based on system dimensions
Efficiency factor per cycle	[-]	92.5% DC roundtrip efficiency	
Lifetime	[cycles]	~5.000	
Lifetime	[years]	10-years warranted	

Reference 1: https://cleantechnica.com/2019/01/19/everything-you-need-to-know-about-the-powerwall-2-2019-edition/
Reference 2: https://cleantechnica.com/2015/05/07/38000-tesla-powerwall-reservations-in-under-a-week-tesla-elon-musk-transcript/

Materials

- Which (raw) materials does the battery contain? Can you provide the material composition in mass-%?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

The specific composition for cathode is not known but assuming NCM 622, $LiNi_{0.6}Co_{0.2}Mn_{0.2}O_2$ (Li 7.16%, Ni 36.33%, Co 12.16%, Mn 11.33%, O 33.02%)
The anode is made of graphite which is basically C but the contribution to the overall battery composition is unknown.

A-4. The social acceptability of Smart Grids

The following information was taken from the Smart Grid Vendée project, where Actility/Flexcity was a partner. The “Smart Grid Vendée” project aimed at experimenting with new solutions for controlling and modernizing the distribution of electricity at the Vendée department (in the Western part of France). Over a period of 5 years, this “open-air laboratory” involved more than 150 local authorities, companies, start-ups, researchers, engineers and teachers, with the aim to test new solutions, paving the way for the power grid of tomorrow (https://www.enedis.fr/smart-grid-vendee-0).

Insights from the „Smart Grid Vendee” project

Since installing a Smart Grid device in a building could lead to overheating or water heater shutdowns, it is important to know how the occupants accommodate these potential inconveniences, or if they even want to accept them.

This report aimed to support a consortium of industrial and energy operators (Enedis, Engie, General Electric, Legrand, RTE, Actility) and an energy syndicate (SyDEV) in the experimentation of Smart Grids (SG) in public buildings of the French department Vendée. The objective was both to "educate users about smart grids and their implications", and to "test their acceptability by elected officials, managers and users in the public buildings concerned".

In 2014, at the launch of the study, the notion of social acceptability was already very present in the debates on energy. Politics as well as industrialists had noticed a rise of controversy over certain environmental projects. The debate on the impact of wind farms on the landscape, for example, was growing in the Vendée territory, the one on the Linky meter was emerging.

At the launch of the project, the positioning of industry on the role to be given to users was already under discussion within the consortium:

- for some, the Smart Grids were first and foremost a technical device and should remain so: they aimed first to introduce a more flexible management of the electrical system to manage the constraints of the intermittency of renewable energies. This should remain transparent to the user.
- for others, conversely, it was necessary to create membership, avoid the rejection of constraints and therefore consider the point of view of the users to assess how far they could impose.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 646426

- For the latter, it was necessary to take advantage of this opportunity to involve the user to have more responsible energy practices. The Smart Grids had to be an opportunity to make it a "consum'actor".

Under this emerging term, it was hypothesized that it would be a responsive individual who was potentially receptive to price incentives, capable of contributing to the consumption reduction of peaks by modulating his demand and moving his usages over time, in order to take part in the balance of the electricity network. The responsible consumer could therefore also respond to signals such as network congestion, the origin of electricity (renewable or not), etc.

This underpinned the idea that the implementation of Smart Grids could change the behaviour of users with regards to their energy consumption and have them act more environmental sustainably.

It is therefore appropriate to go beyond this too simplistic vision of the impact of technology on behaviour because it does not allow thinking the relations between the respective spheres of technology and social. For the sociologist, the object is therefore more about the use of this technological innovation, the way in which individuals appropriate (or not) Smart Grids. It is through this detour that we can interpret the role it can play in the device.

In the sociological literature, the user is certainly the one who consumes the product or the service (decision of the purchase or not, then add option or not), who uses it (face to face between the user and the device), but also the one who appropriates it (or rejects it, or turns it away ...). Behind the usage, we must understand the problematic of the social and individual appropriation of a technology (technical and cognitive mastery of the object).

This debate on the role given or not to the users continued throughout the experimentation period, among the consortium manufacturers, and will probably continue in case of deployment, and this for several reasons that will be explored further. Firstly, because the consumption cut-off took place in buildings, where occupants are often not present during the day (at work during the day), whose logic often take precedence over energy issues.

The whole difficulty is: how to represent a "consumption reduction"? Finally, because the stakeholders do not always know how to accompany this process of acculturation necessarily long and laborious.

Appropriating the concept of Smart Grid or more generally the Smart City for example, assumes a certain maturity in terms of knowledge of the issues of the energy transition. And to acquire this maturity, it takes time and spaces for debate.

Beyond the difficulty of defining the Smart Grid, their deployment, and the practical modalities of their implementation, it took a time of observation and acculturation of the problems as they were asked by some members of the consortium. There is sometimes difficulty between social sciences and engineering sciences to cooperate: two cultures coexisted at first, each with its own language, specific methods, even its interests. As a result, there were sometimes differences in the expectations each person had of the other, when the engineer annoyed behaviour priori "irrational" of the user or waiting to be told "how to make the user accept the constraints related

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

to the Smart Grid", or "what type of equipment he had to develop to inform him ", the sociologist reported on a complex reality incorporating other action logic related to the activity in buildings, or even balked at compare situations of different buildings by explaining the diversity of factors involved in the behaviour of users.

This step repositioned the Smart Grids issue in a more holistic energy approach, to confirm the diversity of factors involved in the relationship to this technology, and particularly of the existence of an energy culture, in the appropriation or not of the stakes of Smart grids. The acceptance of the constraints was even more debated as one addressed already aware of the issues of societal transitions.

For others, the constraints seemed acceptable if they were accompanied by explanations on the issues of the energy transition. For others still, it was important to be wary of technology because it could be a source of control and drift the use of data. For users less aware of energy issues, the perplexity remained in place, between fascination and caution.

The difficulties of access to the ground and the weakness of materials collected from non-users professionals are already a result: they recall that, just as the notion of acceptability, that of Smart Grid is primarily an industrial issue (and at the service of industrialists). Smart Grid combine many different technologies, from different industrial history and culture, with the main objective of enlisting the public and the various stakeholders. One of the difficulties, which emerge, is that the stakeholders themselves are not trained to appropriate it. Smart Grids do not have a physical incarnation, there is no device technique that makes them visible, they do not represent them. There are therefore major difficulties in collecting speeches and opinions about them.

For some, the consumption cut-off was invisible. It is not possible to learn from the criteria of duration or frequency. Returns from occupants interviewed by telephone following deletion very largely reflect an absence felt, regardless of the time of day.

On the other hand, when there are feelings of discomfort or discomfort, they are expressed with some virulence, or at least a feeling of misunderstanding. Several explanations can be put forward regarding this low visibility of flexibilities: First, they relate to equipment having a certain inertia (heating, water heater ...). It can be assumed that the perceptions would have been different if the consumption cut-off had on equipment directly related to the work: electrical outlets, lighting … In fact, the quality of the thermal envelopes of the buildings concerned (exposure, presence of bay glass, insulation ...) is very heterogeneous.

Even if the malfunctions were sometimes not attributable to the Smart Grid (again it was presumably from heating failure), they crystallized all the discontent. Here too, people expressed reluctance to continue experimentation. Flexibility carries risks of misunderstanding, resistance when it can threaten activity or work comfort. It must therefore be explained, justify itself so as not to be rejected.

The social appropriation of a technical innovation refers to complex social processes composed of many elements:

- the technical culture of users and their energy culture,

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426 Project STORY - H2020-LCE-2014-3

- their social representations,
- how it was presented to these users, the type of communication which the accompanying
- practices and uses of innovation,
- the lifestyle of the user and its relation to comfort, his previous experiences of the techniques, the collective dynamics in which he is involved.

In the end it will be remembered that when flexibilities were felt, they could be the subject of misunderstandings, even rejections. This can lead us to establish a certain number of points of vigilance regarding the social conditions of acceptability of energy flexibility, but also the conditions of information. For communities, the management of flexibility must consider the way of life and work and the personal comfort habits. Their priority is to fulfil their mission of welcoming the public. We must also be cautious when they welcome more vulnerable populations (children, people elderly, in care ...). Bad experiences can lead to misunderstanding or rejection and spread across a work group or group of occupants. This potentially calls into question the Smart Grids acceptance.

Lastly, there is no common position of the various actors concerned on the fact of communicating or not about flexibilities with users occupying buildings. More globally the role of users is debated by both industrialists and building managers. All question the relevance or not of informing the occupants of the buildings, sometimes for different reasons. Moreover, in terms of communication, we can ask the question: who has the vocation or legitimacy to take charge of pedagogy?

Conclusion and recommendations

Energy professionals' question themselves whether or not to inform occupants about consumption cut offs. And these do not often have neither time nor sometimes maturity to be interested. What emerges from this reflection is that, as part of the Smart Grid experiment, we have been very far from meeting the "consum'actors" as they had been idealized at the beginning of the project. The consortium partners have not developed tools to enable them to seize the subject. So, we cannot talk about appropriation of Smart Grids by users meaning where we define it above.

The observations made on the experimental sites therefore lead to establish a certain number of points of vigilance regarding social conditions of acceptability of flexibility energy, but also on the conditions of information.

- Starting with the need to be more selective in the choice of building, or by controlling the potential of the building in terms of energy consumption, uses (nature of activity, thermal envelope and especially schedules) or ensuring that buildings do not accommodate vulnerable populations, for example young children, elderly, or sick people, or convalescents.
- This assumes that people would be more involved in the choice and monitoring of the installation have information enabling them to tell remotely whether a break or what could be perceived as a malfunction is the fault or Smart Grid, have the possibility of derogation (knowing that some wish to use it and others not).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646426

- which implies finally that the actors concerned all rise in competence on the questions to position themselves, without necessarily relating them to questions of technology.

Indeed, the deployment of Smart Grid is not just a technical issue, it is also a social issue. If a consensus seems to exist on the stakes of the energy transition, Smart Grids will not be sufficient by themselves to change behaviours towards more sustainability, as some imagine. A new technique can participate in a behavioural transformation, but it is not enough.

It can also have the opposite effect if it is not appropriated. If it does not raise an interest in an experiment, it could be strongly rejected if the constraint became too strong or if it obstructs the smooth running of his activity.

In other words, it seems interesting to complement the surveys carried out directly with "captive" users and in real life, by collective and more or less civic experiences, allowing us to approach the conditions of an authentic deliberation with a view to finding tangible evidence of the conditions of acceptability Social Smart Grids.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3

A-5. Employment creation: Overview of the used sets, parameters, and variables

		Manufacturing	**Construction**	**O&M**	
Technology	**Country**	**Job-Years/MW**	**Jobs-Years /MW**	**Jobs-Years /MW**	**Source**
PV	Spain	-	-	2.7	Moreno & Lopez, 2008
PV	Spain	-	6.06	1.65	Llera et al, 2013
PV	Turkey	12.6	15.4	1.23	Cetin, 2010
PV		18.8	11.2	0.3	Cameron, 2015
PV	US	-	-	2.5	JobCalculator 2006
PV	**Global**	**6.7**	**13**	**0.7**	**Rutowitz 2015, Global**
PV	**Europe**	**12.4**	**16.7**	**0.6**	**Rutowitz 2015, Europe**
PV	**Global**	**12.63**	**12.47**	**1.25**	**Calculation**

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 646426
Project STORY - H2020-LCE-2014-3