LEVIS

LIGHT MATERIALS FOR ELECTRIC VEHICLES

D6.1 INITIAL LCA RESULTS OF LEVIS DEMONSTRATORS

WP6, TASK 6.1

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DoA	The Life Cycle Assessment (LCA) methodology will be used to quantify and compare the environmental impacts of the proposed LEVIS vehicle modules against their benchmark alternatives. LCA models will be built for each of the use cases (suspension system, battery holding set, cross car beam) taking into consideration all life cycle stages, from raw materials extraction to End-of-Life management. Deliverable D6.1 focuses on the LCA for the Benchmark components.

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LIST OF ABBREVIATIONS AND TERMS

ACRONYM	DESCRIPTION
Benchmark product	A (electric) vehicle component used as baseline for the LCA as part of the ‘demonstrator’
BOM	Bill of Materials
CF	Carbon Fiber
CFRP	Carbon Fiber Reinforced Plastics
CN	China
DALY	Disability-Adjusted Life Years
DE	Germany
EU-28	European Union, 28 countries
EV	Electric Vehicle
Global	Global
IT	Italy
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment

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PUBLISHABLE SUMMARY

This report is a key deliverable within Task 6.1 of the LEVIS project. In its entirety, this task will help determine the environmental performance of the LEVIS demonstrators that are designing and developing a selection of new components for electric vehicles. This report contains the Life Cycle Assessment of four electric vehicle components:

- A suspension control arm, which is used to allow the wheel to move along the vertical axis – shaking the suspension - and to rotate around it when steering.
- A battery box, which contains the battery modules and protects them during operation and in case of an accident. It also supports the modules by integrating them within the vehicle frame and has an important role in safety.
- A battery module housing, the module housing is a mechanical casing for the cells. The housing's main function is to thermally, mechanically, and electrically protect the cells and make sure there is electrical distribution through the busbar system.
- A cross car beam, which is a structural component in the dashboard area. The primary function is to provide the structure for the dashboard and all the sub-systems that constitute the IP module (steering column, HVAC, air- bags, EE units).

The project objectives regarding the environmental performance across all demonstrators are listed below:

- The demonstrators are expected to have a 20-40% in weight reduction compared to the benchmark product.
- The demonstrators should have at least a 25% reduction in global warming potential (GWP) at component level.
- The demonstrators should have at least a 7% reduction in global warming potential (GWP) at vehicle level.

The Life Cycle Assessment methodology is used to analyse the environmental performance of the benchmark demonstrators across the entire life cycle. The life cycle includes the mining of the materials, production of the components, transportation of the product, usage of the product and the end-of-life processes of the product. The LCA does not only focus on GHG emissions, but also includes emissions such as (hazardous or toxic) particles and gasses, naturally occurring and waste emissions resulting from extracting materials from its environment (e.g., crude oil and ores).

Key benchmark conclusions

A key conclusion is that the LCA confirms that the material selection has a large influence on the overall impact of the product for all components in this study, often more so than the particular production processes involved or the transportation of the materials during the production of the components. The material selection often dictates the relative influence of the different phases (production, use and end-of-life). This corroborates the choices for project LEVIS to focus on light weighting. However, the project needs to ensure its effects are not limited to the use phase in order to meet its key objectives, particularly related to the Global Warming Potential impact. The cross-car beam and the suspension control arm have very similar LCA results, because these products are made mostly from steel. The battery box has a relatively large environmental impact in the production phase, which comes from the manufacturing and processing of the aluminium. However, this also means that the

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recycling impact is much larger compared to the other benchmark products. The battery module has a relatively small recycling rate for the plastics it uses.

LCA vs iEDGE toolkit

This report also reflects on how the LCA results of the benchmark components for the demonstrators compare with the outcomes of the iEDGE toolkit which the demo partners used at the very start of the project. Its intent was to enable demo partners to help identify and decide where to focus improvements even before any LCA results were known. It is interesting to see to what extent the LCA results confirm the output from the iEDGE Toolkit. There were some differences and similarities found among the results. Ultimately, this suggested that using the LCA methodology could help the designers in the eco-design process by identifying critical life cycle phases and emissions. Even though LCA is an investment in time, it could help steer the design team in the most effective design direction. Yet it also suggests that, should that not be a feasible option for any reason, an approach as that used with the iEDGE toolkit can be an alternative to consider.

What-if scenarios

By also exploring scenarios with different variables, such as assuming a potentially longer lifespan, a higher recycling rate or changing the electricity grid mix for the use phase of the vehicle, this study highlights that such variables could have a significant effect on the results of the Life Cycle Assessment and thus the environmental impact of the product, especially when considering the objectives of the LEVIS project. Decreasing the mass of the components has considerably more effect when the lifespan of the vehicle is increased, or the vehicle is charged with an unsustainable electricity grid, making it all the more likely for LEVIS to meet the objectives in alternating scenarios and ensure impact is not shifted to other phases or impact categories.

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1. INTRODUCTION

This report is a key deliverable within Task 6.1 of the LEVIS project. In its entirety, this task will help determine the environmental performance of the LEVIS demonstrators that are designing and developing a selection of new components for electric vehicles. A Life Cycle Assessment (LCA) methodology will be used to quantify and compare the environmental impacts of these new LEVIS vehicle modules against their benchmark alternatives. LCA models will be built for each of the use cases (suspension system, battery box and module, cross car beam) taking into consideration all life cycle stages, from raw materials extraction to end-of-life management.

This 'initial LCA results' report is to be considered as "part 1" of the full Life Cycle Assessment (LCA) of the LEVIS demonstrators and contains the results of the Life Cycle Assessment (LCA) for the benchmark products that were identified by the LEVIS demonstrator partners as a suitable representative. Only the LCA of the benchmark product will be covered in this report. However, keep in mind that the methodology, goals, and scope will also apply to the "part 2", which covers the LCA of the demonstrators themselves.

1.1. PURPOSE AND TARGET GROUP

To be able to assess the potential for improved environmental performance of the newly (to be) developed EV components, it is necessary to perform an LCA on both a benchmark component and the new component and evaluate the different results. The purpose for these comparisons is to be able to assess whether the new components result in an improved environmental impact by means of using different materials and different processes. The LCAs therefore focus on the impacts across different life cycle stages as well as different impact categories. The aim for this is to identify whether (and to what extent) there is an overall improvement as well as whether improvements in one impact category are not inadvertently resulting in an undesirable negative impact in another category.

With this report (as well as the "part 2" report which will be published later) we aim to provide insights about the environmental impact of newly used materials and processes for different audiences.

These audiences include,

- Firstly, our **LEVIS partners** who are responsible for the designing, testing, and developing of the new demonstrator components.
- The European Union Horizon research and innovation **programme commission** and **sister projects** within the same H2020-LC-GV-2018-2019-2020 / H2020-LC-GV-2020 call
- Industry **TIER suppliers** who wish to learn more about alternative materials and processes for their products
- Industry **OEMs** who wish to learn more about alternatives for their vehicle components
- Fellow **(LCA) researchers** who are interested in the potential of different practices and materials

However, the results of the reports within this Task 1.2 of the LEVIS project may be equally of interest to those with a **general interest in LCAs and environmental impact or developments within the automotive industry** in general. During Task 1.2, the iEDGE toolkit was created in order for the demo partners to apply eco-design during the demonstrator design phase. This toolkit is in accordance with

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the circular economy principles. As such we have attempted to write this report in a way that it may cater to different audiences and therefore includes general or summary explanations of common terms, methods and approaches and is structured to enhance the possibility of reading the content 'per individual demonstrator'.

1.2. CONTRIBUTIONS OF PARTNERS

Table 1 depicts the main contributions from project partners in the development of this deliverable.

Table 1 *Contributions of Partners*

PARTNER SHORT NAME	CONTRIBUTIONS
MSS	Point of contact to Cenex NL for the Suspension Control Arm DEMO to help identify the benchmark product, the correct scoping & objective formulations as well as efforts to provide actual data where feasible, sense-checking the LCA dataset selections.
MERSEN	Point of contact to Cenex NL for the Battery Box DEMO to help identify the benchmark product, the correct scoping & objective formulations as well as efforts to provide actual data where feasible, sense-checking the LCA dataset selections.
YOVA	Point of contact to Cenex NL for the Battery Module DEMO to help identify the benchmark product, the correct scoping & objective formulations as well as efforts to provide actual data where feasible, sense-checking the LCA dataset selections.
TOFAS	Point of contact to Cenex NL for the Cross Car Beam DEMO to help identify the benchmark product, the correct scoping & objective formulations as well as efforts to provide actual data where feasible, sense-checking the LCA dataset selections.
ITA	Point of contact to Cenex NL in the alignment with the project coordination and in the correct scoping & objective formulations relevant to materials and processes.
CANOE	Point of contact to Cenex NL in the correct scoping & objective formulations relevant to materials and processes.
AIMEN	Point of contact to Cenex NL in the correct scoping & objective formulations relevant to materials and processes.
RISE	Point of contact to Cenex NL in the correct scoping & objective formulations relevant to materials and processes.
LEAR	Point of contact to Cenex NL in the correct scoping & objective formulations and alignment with WP1.
PRIVE	Provided support to MERSEN in their role as point of contact to Cenex NL for the Battery Box DEMO.

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1.3. STRUCTURE OF THIS REPORT

This report contains 4 different LCAs based on 4 different (benchmark) products;

- a suspension control arm,
- a battery box,
- battery module and,
- a cross car beam.

As a result, this report is split into sections where general aspects are covered (Chapters 1, 6, 7 and 8) and sections for each demonstrator (Chapters 2, 3, 4 and 5). In summary, this deliverable report contains the following main chapters:

- Context and general explanation of LCA and the structure of this report (Chapter 1)
- The benchmark LCA for DEMO 1, Suspension Control Arm (Chapter 2)
- The benchmark LCA for DEMO 2A, Battery Box (Chapter 3)
- The benchmark LCA for DEMO 2B, Battery Module (chapter 4)
- The benchmark LCA for DEMO 3, Cross Car Beam (Chapter 5)
- Cross DEMO Conclusions (Chapter 6)
- Bibliography (Chapter 7)
- Annex (Chapter 8)

The first chapter provides general context for the report as its role within the LEVIS project, its partners and the method and practices common for LCAs.

Chapters 2 to 5 can be read as its own LCA report. The reasoning behind this structure is to facilitate readability by providing the reader the opportunity to directly go the DEMO of interest and read the information for that particular demonstrator as one 'read-through'. This prevents having to go back and forth between chapters. As a result, information that is the same or similar for all DEMOs may be repeated in each DEMO chapter. This means there is some (sometimes slightly differing) overlap, especially in the first paragraphs. In each of the DEMO LCA chapter we address their Goals and Scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, DEMO specific LC(I)A results as well as an evaluation of Conclusions.

Chapter 6 takes the perspective of looking across the results of all 4 LCAs and highlights any conclusions which can be derived from this evaluation perspective. Chapters 7 and 8 serve as source references.

1.4. INTRO TO LCA

Life Cycle Assessment is used to determine the environmental impact of a product or service during their entire life cycle. The life cycle includes the mining of the materials, production of the components, transportation of the product, usage of the product and the end-of-life processes of the product.

Environmental impact comprises the emissions that occur during these life cycle phases and have an impact on the local or global environment (including humans). These relate not only to GHG emissions, but also include emissions such as (hazardous or toxic) particles and gasses, naturally occurring and waste emissions resulting from extracting materials from its environment (e.g., crude oil and ores).

This LCA complies with the framework in the 14040-14044 standards defined by the International Organisation for Standardization (ISO STANDARDS BYISO/TC 207/SC 5 - Life cycle assessment, 2022).

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The LCA studies within the LEVIS project and for its partners are performed as described as summarized below and uses actual data (where available), supplemented with the use of GaBi databases by Sphera (Gabi Sphera, n.d.), which safeguards also compliant with the (aforementioned) ISO standards.

The main phases of an LCA are the following and are visually depicted in **Figure 1**:

1. *Goal and Scope Definition*; The reasoning for carrying out the research is defined. The required level of detail is described and basis for comparison is chosen.
2. *Life Cycle Inventory Analysis*; A model is created which illustrates the life cycle and the processes involved. Data is gathered to quantify the mass and emission flows
3. *Life Cycle Impact Assessment*; The effect of the emissions and the usage of resources is analysed by grouping the quantified emissions and mass flows into a limited number of environmental impact categories.
4. *Life Cycle Interpretation*; The results are checked for consistency and completeness. They are then evaluated and reported in an informative way.

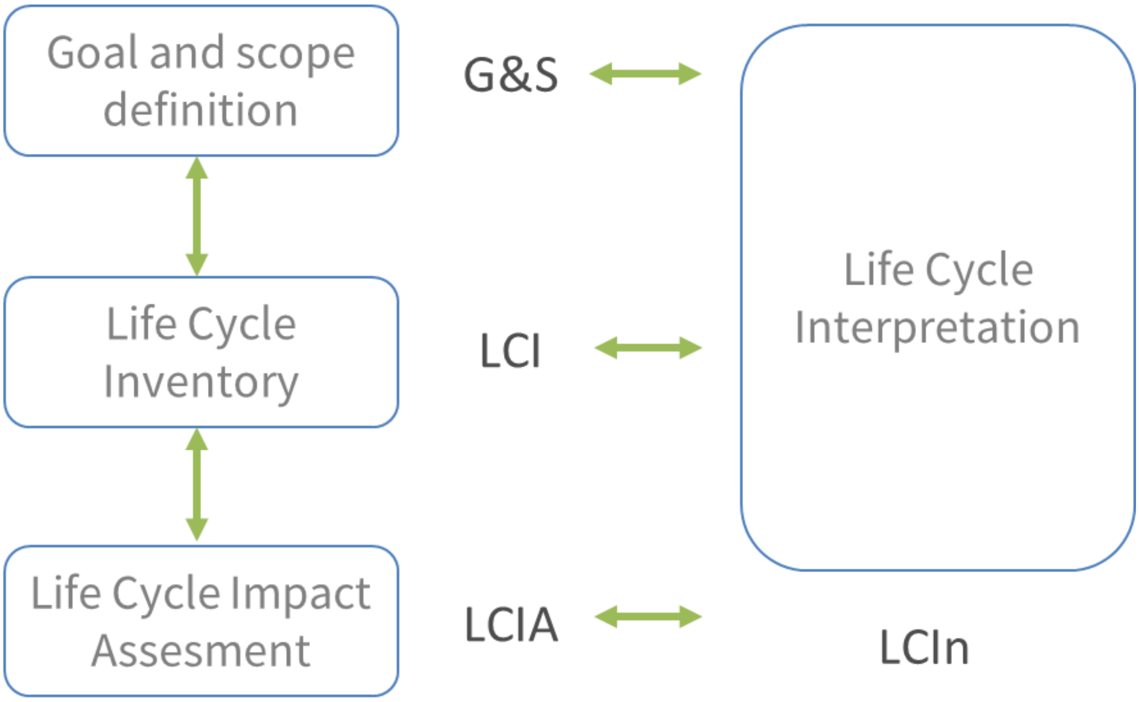

Figure 1: *Phases of LCA methodology*

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2. LCA BENCHMARK DEMO 1 – SUSPENSION CONTROL ARM

2.1. OBJECTIVES AND SCOPE DEFINITION

This chapter describes the goal and scope of the Life Cycle Analysis (LCA) of the LEVIS suspension control arm benchmark product. This benchmark product (i.e., a vehicle component) is relevant to the new product LEVIS partner Marelli is developing. Marelli Suspension Systems Italy S.p.A is one of the Marelli's business lines and in charge of designing and producing suspension modules and components for motor vehicles.

2.1.1. GENERAL DESCRIPTION OF THE COMPONENTS

The suspension control arm has a fundamentally supporting and connecting function between movable (e.g., wheel, knuckle) and fixed parts (e.g., body, frame, cradle). It is intended to allow the wheel to move along the vertical axis – shaking the suspension - and to rotate around it when steering.

The suspension control arm is a structural and safety component. The geometric shape and functionality vary with different suspension architectures properly chosen according to handling and driving comfort targets set up at vehicle level.

There are two front suspension control arms per car (left and right). The suspension control arm has bushings and a ball joint to attach the cradle and the steering knuckle, respectively, as it can be seen in Figure 2. Bushings and the ball joint are usually pressed-in even though the latter could be screwed or riveted according to the process technology chosen.

The product details are provided in **Table 2**. The component identified as benchmark product is not related to an EV but has been in mass production for almost 15 years for an ICE vehicle, a B segment car. However, for the LCA, an EV is used to calculate the use phase emissions in order to make a fair comparison later on in the project with the new design of the demonstrator. Although the benchmark product is produced for an ICE vehicle, for the purpose of this comparison it can be considered plausible it could be utilised for en EV equivalent.

Table 2: *Product details suspension control arm*

Product name	**Lower Suspension Control arm**
Manufacturer	Marelli
Country/countries of manufacturing	Italy
Year of manufacturing	2005-2020
Amount of products sold yearly	80000
Serial no./product ID	199 Project
General description	Lower suspension control arm made out of stamped steel sheet.

The current design consists of a steel stamped sheet where the processes of bending, welding, and stamping are used to form the control arm body and attach the bushing and ball joint.

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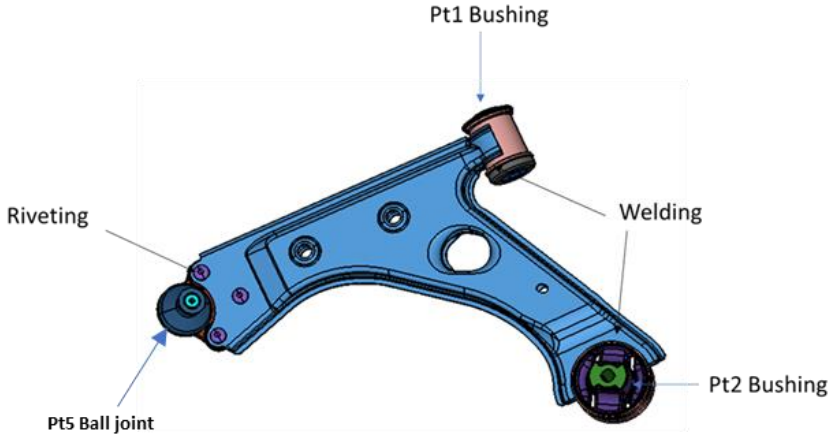

Figure 2: *Visual impression of suspension control arm*

Figure 3: *Control arm body*

Figure 4: *Pt1*

Figure 5: *Pt2*

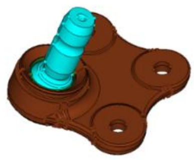

Figure 6: *Ball joint seat*

2.1.2. OBJECTIVES

This study aims to identify the absolute and relative environmental performance of a benchmark suspension control arm and the by LEVIS newly developed suspension control arm and evaluate to what extent the suspension control arm meets the environmental objectives set at the start of the project. This means that the comparative statements will be made regarding the environmental performance of the two products. However, these statements are only included in ‘part 2’ of the LCA reporting. Since ‘part 1’ only covers the environmental performance of the benchmark product.

Overarching project objectives

The projects objectives regarding the environmental performance across all demonstrators are listed below:

1. The demonstrators are expected to have a 20-40% in weight reduction compared to the benchmark product.
2. The demonstrators should have at least a 25% reduction in global warming potential (GWP) at component level.
3. The demonstrators should have at least a 7% reduction in global warming potential (GWP) at vehicle level.

Demonstrator specific objectives

This demonstrator has set a more specific objective to achieve a weight reduction of 30-50%, which significantly exceeds the project objective of 20-40%.

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WP5 formulated the demo specific objective to recover carbon fiber (CF) and Elium resin, where at least 20% of recovered CF from such composite materials will be used to manufacture secondary Carbon Fiber Reinforced Plastics (CFRP). The recycled resin will have at least 80-90% the quality as virgin resin.

Another objective was to increase the potential for circularity of the new suspension control arm design by means of material and production processes selections instigated by the adoption of the identified key eco-design principles from the iEDGE toolkit workshop. Since this is not possible to quantify by means of a LCA, a survey concerning the effects and results of the iEDGE toolkit will be held to determine whether these objectives were met.

The LCAs performed in this study should determine whether the newly designed demonstrators meet the objectives or not. Even though the objectives of the LEVIS project focus on the global warming potential, this study also looks at other emissions and impacts across the life cycle stages and can be clustered across the following impact categories:

- Resource depletion
- Human Health
- Terrestrial ecosystems
- Marine ecosystems
- Freshwater ecosystems

A full list of impact (sub)categories can be found in the ANNEX section, which are split into so called Midpoint and Endpoint indicators (also see Section 2.3 for further explanations).

2.1.3. SYSTEM FUNCTION AND FUNCTIONAL UNIT (RESEARCH QUESTION)

The parameter to define the functionality of the component is called the functional unit and is key in LCA in order to make a measurable evaluation and comparison of the benchmark product and the demonstrator. The lifespan of the vehicle can be different per benchmark vehicle, but for the sake of this study, this is kept equal across all demonstrators. The functional unit is defined as below:

> *The functional unit for this study is the installation and usage of two suspension control arms which last the whole life of a B class electric vehicle driving a WLTP cycle, in a manner that maintains the functionality of the vehicle and safety of the occupants. The average lifespan is considered to be 160.000 km.*

2.1.4. SYSTEM BOUNDARIES

2.1.4.1. GENERAL SYSTEM DESCRIPTION

The life cycle phases (visualized in **Figure 7**) that are being considered for the suspension control arm are the following:

- The extraction of all raw materials.
- The production and manufacturing of the parts.
- The transportation of the materials and parts to the manufacturing sites.
- The usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- Lastly, through the end-of-life of the components themselves.

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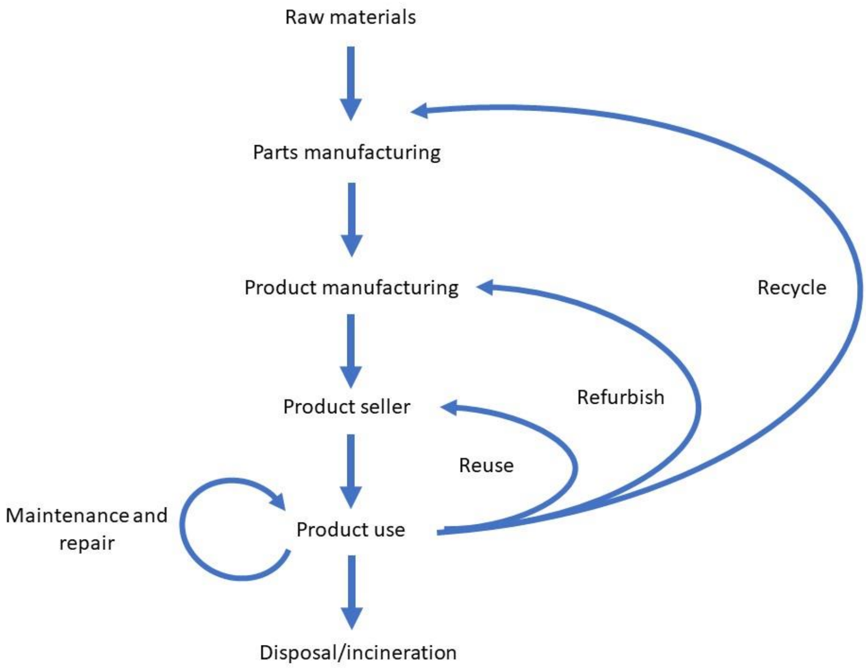

***Figure 7**: Life cycle phases of a product*

2.1.4.2. COVERAGE OF ENVIRONMENTAL INTERVENTIONS AND IMPACTS

As is mentioned in the "objectives" paragraph, the main targets of the LEVIS project relate to the global warming potential of the demonstrators. The results of this study will be mainly focused on the emissions that are related to this impact category. However, all impact categories and associated emissions that are part of the ReCiPe 2016 (RIVM, 2011) impact assessment method are considered. Any "remarkable" results from the impact categories will also be discussed in to results section of the report.

2.1.4.3. TEMPORAL AND GEOGRAPHIC BOUNDARIES

This study mostly uses data extracted from the GaBi database. Other data comes from either literature studies or directly from the industrial plants (provided by the DEMO partners). All datasets that are used have to be valid until the end of the LEVIS project (2024). The geographical representativeness of the datasets is dependent on life cycle stage of the process. As default, the EU-28 (European Union, 28 countries) averages are used, unless specific knowledge of the region of production is known. For example, concerning the manufacturing of the suspension control arm itself, Italy is used as geographical region. When multiple datasets for one process are available, a quick analysis on the specific datasets needs to be performed. The criteria on the choice datasets are the following:

Geographical representativeness:

- Choose the dataset that is located in the specific region the process occurs.
- If unknow or unavailable, use EU-28 (European) averages.
- If unavailable, use the Global (GLO) averages.

Geographical representativeness:

1. Choose the dataset which reference year falls under the 'years of manufacturing' of the benchmark vehicle.

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2. If unavailable or when multiple datasets fall under this requirement, choose the dataset with the most recent reference year.

2.1.4.4. TREATMENT OF RECYCLED MATERIALS

Allocation of the recycling and reuse of the materials is important in LCA. The method in this LCA study to account for this is to apply scrap credits to the steel and aluminium scrap that comes from all the production processes and end-of-life systems. This is called "value-corrected substitution" and is a method used in LCIA (Life Cycle Impact assessment) which tackles the downcycling issue in LCA when handling products with high scrap ratios.

During production and EOL, large volumes of scrap are produced and recycled. However, the material quality is often lower than that of the virgin material, which means that often the scrap material can't be replaced by the virgin material on a one-by-one basis. The "value-corrected substitution" method uses the price ratio between different grades of scrap (based on their quality) and the virgin material. The price ratio for the materials used in the model is the following:

- Steel scrap price ratio: 0,33 (GaBi)

Figure 8 provides an example of how this method is used in LCA. In this example the shredded steel from the post-shredding/sorting process is directed to a process called "No. 4 shredded steel-scrap credit". This is the process containing the price ratio of the scrap and the virgin steel. The number (No. 4 in this example) relates to the quality of the scrap material. The second input in this process is the "DE: Stainless steel cold rolled", which is a negative input, which means that the environmental impact of the stainless steel is now environmental savings (negative emissions).

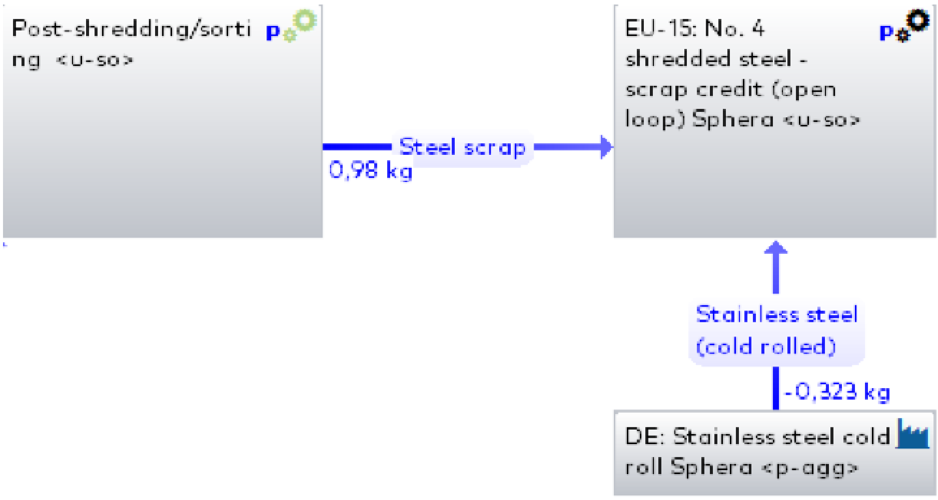

Figure 8: *Example value-corrected substitution method in EOL phase*

2.1.4.5. EXCLUSION AND CUT-OFF CRITERIA

This report is part of a comparative LCA. However, it was decided that, even though two systems are compared to each other, the identical processes are still accounted for in the LCA. Processes will be excluded if the mass or energy flows are less than 1% of the total. Mass and energy are used to estimate the environmental relevance, since it is not possible to determine the environmental relevance of a flow without having to perform a LCA in the first place.

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2.1.5. DATA SOURCES AND ASSUMPTIONS

The data of the database from Sphera GaBi is used for the all the background processes of the life cycle of the demonstrators. This includes the production of steel ingots, sheets and plastic granulate, but also the flow inputs as electricity and cooling water. The most representable data regarding the real-life scenario is used to make an as accurate analysis as possible. The processes that are used to fabricate the parts themselves are derived from Marelli and the production area.

2.2. LIFE CYCLE INVENTORY

2.2.1. PRODUCTION

2.2.1.1. MATERIAL PRODUCTION AND REFINING

The following materials (**Table 3**) are based on the Bill of Materials (BOM). Although the secondary materials that are needed for the manufacturing processes are included in the entirety of the LCA, they are not specified in this table. All the materials are coupled with the datasets provided by the GaBi database. The column "region" relates to the geographical representativeness of the datasets. The materials "Stainless steel cold roll" and "Steel forged component" have Germany as geographical region. These datasets represent the extraction of raw materials. As described in Chapter 2.1.4.5 the materials flows accounting for less than 1% of the total mass are not accounted for.

Table 3: *Material use suspension control arm*

Material	**Mass % of product**	**Mass % of material**	**Region**
Steel	92%		
Stainless steel cold roll		77%	DE
Steel forged component		15%	DE
Worldsteel		8%	EU-28
Aluminium	3%		EU-28
Rubber (Styrene-butadiene rubber)	4%		EU-28

2.2.1.2. MANUFACTURING PROCESSES

The processes that are used to manufacture the suspension control arm are listed in **Table 4** below:

Table 4: *Processes suspension control arm*

Processes	**Database**	**Source**	**Country**
MIG welding	Literature	Marelli	IT
Steel sheet deep drawing	GaBi	Sphera	DE
Steel sheet stamping and bending	GaBi	Sphera	DE
Cataphoresis painting	Literature	Marelli	IT
Aluminium extrusion	GaBi	Sphera	EU-28

2.2.2. USE

The (benchmark) demonstrators do not have a 'direct' use phase, in which they use energy by themselves. However, on a vehicle level, they do influence the energy consumption of the vehicle by their weight. In order to calculate the energy consumption associated with the benchmark demonstrator, the following formula is used:

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$$EC_{benchmark} = \frac{ERV * m_{benchmark} * mileage_{use}}{10000}$$

Where;

ERV = Energy Reduction Value (kWh/(100kmx100kg));

$m_{Benchmark}$ = Vehicle mass reduction (kg)

$EC_{benchmark}$ = Energy consumption through mass (kWh)

$mileage_{use}$ = Lifetime vehicle (km)

The ERV (see **Table 5**) is extracted from the literature based on Del Pero, et al. (2020) and is based on the vehicle class and driving cycle. For this study, the World Light Test Procedure (WLTP) is used.

Table 5: *Benchmark vehicle demonstrators*

Demonstrator	**Vehicle class**	**Milage (km)**	**ERV (kWh/100km*100kg)**
Suspension Control Arm	B	160.000	0.56
Battery Holding Set	D	160.000	0.66
Cross Car Beam	C	160.000	0.58

2.2.3. END-OF-LIFE

The processes of the end-of-life phase are provided by Marelli. The end-of-life phase of the suspension control arm follows the same path as the rest of the vehicle since the suspension control arm is often not dismantled and separated from the vehicle after the use phase. The vehicle is shredded into small pieces, after which the different materials, in this case mostly steel, are sorted and recycled if possible. The model does not account for the remelting of the steel scrap since this is allocated to the second life product.

2.3. LIFE CYCLE IMPACT ASSESSMENT

ReCiPe 2016 is chosen as the primary assessment method for this study. This method is recognized by the EU (EUR 25167 EN - 2012) as a Life Cycle Impact Assessment (LCIA) method. The ReCiPe method can be used using three different cultural perspectives. These cultural perspectives represent different expectations such as timespan or the level of impact by future technology to avoid or mitigate future damages. The ReCiPe method differentiates the following three perspectives:

1. Individualist: Short term view and optimistic about future technology
2. Hierarchist: Default model. Used most often in scientific models and assumed to be the consensus model.
3. Egalitarian: Long term view which is based on precautionary principle thinking.

For this study, the consensus model (Hierarchist) will be used as the preferred method. The Global Warming Potential (GWP) for the ReCiPe model is described as “Climate Change” in GaBi. Thus, the results of this study are all related to the effect of the components on Climate Change and are expressed kg CO2-eq as metric unit.

In the results, both the so called „Midpoint” and „Endpoint“ indicators of the whole life cycle process are calculated. Midpoint indicators focus on a single environmental problem, while Endpoint indicators

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show the environmental impact of the Midpoint indicators on three higher aggregation level (RIVM, 2011):

- Damage to Human Health (DALY)
- Damage to ecosystems (species per year) containing:
  - Terrestrial ecosystems
  - Marine ecosystems
  - Freshwater ecosystems
- Resource depletion ($)

The unit "DALY" stands for Disability-Adjusted Life Years and takes into account the years lost to reduced quality of life due to illness and premature death. One DALY represents the loss of one year of a healthy life for one person. The unit "Species per year" stands for the number of species lost per year due to the environmental impact. While the unit dollars ($) of resource scarcity represents the extra costs involved to extract future mineral and fossil resources.

As explained in chapter 2.1.4.2, the (midpoint) impact categories which show „remarkable" results are discussed. The following impact categories were considered for in the results section:

- Climate Change (kg CO2 eq.): (Human made) emissions that have effect on the radiative forcing of the earth's atmosphere.
- Human toxicity (kg 1,4-dichlorobenzene eq.): Toxic substances that are emitted in the environment that damage human health.
- Fine Particulate Matter Formation (kg PM2.5 eq.): Particles with a diameter of 2,5 µm or less which is suspended in the atmosphere. These particles have a negative effect on human health when inhaled into the lungs.
- Fossil depletion (kg oil eq.): Extraction of non-renewable natural fossil resources.

2.3.1. CALCULATIONS TOOLS AND METHODS

GaBi Professional is used as the LCA software modelling tool to calculate the GHG emissions of the benchmark products. The GHG emissions are expressed by the ReCiPe method as 'impact on climate change'. GaBi is also used as the database to quantify the flows that were unavailable by the LEVIS partners, in order to complete the Life Cycle Inventory. The final results are calculated by using the data derived from the LEVIS partners (foreground data, in-house processes) and cradle-to-gate background flows and processes. GaBi is then also used to perform the Life Cycle Impact Assessment and compute the final results of the study.

2.3.2. LIMITATIONS, DEVIATIONS AND LINKS TO OTHER WPS

Deviations from the Grant Agreement were made concerning the benchmark vehicles. Every demonstrator has a benchmark product that is used for a different type of vehicle, meaning that the original benchmark vehicle (1500 kg EV) is no longer relevant. The benchmark vehicles are described in chapter 2.2.2.

There was limited data available for the emissions and energy use for the production and EOL phase of the benchmark products. The LCA was largely reliant on datasets from databases in GaBi.

Links between workpackages were mostly with WP1 (see chapter 2.1.1 & 0, eco-design and the description of the demonstrators). The LCA of the demonstrators themselves (not included in this report) will have a link with WP1 to WP6. The demonstrators are made partly from new composite

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materials from new processes, making the LCA less reliant on databases and more reliant on data from other partners and workpackages.

2.4. RESULTS

The results are presented and compared along three different life cycle phases; the production phase, the use phase and the end-of-life phase. The three phases consist of the following:

1. Production phase: The extraction of the raw materials, the production and manufacturing of the parts and the transportation of the materials and parts to the manufacturing sites
2. The Use phase; the usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
3. The End-of-Life phase: The processes needed to recover, recycle, or dispose of the product and its materials. It also consists of the credits gained due to the second-life of the materials through potential recycling or reuse.

2.4.1. WHOLE LIFE CYCLE IMPACT

Table 6 shows the environmental impact on the three impact levels (as mentioned in chapter 2.3). In this table, we will look at the impact categories with the highest impact on their respective impact level (damage to human health, resource depletion and damage to ecosystems). A more detailed overview for the environmental impact of the benchmark product is provided in **Table 46** and **Table 47** in Annex 8.1.

Table 6 shows for each life cycle phase the impact category which causes the most impact (including the indicators which are most relevant to this impact). These impacts are indicated in % as relative impact of the total impact per category (and indicator). Additionally, it indicates for life cycle phase per impact category what the relative impact is within the category, meaning that for each impact category (and indicator(s)) the total percentages across the life cycle phases add to 100% (with 1% deviation because of rounding off to whole percentages). The 100% represents the total impact for this category. Keep in mind that the EOL (end-of-life) phase also accounts for the recycling credits, which means that the EOL phase will almost always have negative emissions (emission savings).

Table 6: *Suspension control arm: impact categories with highest % of total impact. Incl. indication of which phase shares the largest contribution per impact category*

	Percentage of total impact to endpoint indicator	Relative influence of production	Relative influence of use phase	Relative influence of recycling	Relative influence of EOL
Resource depletion					
Fossil depletion	93%	48%	60%	-9%	1%
Damage to Human health					
Climate change	39%	57%	54%	-12%	<1%
Fine Particulate Matter Formation	22%	97%	28%	-26%	<1%
Human toxicity, cancer	37%	145%	0%	-45%	<1%
Damage to ecosystems					
Climate change	69%	93%	31%	-24%	<1%

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From the table above, it is interesting to see that the use phase and production phase have similar effect on the fossil depletion and the climate change impact categories. However, in the case of the PMF and human toxicity emissions, the production phase has considerably more effect. The large emission savings by the EOL (recycling) phase suggests that this mostly comes from the material use of the product, which is steel (which generates large emission savings when recycled).

2.4.2. PRODUCTION

As can be seen in the previous paragraph, the production phase has a considerable environmental impact, especially regarding the impact related to FPM and Human toxicity. For this research, we will focus mainly on the materials and processes that have the highest influence on the selected impact categories of **Table 6**.

Figure 9 shows the CO2 eq. emissions (the Climate Change impact category) during the production phase. The left bar shows the total emissions during the production phase, while the bars to the right show the emissions per component. The largest influence is the control arm, which is logical since this has the highest mass of all the components and is made primarily from steel. **Figure 10** shows the CO2 eq. emissions that are emitted during the production of the control arm only. It is clear that most emissions come from the material use. Emissions resulting from the material use during production is also the largest impact category for the components 'small parts' (which consists of fasteners, bearings, etc.), and is shown in **Figure 11**.

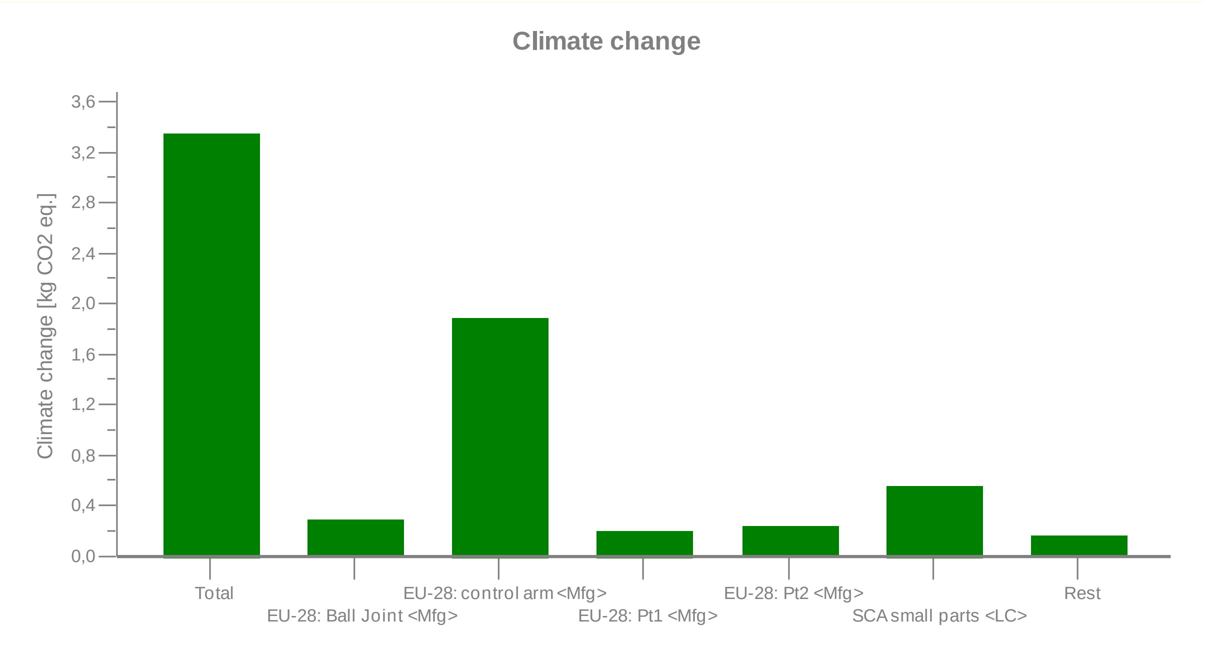

***Figure 9:** Impact on Climate Change by Production of benchmark suspension control arm*

The impact of the material usage is also high for the other impact categories, which is also shown in **Figure 12**, where the impact of the control arm is even higher than the other parts. This is due to the impact of steel production on human toxicity. The component 'small parts' also uses some plastics and rubbers. Plastics and rubber have a relatively lower impact on human toxicity than climate change in comparison to steel, which raises the human toxicity impact of components that only use aluminium as material (as such does the control arm).

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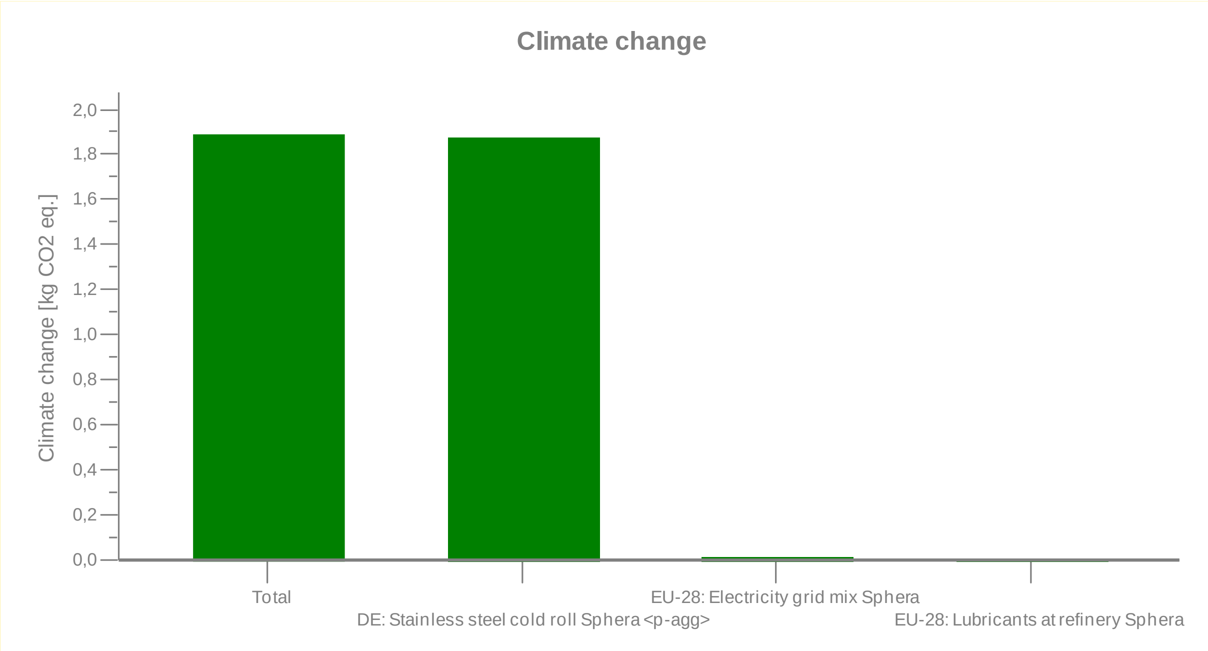

Figure 10: *Impact on climate change production control arm*

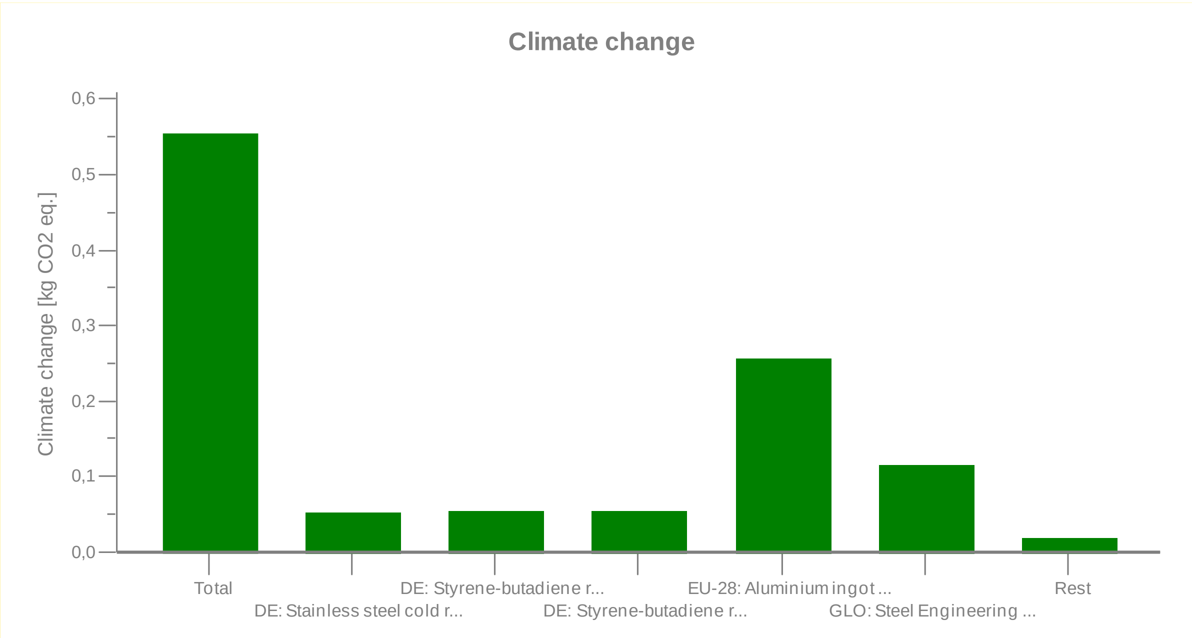

Figure 11: *Impact on climate change by production of the small parts of the suspension control arm*

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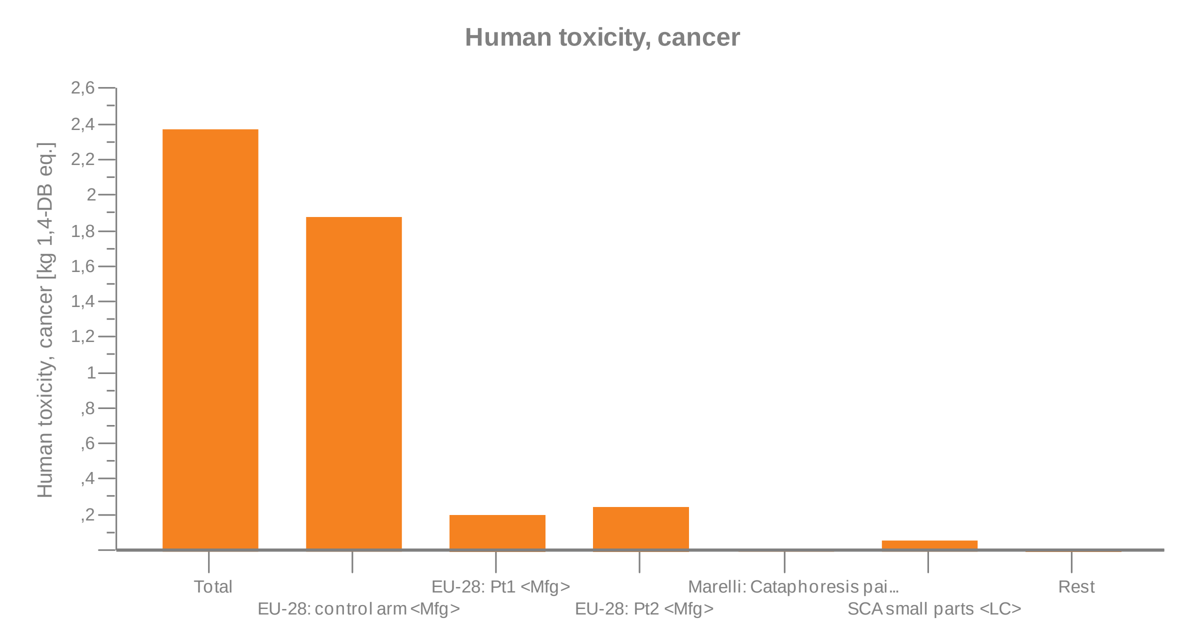

Figure 12: *Impact on Human Toxicity, cancer by the production of the suspension control arm*

2.4.3. USE PHASE

In **Table 7**, the primary energy demand for the use phase of the suspension control arm is provided. This is the associated energy consumption for 1 kg of a class B electric vehicle driving 160.000 km in its lifetime. As can be seen from the table below, about two thirds of the primary energy demand come from non-renewable energy resources. Charging the EV with other energy grid mix could change this number and therefore the environmental impact in the use phase.

Table 7: *Primary energy demand use phase suspension control arm*

	Use phase
Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]	96,6
Primary energy from non-renewable resources (gross cal. value) [MJ]	63,3
Primary energy from renewable resources (gross cal. value) [MJ]	33,3

2.4.4. END-OF-LIFE

As can be seen from the **Figure 13**, the environmental impact for the electricity use of the shredder used in the end-of-life phase is minimal compared to the other phases. Similar effects can be seen looking at other impact categories. Since steel has a high recycling rate, the emission savings (in **Figure 13** it is shown as DE: Stainless steel cold r…) are significant.

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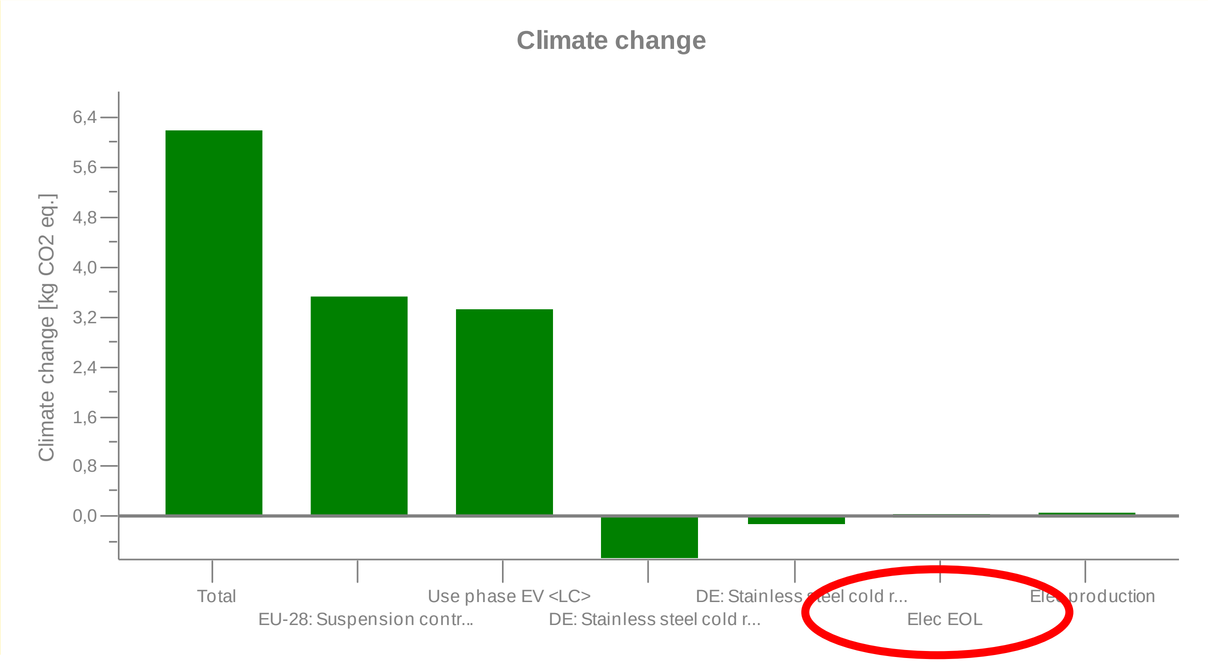

Figure 13: *Impact on climate change life cycle suspension control arm. Red circle is the environmental effect of the energy usage for the EOL phase of the suspension control arm.*

2.4.5. SENSITIVITY ANALYSIS

The indicated System Function and Functional unit (section 2.1.3) reflects a specific scenario (a set of parameters and assumptions) against which results are calculated. As these parameters and assumptions contain a certain degree of variability and uncertainty, it would be good practice to explore a few 'what if' scenarios. For this purpose, a sensitivity analysis is performed to evaluate the influence of these assumptions and parameters on the conclusions of this report. For this study, three variables are chosen for the sensitivity analysis.

2.4.5.1. LIFESPAN

This study uses the general lifespan as a variable for the sensitivity analysis. The baseline lifespan is defined (see scope definition) as 160.000 kilometres. This can be considered a conservative assumption, since research showed that the lifespan of EVs can be significantly longer (C. P. Aiken, 2022). For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 160.000 km (baseline lifespan),
- 240.000 km (150% of baseline) and
- 300.000 km (as least conservative estimation)

The results of the sensitivity analysis are provided in **Table 8**. Keep in mind that these results are provided in kg CO2 eq. per kilometre driven. The table shows the environmental impact, and the emission savings when increasing the expected lifespan of the vehicle compared to the baseline. What is clear is that the largest "savings" can be found in the human toxicity and fine particulate matter impact categories. This is logical, since these emissions come mostly from the production phase, which remains unaltered when raising the lifespan of the vehicle. As a result, the relative contribution per driven kilometre decreases. **Figure 14** and **Figure 15** show the total (so not per km) environmental

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impact on climate change and FPMF respectively, which again illustrates that the impact on climate change has more effect in the use phase than FPMF.

Table 8: *Sensitivity analysis lifespan suspension control arm (per kilometre)*

	160000 km		240000 km		300000 km	
Climate change [kg CO2 eq.]	3,58E-05	*100%*	3,08E-05	*86%*	2,88E-05	*80%*
Fine Particulate Matter Formation [kg PM2.5 eq.]	2,76E-08	*100%*	2,15E-08	*78%*	1,90E-08	*69%*
Fossil depletion [kg oil eq.]	1,36E-05	*100%*	1,19E-05	*88%*	1,13E-05	*83%*
Human toxicity, cancer [kg 1,4-DB eq.]	7,38E-06	*100%*	4,92E-06	*67%*	3,93E-06	*53%*

The longer the lifespan of the EV, the higher the relative impact of the use phase of the product in comparison to the production and end-of life phase. Since the use phase impact (by electricity consumption) is solely driven by the mass of the product (see chapter 2.2.2), the potential environmental savings are also larger in the longer lifespan scenarios. It could be argued that a longer lifespan may also have a carryover effect in avoided or postponed impact from replacement needs. As such, the sensitivity analysis confirms that a longer lifespan could have significant impact on the final results of the LEVIS project, which will be explored and evaluated further in the final LCA deliverable, D6.2.

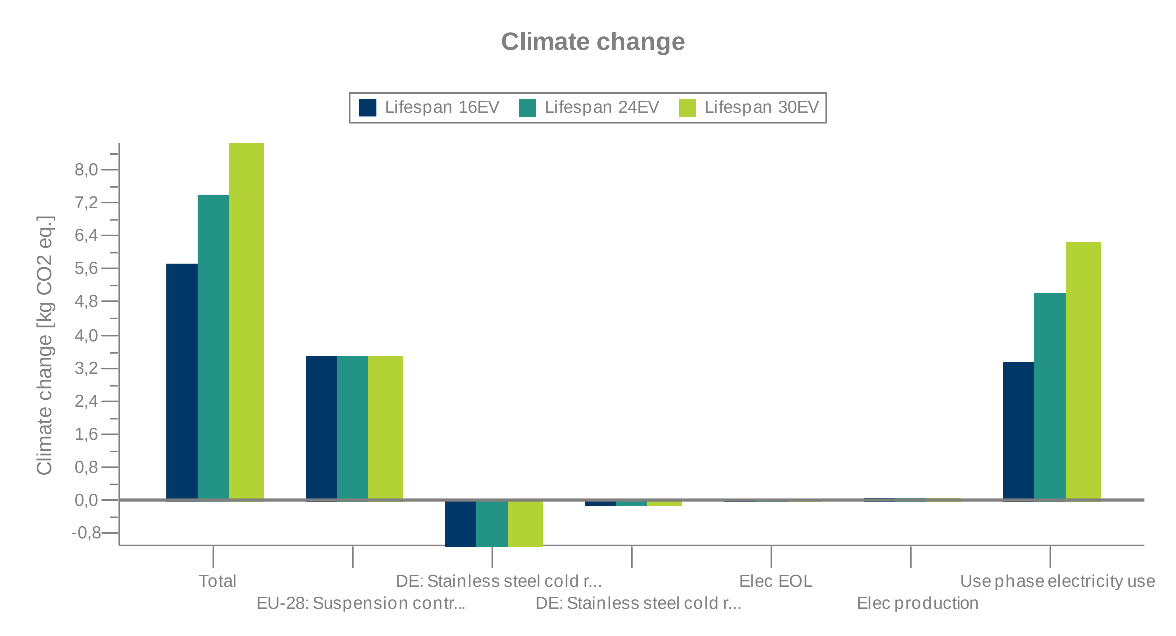

Figure 14: *Sensitivity analysis lifespan suspension control arm. Climate change.*

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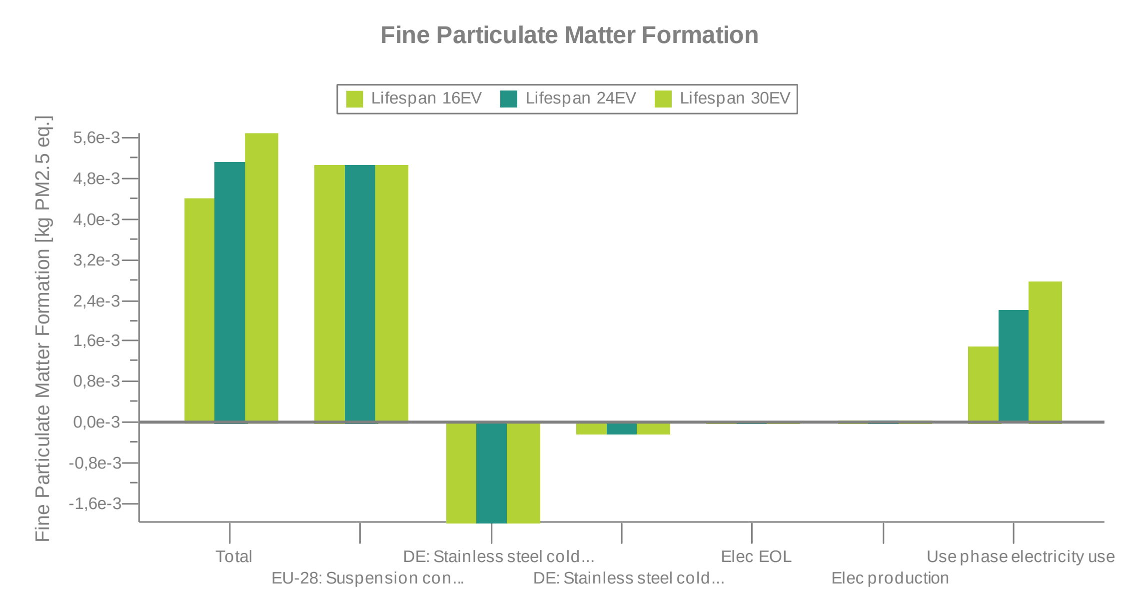

Figure 15: *Sensitivity analysis lifespan suspension control arm. Particulate Matter Formation.*

2.4.5.2. ELECTRICITY GRID MIX

This study uses the electricity grid mix for the use phase as a variable for the sensitivity analysis. The baseline is the EU-28 electricity grid mix. The other two electricity grid mixes that are chosen are the Chinese (CN) and the United Stated (US) grid mixes. They are chosen, because they form a relatively large percentage of the total energy consumption in the world, for a single country. They are also chosen because they consist of quite different energy source mixes (see **Figure 17**). The Chinese grid mix relies most on coal power, while the US also on gas and nuclear. The EU-28 has the most diverse electricity grid mix.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 9**. Keep in mind that these are the results concerning the whole life cycle of the component, not just the use phase. It is clear from the results that the difference between electricity production can have a massive influence on the results of the study. This is especially applicable for the environmental impacts on climate change and FPMF. As mentioned before, Chinese electricity grid mixes are currently mostly reliant on coal, which is a large contributor to GHG and FPM emissions.

Table 9: *Sensitivity analysis electricity grid mix suspension control arm*

	EU28		CN		US	
Climate change [kg CO2 eq.]	5,75E+00	*100%*	1,10E+01	*191%*	7,85E+00	*137%*
Fine Particulate Matter Formation [kg PM2.5 eq.]	4,39E-03	*100%*	9,73E-03	*222%*	4,59E-03	*105%*
Fossil depletion [kg oil eq.]	2,17E+00	*100%*	2,80E+00	*129%*	2,75E+00	*127%*
Human toxicity, cancer [kg 1,4-DB eq.]	1,18E+00	*100%*	1,18E+00	*100%*	1,18E+00	*100%*

Figure 16 shows the impact on climate change of the three scenarios. A large spike can be seen in the use phase for the Chinese electricity grid mix, and a smaller one for the US electricity grid mix. This

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also increases the relative impact of the use phase of the product and implies that, similar to the chapter 2.4.5.1, the potential impact of the weight reduction objective within the LEVIS project, will have greater environmental savings in absolute numbers if the electric vehicles are used in regions with less environmentally friendly energy grid mixes. Consequently, any relative increase in the (electric) energy required for the production and end-of-life phases for the new designs would also translate into a higher absolute environmental impact.

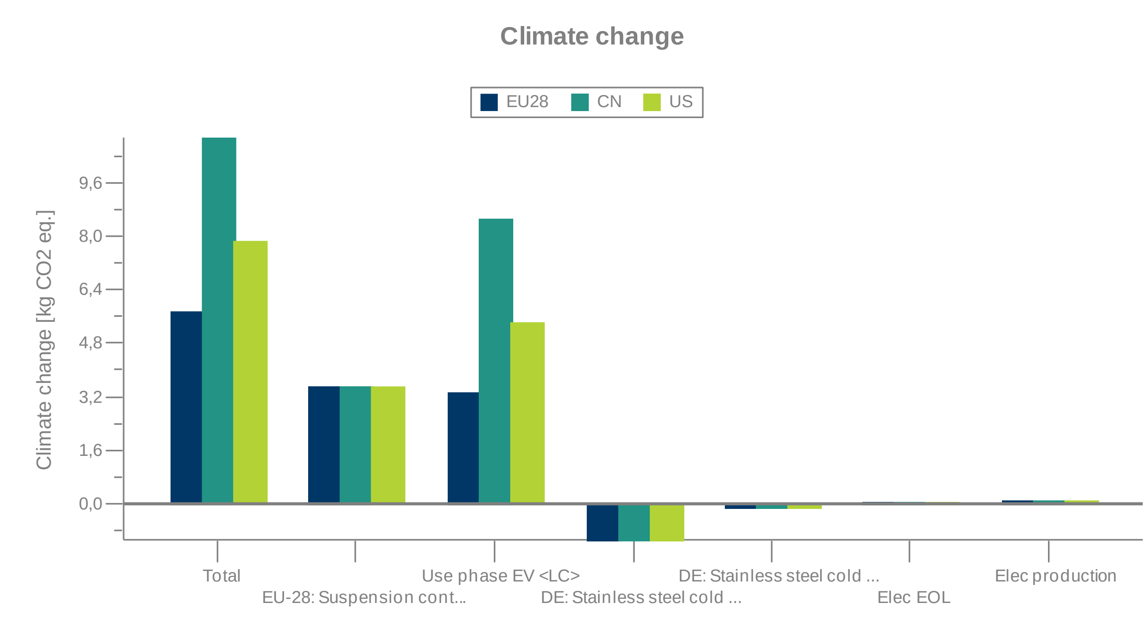

***Figure 16**: Sensitivity analysis electricity grid mix suspension control arm. Climate change.*

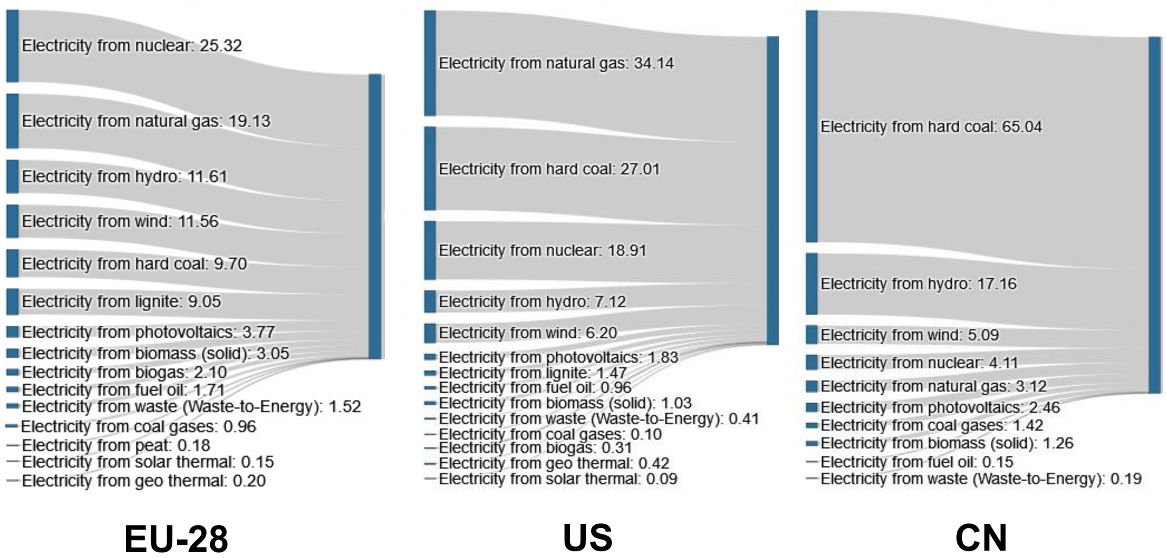

***Figure 17:** Electricity grid mixes in percentages for the European Union (28 countries), Unites States and China. (Sphera Solutions GmbH, 2018)*

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2.4.5.3. RECYCLING RATE

This study uses the price ratio between scrap and virgin material described by GaBi as the recycling rate. A reasonably conservative baseline was chosen. Future improvements in end-of-life processes are not taken into account for the baseline study. For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 0,33 (Steel) as baseline recycling rate,
- 50 more than the baseline and
- 100% more than the baseline

The results of the sensitivity analysis for the different recycling rates are provided in **Table 10**. It is clear that the effect of the higher recycling rate is the highest for the impact categories which are largely determined by the material choice, steel (see **Table 6**). Most noticeably it is the impact on human toxicity that is greatly reduced by having a higher recycling ratio, which can be explained by the fact that the human toxicity emissions mostly occur during the production of the virgin material.

Table 10: *Sensitivity analysis recycling rate suspension control arm*

	Baseline		50% more recycling		100% more recycling	
Climate change [kg CO2 eq.]	6,20E+00	100%	5,82E+00	94%	5,46E+00	88%
Fine Particulate Matter Formation [kg PM2.5 eq.]	5,21E-03	100%	4,52E-03	87%	3,87E-03	74%
Fossil depletion [kg oil eq.]	2,30E+00	100%	2,19E+00	95%	2,09E+00	91%
Human toxicity, cancer [kg 1,4-DB eq.]	1,63E+00	100%	1,25E+00	77%	8,94E-01	55%

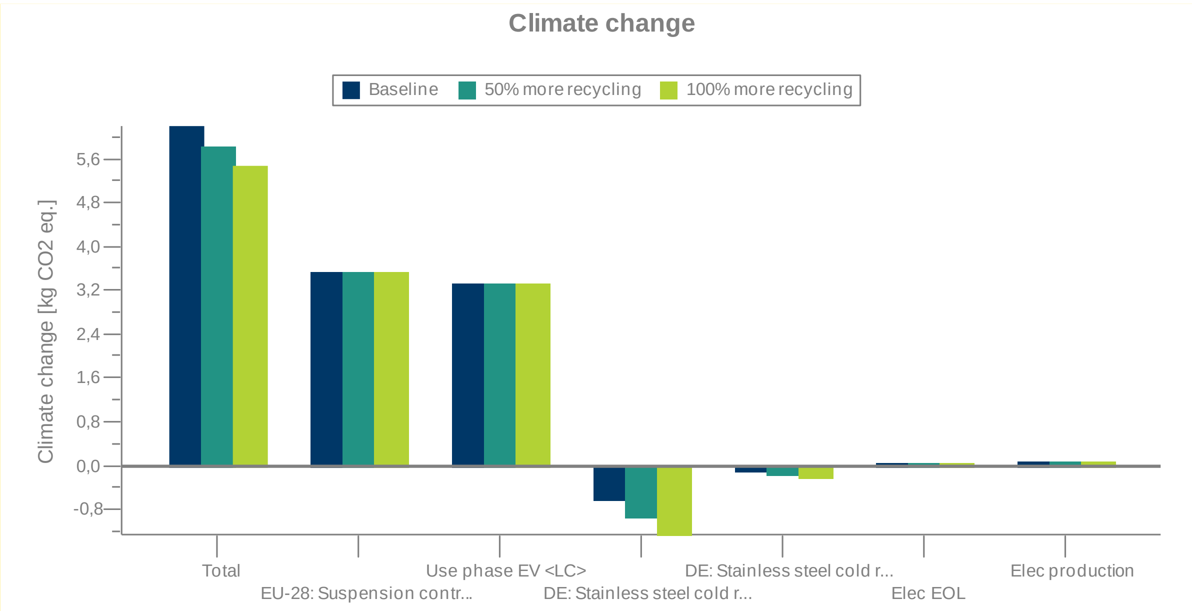

Figure 18: *Sensitivity analysis recycling rate suspension control arm. Climate change.*

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Figure 18 and **Figure 19** show the impact on climate change and human toxicity for the three scenarios. By comparing these figures, it is possible to visualise how the relative impact of the EOL increases when the emissions are mostly coming from the production phase. Since the production emissions are mostly coming from the material usage, these emissions are also saved when the materials are being recycled in the EOL phase.

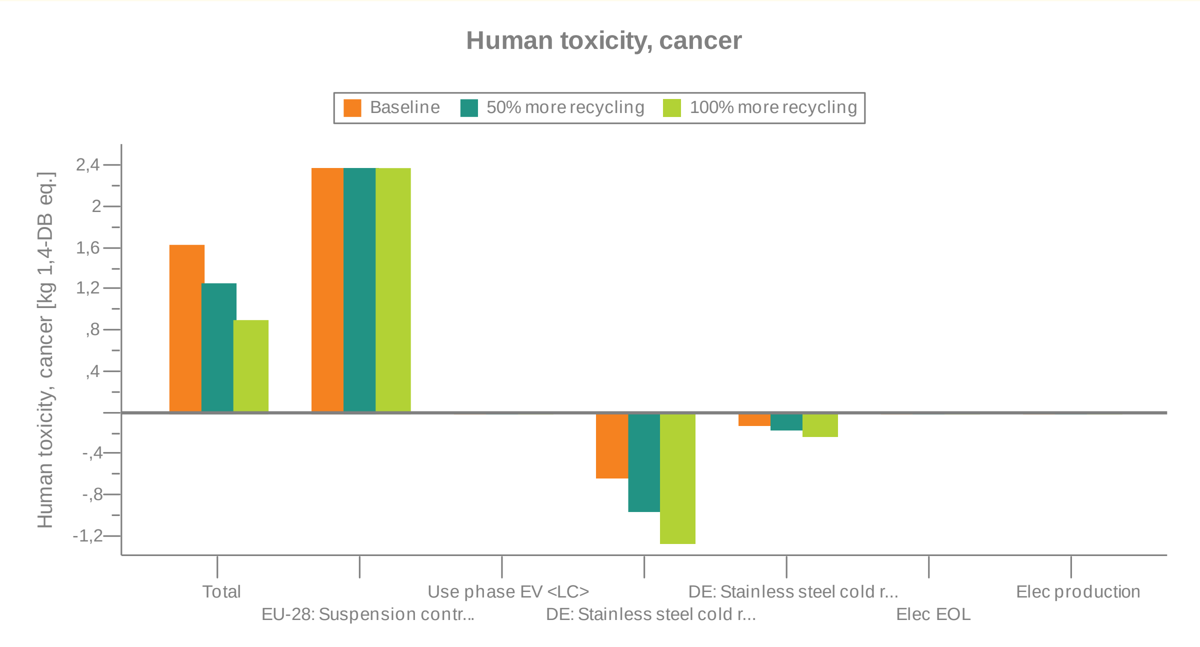

Figure 19: *Sensitivity analysis recycling rate suspension control arm. Human toxicity, cancer.*

2.5. BENCHMARK EVALUATION CONCLUSIONS

2.5.1. MAIN CONCLUSIONS FROM RESULTS

The results of the LCA show that there is not one life cycle phase which is dominant in its GHG emission output, meaning that improvement can be found on different levels. However, when concentrating more on the production phase, it is visible that the dominant factor for the emissions in this phase is the material selection (steel). Since the new design of the demonstrator will use new lightweight composite materials, it is possible that this can have a large impact on the total impact on the life cycle of the suspension control arm, but attention is required that impact is not shifted from one phase to another or to a different impact category as a direct result from the change in materials.

The LCIA indicates that multiple types of emissions have an impact on human health or ecosystems. In the case of the suspension control arm, emissions from fine particulate matter and the human toxicity impact both had a large share in the damage they've dealt to human health as does the GHG emissions. Thus these emissions cannot be ignored and should decrease as well as the GHG emissions. These emissions are most dominant in the production phase by the material that is used (steel).

The sensitivity analysis substantiates that changing variables can have a large influence on the results of the LCA. This also applies when taking into account the implications it can have for the end result of the LEVIS project, where the benchmark product is compared to the new design. The main take away from the sensitivity analysis is that the variables, which increase the influence of the use phase (electricity grid mix and lifespan of the vehicle/product), can significantly influence the difference between the environmental impact of the benchmark product and the new design, since the new

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design's aim of lightweighting mostly aims at lowering the use phase of the vehicle. The sensitivity analysis also shows that the impact of increasing the recycling rate is significant, especially for the indicators that are influenced by the material choice, which suggests that the effect of the LEVIS objectives to reuse and recycle the composite materials should be noticeable in the next LEVIS LCA report.

2.5.2. LINK TO ECO-DESIGN TOOLKIT RESULTS (D1.3)

At the start of the LEVIS project, all demonstrator partners participated in Task 1.2 (with report D1.3 as result). This task involved the development of an 'eco-design' tool and guideline (iEDGE toolkit) aimed to help the decision-making process.

The toolkit was used in WP1 of the LEVIS project in order to incorporate eco-design into the design process. Eco-design methodology is used during the first stages of a design process by identifying opportunities to improve integration of eco-design and circular economy principles into a new design. At the time the LCA was not yet performed and thus the iEDGE toolkit was performed by the partners without any LCA knowledge on their benchmark products. The tool therefore focused on providing decision-making guidance in the early (or pre) design stages. Now that the LCA of the selected benchmark product has been completed, the question arises: How do these LCA results relate to the exercise and outcomes of Eco-Design toolkit?

Table 11: *Eco-Design high level requirements suspension control arm*

Importance rating	High-level requirements - (What) ↓
3	Less waste
5	Mechanical Performances
4	Price per kg
4	Reduce energy consumptions
5	Improve environmental footprint
5	Number of injuries during production
5	Safest work environment
4	Energy-efficient low carbon transport modes
5	Non-compliant sample reduction
5	Less emission damaging human health
5	Lightweight solution to decrease use-phase impact
4	Serviceability
3	Open Loop recycling
4	Less emission damaging human health
4	Energy use for material recovery
4	Enhance part functionality

By examining the link between these results and those of the iEDGE toolkit, we can identify the benefits of incorporating LCA into the (eco-)design process. **Table 11** shows the high-level requirements Marelli identified as important for the suspension control arm in the design phase. Apart from the requirements that are more concentrated on the structural performance of the product, the focus was not only on the project objectives of simply having less GHG emissions, but also to consider other

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emissions which damage human health. The LCIA of this report showed that other impact categories (such as human toxicity and fine particulate matter formation) had considerable impact on human health.

Figure 20 shows the improvement options that Marelli suggested after the performance analysis using the iEDGE toolkit. The improvements were mainly focused on using different and less materials. Looking at the results of this LCA study, this could have a large impact on the total LCA results, both on the production phase and the use phase. Of course, the newly developed composite material should prove to have less environmental impact than steel to be able to reduce the effect of the material usage. Re-designing the component which lowers the amount of material needed should decrease the effect of both the production phase as the use phase.

Design (life-cycle) strategies	No.	Improvement option	Application Description	Intended KPI effect	Design priorities			
					Feasibility	Desirability	Priotity	New design choice
1. Material selection	1.0	Use polymeric composite instead of steel	Re-design the part to suit composite processing methodologies	GWP index [kg Co2 equ], Product weigth, Primary energy demand PED	Feasible-short term	Desirable	High Priority	Yes
2. Mining and production	2.0	Improve mining and production induced emissions	Use of thermoplastic materials and bio-sourced carbon fibers	GWP index [kg Co2 equ], Primary energy demand PED, Credits and debts at EOL	Feasible-short term	Desirable	High Priority	Yes
4. Utilisation (First and Extended use)	4.0	Part re-design to decrease the total weigth	Reduce the number of parts thanks to a different processing technology	Product weigth, GWP index [kg Co2 equ]	Feasible-short term	Desirable	High Priority	Yes

***Figure 20:** Eco-design focus strategies suspension control arm*

Looking at **Figure 21**, it can be seen that the benchmark product scores low on the material selection, utilisation and mining and production phases. The LCIA shows that the material selection and the use phase are important factors to consider to reduce the environmental impact of the suspension control arm. The transportation of the materials however did not seem to have a great impact on the overall emissions, which suggests that this was an overestimation during the design phase of the component.

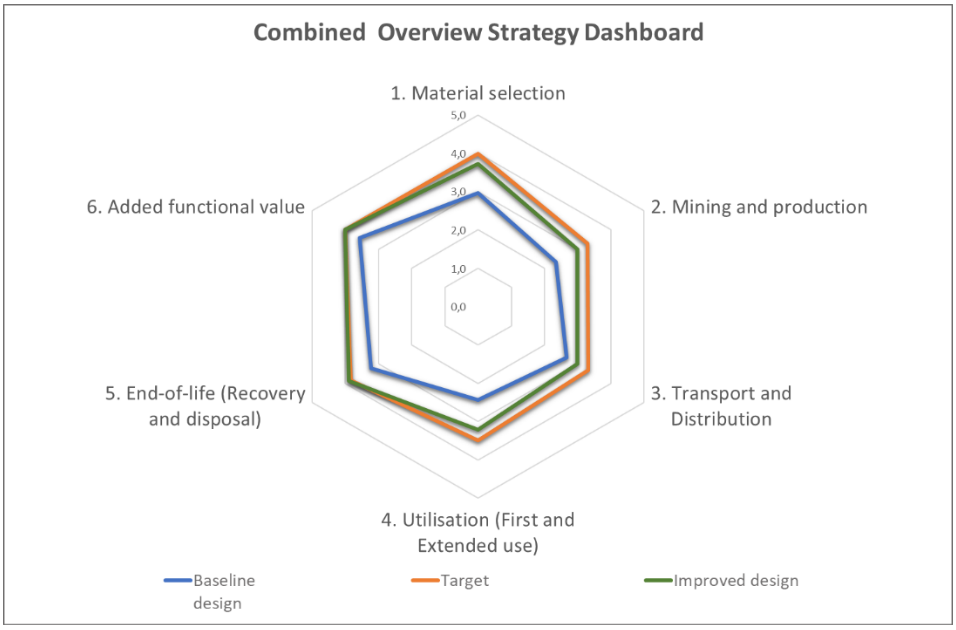

***Figure 21:** Results eco-design toolkit suspension control arm*

Overall, it can be concluded that the iEDGE toolkit already helped identify some of the bottlenecks of the current design. However, some life cycle phases (e.g., transport and distribution) are

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overestimated in importance while others (material selection) may be underestimated (looking at **Figure 21**). Using the LCA could help the designers in the eco-design process by identifying critical life cycle phases and emissions (such as the human toxicity and fine particulate matter for the suspension control arm). Even though LCA is an investment in time, it could help steer the design team in the most effective design direction.

2.5.3. POTENTIAL FOR OBJECTIVES

The impact of the use phase on the whole life cycle impact is different for every impact category (**Table 6**). It is therefore interesting to see what the impact would be if the mass would be reduced within the LEVIS objectives (20 to 40 percent). **Table 12** shows what would happen if the weight reduction requirements would be met and what the effect on the life cycle impact on a component level would be. In this scenario, the assumption is made that the energy consumption in the use phase would be considerably lower, but the production and EOL phase are unchanged.

Looking at this table, it is clear that the emission reduction objective of 25% of GHG emissions will be met only if, in addition to the decreasing of emissions during the use phase, there are also additional contributions from the rest of phases to the reduction of the GHG emissions. However, as has been stated before, the variables like lifespan, electricity grid mix and recycling rate have a large influence on the potential relative emission savings of the LEVIS demonstrators. As it is visualised as an example in **Table 12**, LEVIS will meet its objectives when the EVs would be charged in China or the US during their lifespan.

N.B: Please note that these numbers purely highlight the importance of all the life cycle phases. They are not in any way a prediction of the reduction in GHG emissions from the new design demonstrators. By light weighting through the use of new materials, one will inevitably have different emissions through all life cycle phases, with the potential of different effects on the corresponding impact categories. We expect that the final results from the LEVIS demonstrators (to be published in D6.2 towards the end of the project) will provide more concrete insights and we will be able to say more definitively whether, or to what extent, LEVIS is able to meet its environmental objectives.

Table 12: *Suspension control arm: Potential emission reduction effect of lightweight design in percentages (when it only affects use phase) for the electricity grid mix scenario.*

	EU-28		CN		US	
Mass reduction	**20%**	**40%**	**20%**	**40%**	**20%**	**40%**
Resource depletion						
Fossil depletion (%)	12	24	14	27	14	28
Damage to Human health						
Climate change (%)	11	21	15	30	13	26
Fine Particulate Matter Formation (%)	6	11	13	26	6	12
Human toxicity, cancer (%)	0	0	0	0	0	0
Damage to ecosystems						
Climate change (%)	11	21	15	30	13	26

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006888.

3. LCA BENCHMARK DEMO 2A – BATTERY BOX

3.1. GOALS AND SCOPE DEFINITION

This chapter describes the goal and scope of the Life Cycle Analysis (LCA) of the LEVIS battery box benchmark product. This benchmark product (i.e., a vehicle component) is relevant to the new product LEVIS partner Yesilova is developing.

3.1.1. GENERAL DESCRIPTION OF BENCHMARK PRODUCT

The battery box used as a benchmark is related to an EV which is produced in China. The electric vehicle is a D class type and the battery has a capacity between 80 and 100Kwh depending on the configurations. It contains 10 battery modules and protects them during operation and in case of an accident. It also supports the modules by integrating them within the vehicle frame and has an important role in safety. The internal structure is very accurate to facilitate wiring and heat dissipation within the battery modules. The battery box is mostly made of aluminium with some plastic or rubber components. The product details are shown in **Table 13**.

Table 13: *Product details battery box*

Product name	Battery Box
Model	Thunder power EV/TP
Manufacturer	Thunder Power
Country/countries of manufacturing	China
Year of manufacturing	2019

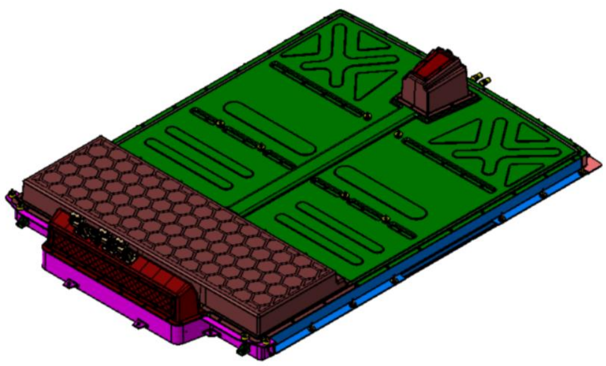

Figure 22: *Battery box*

Figure 23: *Battery box welded internal and external profiles*

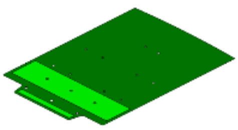

Figure 25: *Battery box bottom cover sheet*

Figure 24: *Battery box upper cover sheet*

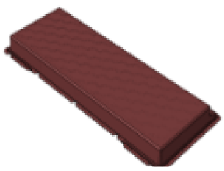

Figure 26: *Battery box plastic parts of upper cover*

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3.1.2. OBJECTIVES

This study aims to identify the absolute and relative environmental performance of a benchmark battery box and the LEVIS newly developed battery box. The goal of this study is to see whether the battery box meets the environmental objectives set at the start of the project. This means that the comparative statements will be made regarding the environmental performance of the two products. However, these statements are only included in "part 2" of the LCA reporting. Since "part 1" only covers the environmental performance of the benchmark product.

Overarching project objectives

The project objectives regarding the environmental performance across all demonstrators are listed below:

- The demonstrators are expected to have a 20-40% in weight reduction compared to the benchmark product.
- The demonstrators should have at least a 25% reduction in global warming potential (GWP) at component level.
- The demonstrators should have at least a 7% reduction in global warming potential (GWP) at vehicle level.

Demonstrator specific objectives

WP5 stated as objective that the hybrid CFRP/metal components (side beam and internal profile see **Figure 23**) will be de-bonded, where at least 80% of the de-bonded CFRP will be reused, repurposed or recovered from CF and Elium resin. The metal part will be 95-98%% recycled, so at least 80% of the CFRP/metal components will be recycled.

In relation to the overarching project objective, one of the demo specific objectives is to increase the potential for circularity of the new battery box by aiming for the highest feasible level of modularity of the design in such a way that dismantling, repairs or replacements require no or minimally specialised efforts (such as additional machinery, skills or certifications). Since this is not possible to quantify by means of a LCA, a survey concerning the effects and results of the iEDGE toolkit will be held to determine whether these objectives were met.

The LCAs performed in this study should determine whether the newly designed demonstrators meet the objectives or not. Even though the objectives of the LEVIS project focus on the global warming potential, this study also looks at other emissions and impacts across the life cycle stages and can be clustered across the following impact categories:

- Resource depletion
- Human Health
- Terrestrial ecosystems
- Marine ecosystems
- Freshwater ecosystems

A full list of impact (sub)categories can be found in the ANNEX section, which are split into so called Midpoint and Endpoint indicators (also see 3.3 for further explanations).

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3.1.3. SYSTEM FUNCTION AND FUNCTIONAL UNIT (RESEARCH QUESTION)

The parameter to define the functionality of the component is called the functional unit and is key in LCA in order to make a measurable evaluation and comparison of the benchmark product and the demonstrator. The lifespan of the vehicle can be different per benchmark vehicle, but for the sake of this study, this is kept equal across all demonstrators. The functional unit is defined as below:

> *The functional unit for this study is the installation and usage of a battery box which last the whole life of a D class electric vehicle driving a WLTP cycle, in a manner that maintains the functionality of the vehicle and safety of the occupants. The average lifespan is considered to be 160.000 km.*

3.1.4. SYSTEM BOUNDARIES

3.1.4.1. GENERAL SYSTEM DESCRIPTION

The life cycle phases (visualized in **Figure 27**) that are being considered for the battery box are the following:

- The extraction of all raw materials.
- The production and manufacturing of the parts.
- The transportation of the materials and parts to the manufacturing sites.
- The usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- Lastly, through the end-of-life of the components themselves.

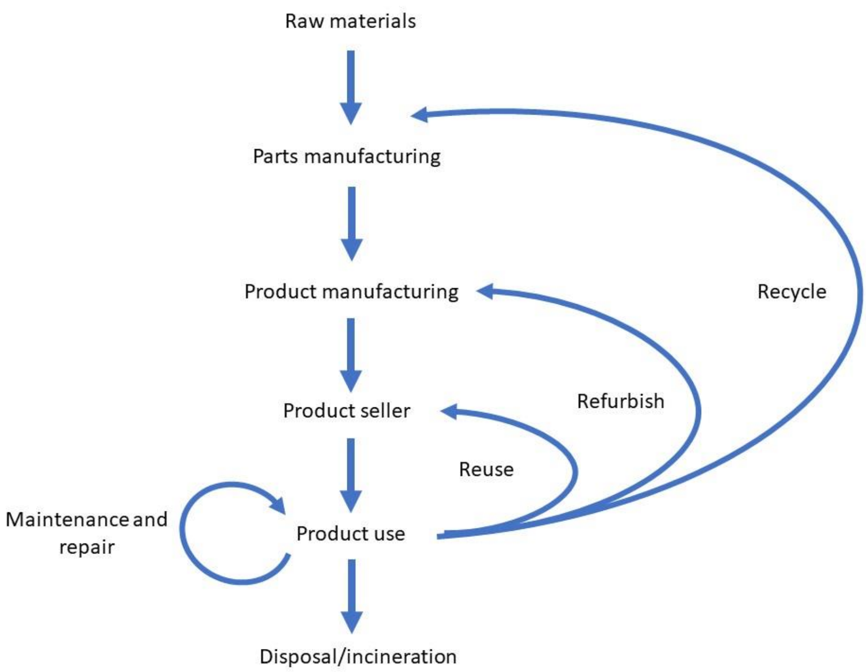

***Figure 27**: Life cycle phases of a product*

3.1.4.2. COVERAGE OF ENVIRONMENTAL INTERVENTIONS AND IMPACTS

As is mentioned in the “objectives” paragraph, the main targets of the LEVIS project relate to the global warming potential of the demonstrators. The results of this study will be mainly focused on the emissions that are related to this impact category. However, all impact categories and associated emissions that are part of the ReCiPe 2016 (RIVM, 2011) impact assessment method are considered.

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Any "remarkable" results from the impact categories will also be discussed in to results section of the report.

3.1.4.3. TEMPORAL AND GEOGRAPHIC BOUNDARIES

This study mostly uses data extracted from the GaBi database. Other data comes from either literature studies or directly from the industrial plants (provided by the DEMO partners). All datasets that are used have to be valid until the end of the LEVIS project (2024). The geographical representativeness of the datasets is dependent on life cycle stage of the process. As default, the EU-28 (European Union, 28 countries) averages are used, unless specific knowledge of the region of production is known. For example, concerning the manufacturing of the battery box itself, China is used as geographical region. When multiple datasets for one process are available, a quick analysis on the specific datasets needs to be performed. The criteria on the choice datasets are the following:

Geographical representativeness:

- Choose the dataset that is located in the specific region the process occurs.
- If unknow or unavailable, use EU-28 (European) averages.
- If unavailable, use the Global (GLO) averages.

Geographical representativeness:

- Choose the dataset which reference year falls under the 'years of manufacturing' of the benchmark vehicle.
- If unavailable or when multiple datasets fall under this requirement, choose the dataset with the most recent reference year.

3.1.4.4. TREATMENT OF RECYCLED MATERIALS

Allocation of the recycling and reuse of the materials is important in LCA. The method in this LCA study to account for this is to apply scrap credits to the steel and aluminium scrap that comes from all the production processes and end-of-life systems. This is called "value-corrected substitution" and is a method used in LCIA (Life Cycle Impact assessment) which tackles the downcycling issue in LCA when handling products with high scrap ratios.

During production and EOL, large volumes of scrap are produced and recycled. However, the material quality is often lower than that of the virgin material, which means that often the scrap material can't be replaced by virgin material on a one-by-one basis. The "value-corrected substitution" method uses the price ratio between different grades of scrap (based on their quality) and the virgin material. The price ratio for the materials used in the model are the following:

- ABS scrap price ratio: 0,264 (Plasticker, n.d.)
- Aluminium scrap price ratio: 0,21 (GaBi)

Figure 28 provides an example of how this method is used in LCA. In this example the shredded steel from the post-shredding/sorting process is directed to a process called "No. 4 shredded steel-scrap credit". This is the process containing the price ratio of the scrap and the virgin steel. The number (No. 4 in this example) relates to the quality of the scrap material. The second input in this process is the "DE: Stainless steel cold rolled", which is a negative input, which means that the environmental impact of the stainless steel is now environmental savings (negative emissions).

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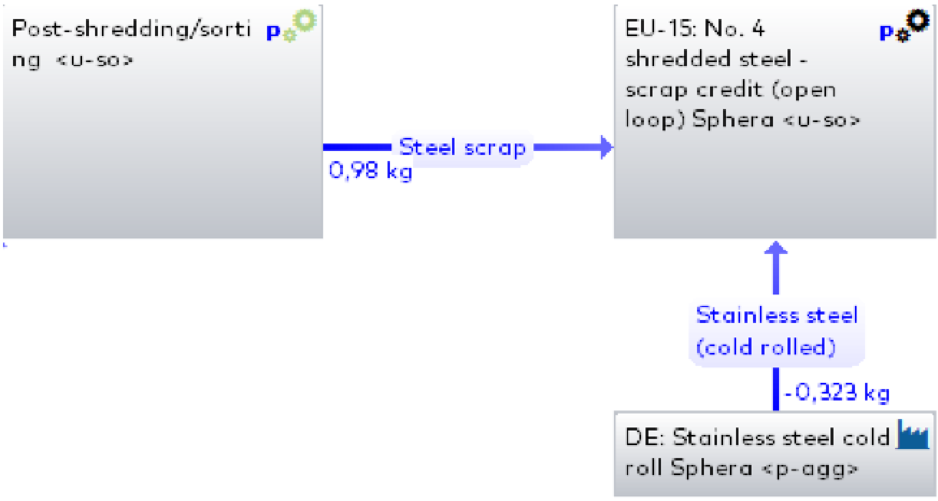

Figure 28: *Example value-corrected substitution method in EOL phase*

3.1.4.5. EXCLUSION AND CUT-OFF CRITERIA

This report is part of a comparative LCA. However, it was decided that, even though two systems are compared to each other, the identical processes are still accounted for in the LCA. Processes will be excluded if the mass or energy flows are less than 1% of the total. Mass and energy are used to estimate the environmental relevance, since it is not possible to determine the environmental relevance of a flow without having to perform a LCA in the first place.

3.1.5. DATA SOURCES AND ASSUMPTIONS

The data of the database from Sphera GaBi is used for the all the background processes of the life cycle of the demonstrators. This includes the production of aluminium ingots, sheets and plastic granulate, but also the flow inputs as electricity and cooling water. The most representable data regarding the real-life scenario is used to make an as accurate analysis as possible. The processes that are used to fabricate the parts themselves are derived from Yesilova and the production area.

3.2. LIFE CYCLE INVENTORY

3.2.1. PRODUCTION

3.2.1.1. MATERIAL PRODUCTION AND REFINING

The following materials (**Table 14**) are based on the Bill of Materials (BOM). Although the secondary materials that are needed for the manufacturing processes are included in the entirety of the LCA, they are not specified in this table. All the materials are coupled with the datasets provided by the GaBi database. The column "region" relates to the geographical representativeness of the datasets. These datasets represent the extraction of raw materials. As in Chapter 3.1.4.2 the materials flows accounting for less than 1% of the total mass are not accounted for.

Table 14: *Material use battery box*

Material	**Mass % of product**	**Mass % of material**	**Region**
Aluminium	95%		
Aluminium ingot		64%	CN
Aluminium sheet		36%	CN
Acrylonitrile-Butadiene-Styrene Granulate	5 %		DE

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3.2.1.2. MANUFACTURING PROCESSES

The processes that are used to manufacture the battery box are listed in **Table 15** below:

All processes except for plastic injection and aluminium forging are extracted from the production site. The dataset of the plastic injection process represents averages in Germany, which was the most representable dataset available in the database.

Table 15: *Processes battery box*

Processes	**Database**	**Source**	**Country**
Aluminium sheet welding	Production site	Yesilova	CN
Aluminium forging	Sphera	GaBi	CN
Aluminium casting	Production site	Yesilova	CN
Plastic injection	Sphera	GaBi	DE
Laser cutting aluminium	Production site	Yesilova	CN
Aluminium extrusion	Production site	Yesilova	CN

3.2.2. USE

The (benchmark) demonstrators do not have a 'direct' use phase, in which they use energy by themselves. However, on a vehicle level, they do influence the energy consumption of the vehicle by their weight. In order to calculate the energy consumption associated with the benchmark demonstrator, the following formula is used:

$$EC_{benchmark} = \frac{ERV * m_{benchmark} * mileage_{use}}{10000}$$

Where;

ERV = Energy Reduction Value (kWh/(100kmx100kg));

$m_{Benchmark}$ = Vehicle mass reduction (kg)

$EC_{benchmark}$ = Energy consumption through mass (kWh)

$mileage_{use}$ = Lifetime vehicle (km)

The ERV (see **Table 16**) is extracted from the literature based on Del Pero, et al. (2020) and is based on the vehicle class and driving cycle. For this study, the World Light Test Procedure (WLTP) is used.

Table 16: *Benchmark vehicle demonstrators*

Demonstrator	**Vehicle class**	**Milage (km)**	**ERV (kWh/100km*100kg)**
Suspension Control Arm	B	160.000	0.56
Battery Holding Set	D	160.000	0.66
Cross Car Beam	C	160.000	0.58

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3.2.3. END-OF-LIFE

The processes of the end-of-life phase are provided by Yesilova. During the End-of-Life phase the battery box is dismantled, and the metals, plastics and batteries are separated. The metals follow the following process steps:

- Sorting aluminium by cutting the welded parts and separating all the parts according to the material type.
- Shredding the parts into small pieces
- Using mechanical and chemical cleaning processes
- Melt the aluminium for secondary casting.

The melting and casting process is not taken into account during the analysis. This is because this is allocated to the secondary aluminium product.

There is some rubber waste from the sealing and gasketing, which is send to landfill. The batteries and their end-of-life processes are not taken into account for this analysis.

3.3. LIFE CYCLE IMPACT ASSESSMENT

ReCiPe 2016 is chosen as the primary assessment method for this study. This method is recognized by the EU (EUR 25167 EN – 2012, (European Commission, 2011)) as a Life Cycle Impact Assessment (LCIA) method. The ReCiPe method can be used using three different cultural perspectives. These cultural perspectives represent different expectations such as timespan or the level of impact by future technology to avoid or mitigate future damages. The ReCiPe method differentiates the following three perspectives:

- Individualist: Short term view and optimistic about future technology
- Hierarchist: Default model. Used most often in scientific models and assumed to be the consensus model.
- Egalitarian: Long term view which is based on precautionary principle thinking.

For this study, the consensus model (Hierarchist) will be used as the preferred method. The Global Warming Potential (GWP) for the ReCiPe model is described as “Climate Change” in GaBi. Thus, the results of this study are all related to the effect of the components on Climate Change and are expressed kg CO2-eq as metric unit.

In the results, both the so called „Midpoint” and „Endpoint“ indicators of the whole life cycle process are calculated. Midpoint indicators focus on a single environmental problem, while Endpoint indicators show the environmental impact of the Midpoint indicators on three higher aggregation level (RIVM, 2011):

- Damage to Human Health (DALY)
- Damage to ecosystems (species per year) containing:
    - Terrestrial ecosystems
    - Marine ecosystems
    - Freshwater ecosystems
- Resource depletion ($)

The unit “DALY” stands for Disability-Adjusted Life Years and takes into account the years lost to reduced quality of life due to illness and premature death. One DALY represents the loss of one year

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of a healthy life for one person. The unit "Species per year" stands for the number of species lost per year due to the environmental impact, while the unit dollars ($) of resource scarcity represents the extra costs involved to extract future mineral and fossil resources.

As explained in chapter 3.1.4.2, the (midpoint) impact categories which show „remarkable" results are discussed. The following impact categories were considered in the results section:

- Climate Change (kg CO2 eq.): (Human made) emissions that have effect on the radiative forcing of the earth's atmosphere.
- Fine Particulate Matter Formation (kg PM2.5 eq.): Particles with a diameter of 2,5 µm or less which is suspended in the atmosphere. These particles have a negative effect on human health when inhaled into the lungs.
- Fossil depletion (kg oil eq.): Extraction of non-renewable natural fossil resources.
- Terrestrial Acidification (kg SO2 eq.): Toxic substances which change soil chemical properties, decline the pH level and decrease fertility of the soil.

3.3.1. CALCULATIONS TOOLS AND METHODS

GaBi Professional is used as the LCA software modelling tool to calculate the GHG emissions of the benchmark products. GaBi is also used as the database to quantify the flows that were unavailable by the LEVIS partners, in order to complete the Life Cycle Inventory. The final results are calculated by using the data derived from the LEVIS partners (foreground data, in-house processes) and cradle-to-gate background flows and processes. GaBi is then also used to perform the Life Cycle Impact Assessment and compute the final results of the study.

3.3.2. LIMITATIONS, DEVIATIONS AND LINKS TO OTHER WPS

Deviations from the Grant Agreement were made concerning the benchmark vehicles. Every demonstrator has a benchmark product that is used for a different type of vehicle. Meaning that the original benchmark vehicle (1500 kg EV) is no longer relevant. The benchmark vehicles are described in chapter 3.2.2.

There was limited data available for the emissions and energy use for the production and EOL phase of the benchmark products. The LCA was largely reliant on datasets from databases in GaBi.

Links between Workpackages were mostly with WP1 (see chapter 3.5.2 & 3.1.1, eco-design and the description of the demonstrators). The LCA of the demonstrators themselves (not included in this report) will have a link with WP1 to WP6. The demonstrators are made partly from new composite materials from new processes, making the LCA less reliant on databases and more reliant on data from other partners and workpackages.

3.4. RESULTS

The results are presented and compared along three different life cycle phases: the production phase, the use phase and the end-of-life phase. The three phases consist of the following:

- Production phase: The extraction of the raw materials, the production and manufacturing of the parts and the transportation of the materials and parts to the manufacturing sites
- The Use phase: the usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.

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- The End-of-Life phase: The processes needed to recover, recycle, or dispose of the product and its materials. It also consists of the credits gained due to the second-life of the materials through potential recycling or reuse.

3.4.1. WHOLE LIFE CYCLE IMPACT

The total environmental impact of the benchmark product is provided in **Table 48** & **Table 49** in Appendix 8.2. **Table 17** shows the environmental impact on the three impact levels (as mentioned in Section 3.3). In this table, we will look at the impact categories with the highest impact on their respective impact level (damage to human health, resource depletion and damage to ecosystems). The following impact categories are selected as having the highest impact on their impact level (see **Table 17**). This table also shows which life cycle phase has the most impact on set impact category.

From the table, it is interesting to see that the production phase has by far the most effect on all the relevant impact categories. Since this is the only demonstrator that uses a relatively high amount of aluminium, it is suggested that this material has a relatively amount of emissions per kilogram compared to ABS and steel (which is the main material of the other demonstrators).

Table 17: *Battery box: impact categories with highest percentage of total impact. Included is the indication of which life cycle phase shares the largest contribution to that particular impact category*

	Percentage of total impact to endpoint indicator	Relative influence of production	Relative influence of use phase	Relative influence of recycling	Relative influence of EOL
Resource depletion					
Fossil depletion	98%	106%	23%	-35%	6%
Damage to Human health					
Climate change	54%	96%	21%	-18%	1%
Fine Particulate Matter Formation	44%	109%	8%	-18%	1%
Damage to ecosystems					
Climate change	70%	96%	21%	-18%	1%
Terrestrial Acidification	18%	110%	9%	-19%	1%

3.4.2. PRODUCTION

The production phase of the battery box contains many different components and processes. For this research, we will focus mainly on the materials and processes that have the highest influence on the selected impact categories of **Table 17**.

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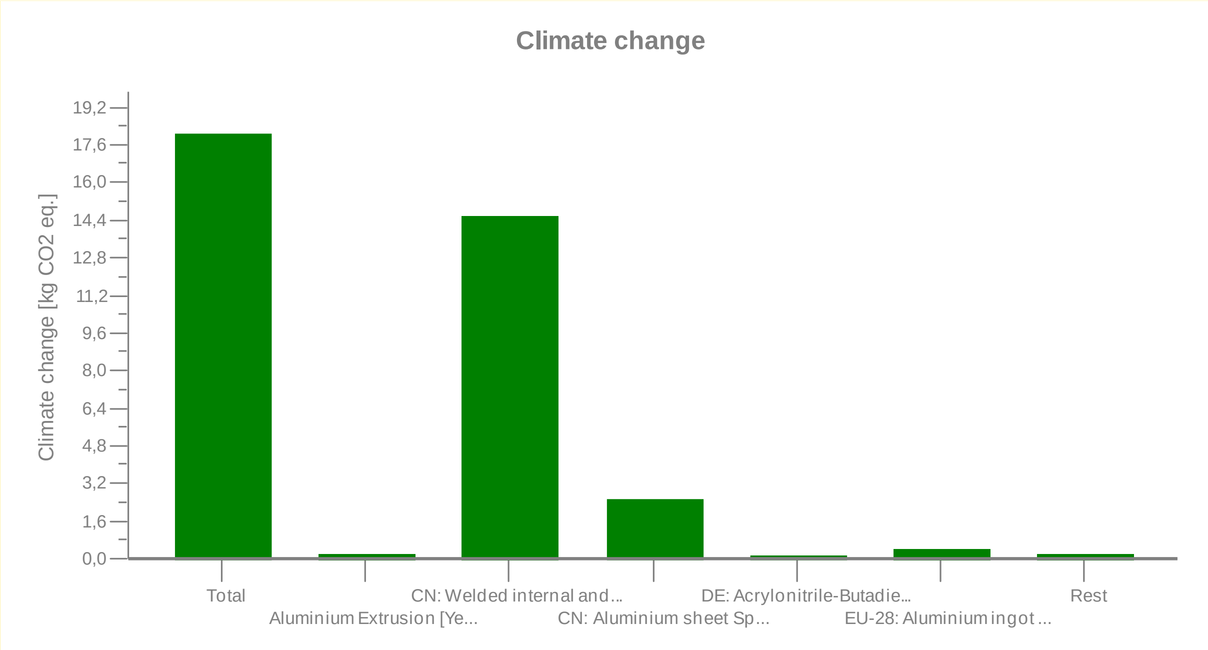

***Figure 29:** Battery box: impact of production on climate change*

Figure 29 shows the CO2 eq. emissions (climate change impact category) that are emitted during the production phase. The left bar shows the total emissions during the production phase, while the bars to the right show the emissions per component. The largest influence is the production of the internal and external profiles which are produced by aluminium extrusion (these profiles are welded to each other during the assembly process). **Figure 30** shows the CO2 eq. emissions that are emitted during the production of the welded internal and external profile only. It is clear that most emissions come from the material use. However, the electricity usage needed for the bending, stamping, welding and forging of the aluminium also seems to have a considerate impact.

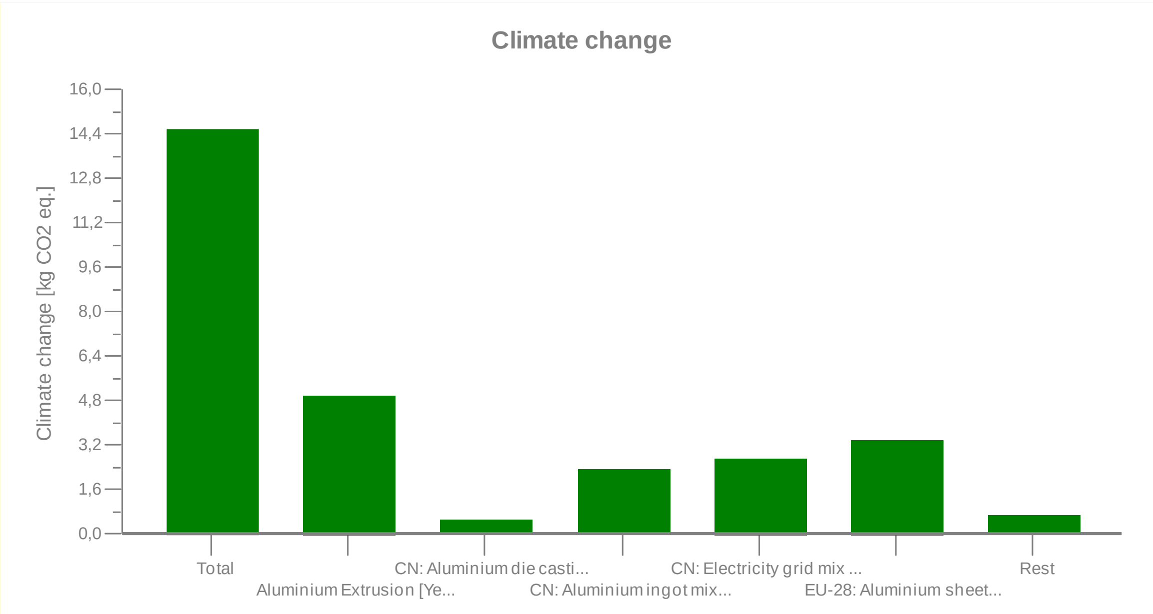

***Figure 30:** Battery box: impact of internal and external profiles on climate change*

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3.4.3. USE

In **Table 18**, the primary energy demand for the use phase of the battery box is provided. This is the associated energy consumption for 1 kg of a class D electric vehicle driving 160.000 km in its lifetime. As can be seen from the table below, about two thirds of the primary energy demand come from non-renewable energy resources. Charging the EV with other energy grid mix could change this number and therefore the environmental impact in the use phase.

Table 18: *Primary energy demand use phase battery module*

	Use phase
Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]	114
Primary energy from non-renewable resources (gross cal. value) [MJ]	74,6
Primary energy from renewable resources (gross cal. value) [MJ]	39,2

3.4.4. END-OF-LIFE

As can be seen from **Figure 31**, the environmental impact for the electricity consumption and thermal energy of the shredder used in the end-of-life phase is minimal compared to the other phases. Similar effects can be seen looking at other impact categories. The emission savings that come from the recycling of the aluminium is by far the largest influence on the total emissions in the EOL phase. The largest influence on improvement would be to increase the reuse, recovery and/or recycling rate and quality of aluminium scrap.

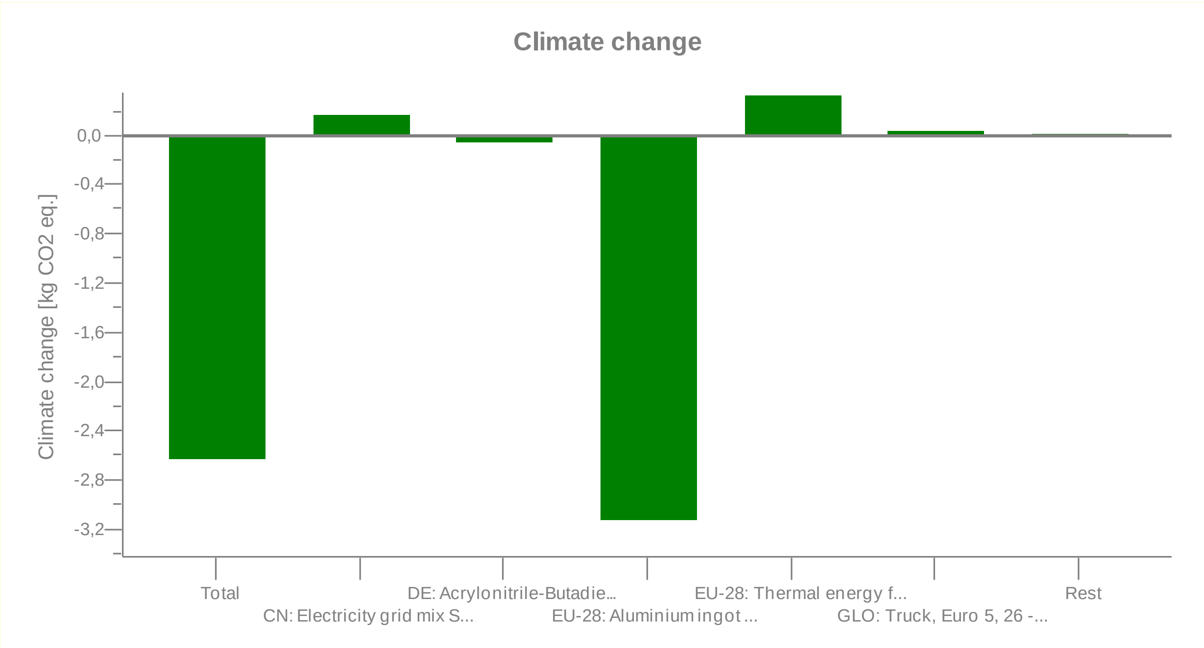

Figure 31: *Impact on climate change EOL battery box.*

3.4.5. SENSITIVITY ANALISYS

The indicated System Function and Functional unit (section 3.1.3) reflects a specific scenario (a set of parameters and assumptions) against which results are calculated. As these parameters and assumptions contain a certain degree of variability and uncertainty, it would be good practice to

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explore a few 'what if' scenarios. For this purpose, a sensitivity analysis is performed to evaluate the influence of these assumptions and parameters on the conclusions of this report. For this study, three variables are chosen for the sensitivity analysis.

3.4.5.1. LIFESPAN

This study uses the general lifespan as a variable for the sensitivity analysis. The baseline lifespan is defined (see scope definition) as 160.000 kilometres. This can be considered a conservative assumption, since research showed that the lifespan of EVs can be significantly longer (C. P. Aiken, 2022). For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 160.000 km (baseline lifespan),
- 240.000 km (150% of baseline) and
- 300.000 km (as least conservative estimation)

The results of the sensitivity analysis are provided in **Table 19**. Keep in mind that these results are provided in kg CO2 eq. per kilometre driven. The table shows the environmental impact, and the emission savings when raising the lifespan of the vehicle compared to the baseline. What is clear is that the largest "savings" can be found in the terrestrial acidification and fine particulate matter impact categories. This is logical, since these emissions come mostly from the production phase, which stays unaltered when increasing the lifespan of the vehicle. As a result, the relative contribution per driven kilometre reduces.

***Table 19**: Results sensitivity analysis lifespan battery box*

	160000 km		240000 km		300000 km	
Climate change [kg CO2 eq.]	1,18E-04	*100%*	8,71E-05	*74%*	7,47E-05	*63%*
Fine Particulate Matter Formation [kg PM2.5 eq.]	1,39E-07	*100%*	9,67E-08	*69%*	7,97E-08	*57%*
Fossil depletion [kg oil eq.]	3,26E-05	*100%*	2,51E-05	*77%*	2,21E-05	*68%*
Terrestrial Acidification [kg SO2 eq.]	3,86E-07	*100%*	2,69E-07	*70%*	2,22E-07	*58%*

Figure 32 and **Figure 33** show the total (so not per km) environmental impact on climate change and FPMF respectively, which again illustrates that the impact on climate change has more effect in the use phase than FPMF.

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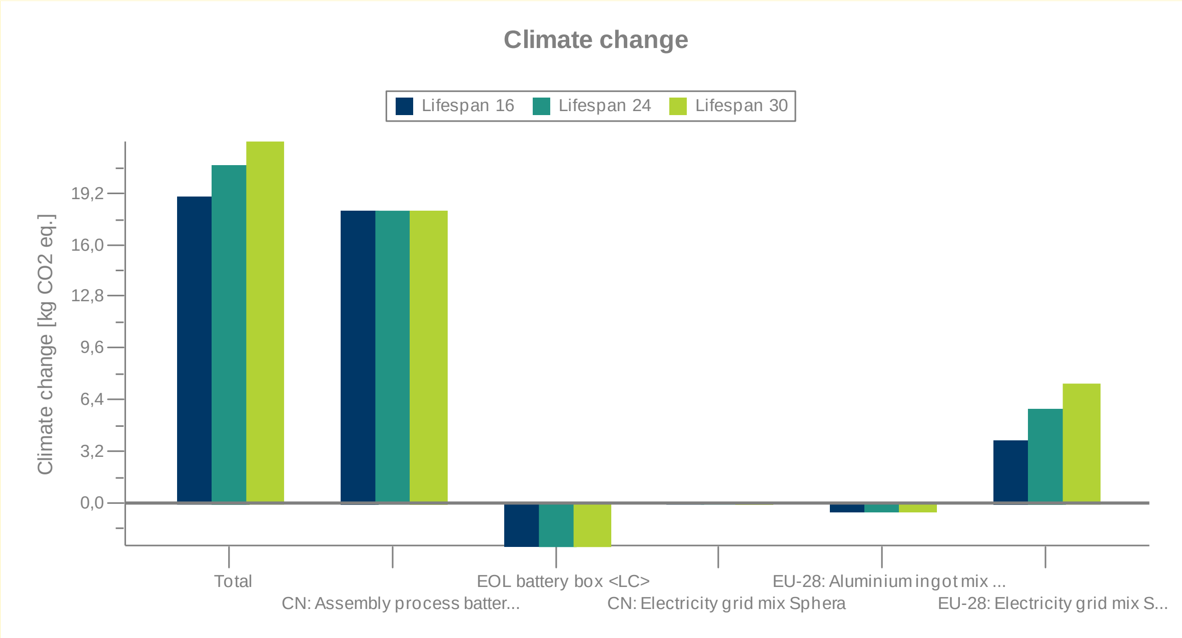

***Figure 32**: Sensitivity analysis lifespan battery box. Climate change.*

The longer the lifespan of the EV, the higher the relative impact of the use phase of the product in comparison to the production and end-of life phase. Since the use phase impact (by electricity consumption) is solely driven by the mass of the product (see chapter 3.2.2), the potential environmental savings are also larger in the longer lifespan scenarios. It could be argued that a longer lifespan may also have a carryover effect in avoided or postponed impact from replacement needs. As such, the sensitivity analysis confirms that a longer lifespan could have significant impact on the final results of the LEVIS project, which will be explored and evaluated further in the final LCA deliverable, D6.2.

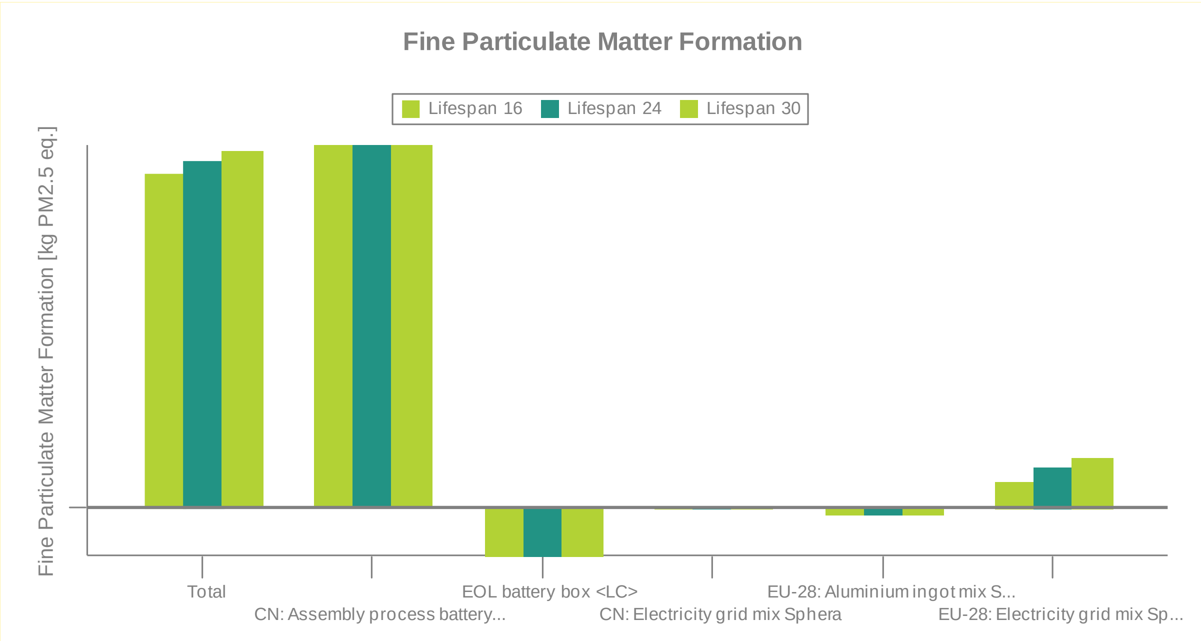

***Figure 33**: Sensitivity analysis lifespan battery box. Fine Particulate Matter Formation.*

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3.4.5.2. ELECTRICITY GRID MIX

This study uses the electricity grid mix for the use phase as a variable for the sensitivity analysis. The baseline is the EU-28 electricity grid mix for the use phase. The two other two electricity grid mixes that are chosen are the Chinese (CN) and the United Stated (US) grid mixes. They are chosen, because they form a relatively large percentage of the total energy consumption in the world, for a single country. They are also chosen because they consist of quite different energy source mixes (see **Figure 35**). The Chinese grid mixes relies most on coal power, while the US also on gas and nuclear. The EU-28 has the most diverse electricity grid mix.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 20**. Keep in mind that these are the results concerning the whole life cycle of the component, not just the use phase. It is clear from the results that the difference between electricity production can have a massive influence on the results of the study, which is true for all impact categories. As mentioned before, Chinese electricity grid mixes are currently mostly reliant on coal, which is a large contributor to the emissions.

Table 20: *Results sensitivity analysis electricity grid mix battery box.*

	EU28		CN		US	
Climate change [kg CO2 eq.]	1,89E+01	100%	2,90E+01	153%	2,05E+01	108%
Fine Particulate Matter Formation [kg PM2.5 eq.]	2,23E-02	100%	2,91E-02	130%	2,23E-02	100%
Fossil depletion [kg oil eq.]	5,21E+00	100%	7,56E+00	145%	5,54E+00	106%
Terrestrial Acidification [kg SO2 eq.]	6,18E-02	100%	8,09E-02	131%	6,15E-02	100%

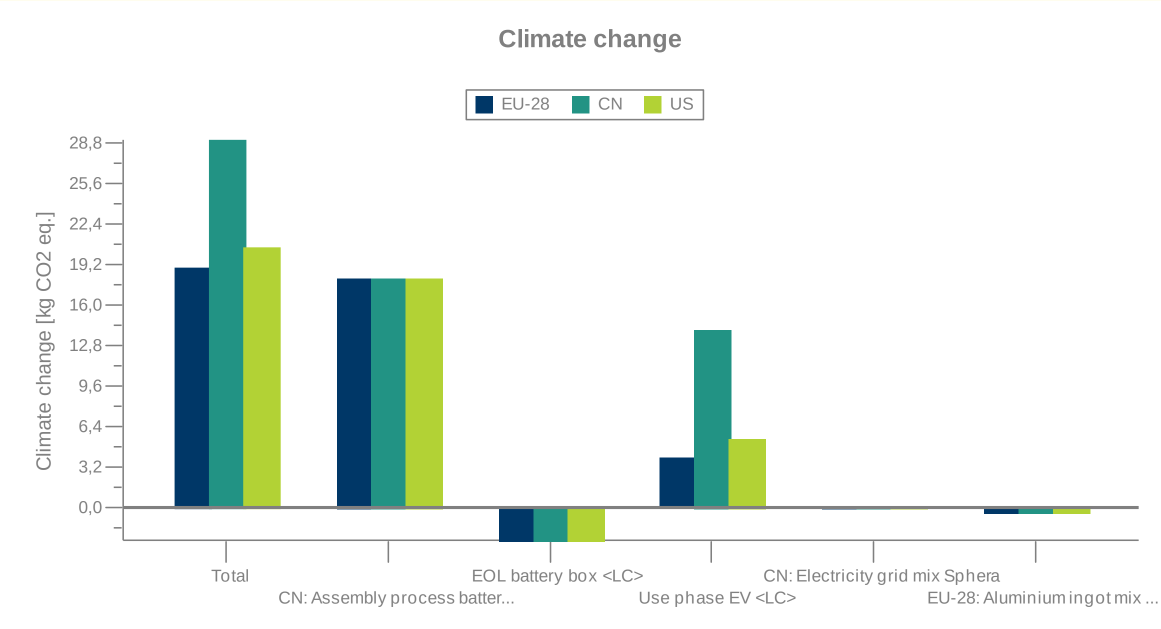

Figure 34: *Results sensitivity analysis electricity grid mix battery box. Climate change.*

Figure 34 shows the impact on climate change in the three scenarios. A large spike can be seen in the use phase for the Chinese electricity grid mix, and a smaller one for the US electricity grid mix. This also increases the relative impact of the use phase of the product and implies that, similar to the chapter 3.4.5.1, the potential impact of the weight reduction objective within LEVIS project, will have greater environmental savings in absolute numbers if the electric vehicles are used in regions with less environmental friendly energy grid mixes. Consequently, any relative increase in the (electric) energy required for the production and end-of-life phases for the new designs would also translate into a higher absolute environmental impact.

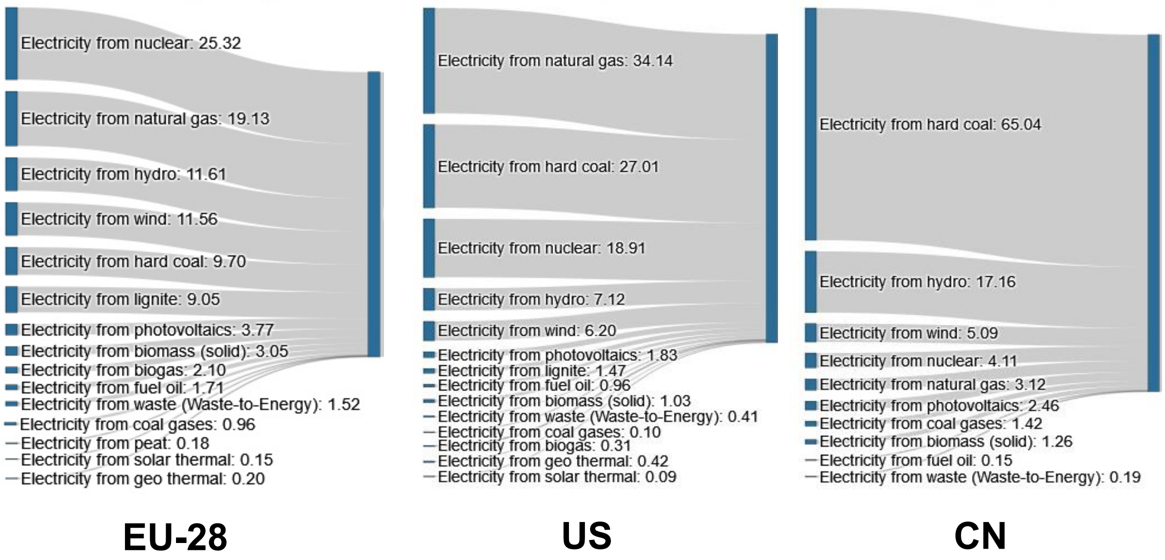

***Figure 35:** Electricity grid mixes in percentages for the European Union (28 countries), Unites States and China. (Sphera Solutions GmbH, 2018)*

3.4.5.3. RECYCLING RATE

This study uses the price ratio between scrap and virgin material described by GaBi as the recycling rate. A reasonably conservative baseline was chosen. Future improvements in end-of-life processes are not taken into account for the baseline study. For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 0,264 for ABS and 0,21 for aluminium as the baseline recycling rate,
- 50 more than the baseline and
- 100% more than the baseline

The results of the sensitivity analysis for the different recycling rates are provided in **Table 21** and **Figure 36**. The effect of increasing the recycling rate is almost equal in all impact categories, which is logical since the relative influence of the production phase is also almost equal in all impact categories. The emissions from the production phase mostly come from the material usage. These emissions are also “saved” when the materials are being recycled. It is interesting to see that the savings are still relatively small (in comparison to the results of the other LEVIS demo’s benchmark products), especially since the production phase and the material choice (aluminium) have such a high influence on the total emissions of the battery box. The most probable explanation for this would be that the for

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the EOL phase, **EU-28** aluminium is used to calculate the emission "savings" (see chapter 3.2.3 for more information on the LCA recycling method used), which is different from the aluminium that is used for the production (**CN** aluminium). Like the difference between electricity grids, the origin of materials also has a significant influence on the total emissions of the vehicle. The EU-28 aluminium for the EOL phase was chosen, because in the real-life scenario, the recycling of the materials does not always occur within the country of production.

***Table 21**: Results sensitivity analysis recycling rate battery box*

	Baseline		50% more recycling		100% more recycling	
Climate change [kg CO2 eq.]	1,89E+01	100%	1,73E+01	92%	1,58E+01	84%
Fine Particulate Matter Formation [kg PM2.5 eq.]	2,23E-02	100%	2,05E-02	92%	1,88E-02	84%
Fossil depletion [kg oil eq.]	5,21E+00	100%	4,73E+00	91%	4,28E+00	82%
Terrestrial Acidification [kg SO2 eq.]	6,18E-02	100%	5,62E-02	91%	5,10E-02	83%

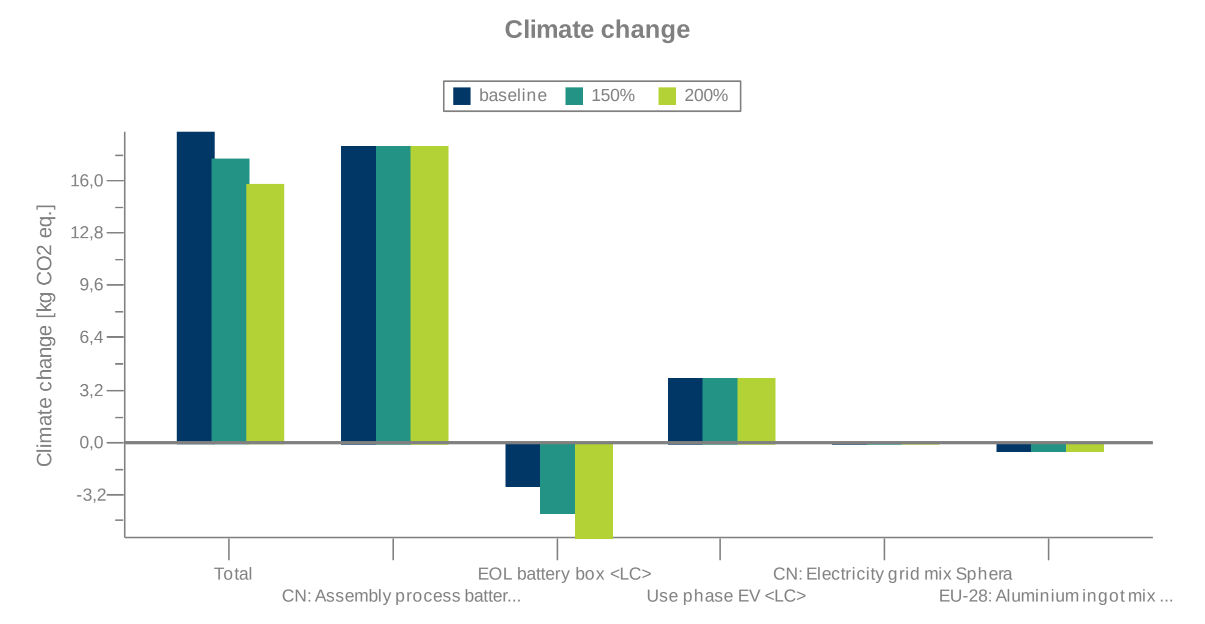

***Figure 36:** Results sensitivity analysis recycling rate battery box. Climate change.*

3.5. BENCHMARK EVALUATION CONCLUSIONS

3.5.1. MAIN CONCLUSIONS FROM RESULTS

The results of the LCA show that the life cycle phase which is dominant in its GHG emission output is the production phase. When concentrating more on the production phase, it is visible that the dominant factor for the emissions in this phase is the material selection and chosen production methods (e.g. aluminium and casting). Since the new design of the demonstrator aims to remove the casted parts, reduce 90% welding and weight in all aluminium parts (for instance 60% weight reduction in bottom cover etc.) and use new lightweight composite materials, it is possible that this can have a large impact on the total impact on the life cycle of the battery box. But it should be ensured that impact is not shifted from one phase to another or to a different impact category as a direct result from the change in materials.

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The LCIA indicates that multiple types of emissions have an impact on human health or ecosystems. In the case of the battery box, emissions from fine particulate matter almost had an equal share as the GHG emissions in the damage to human health impact category, meaning that the FPM emissions cannot be ignored and should decrease as well as the GHG emissions.

The sensitivity analysis substantiates that changing variables can have a large influence on the results of the LCA. This also applies when taking into account the implications it can have for the end result of the LEVIS project, where the benchmark product is compared to the new design. The main take away from the sensitivity analysis is that the variables which increase the influence of the use phase (electricity grid mix and lifespan of the vehicle/product) can significantly influence the difference between the environmental impact of the benchmark product and the new design, since the new design's aim of light weighting mostly aims at lowering the use phase of the vehicle. The sensitivity analysis also showed that the impact of increasing the recycling rate is significant and could be even larger when the recycled materials replace virgin materials from the same origin of production. This suggests that the effect of the LEVIS objectives to reuse and recycle the composite materials should be noticeable in the next LEVIS LCA report.

3.5.2. LINK TO ECO-DESIGN TOOLKIT RESULTS (D1.3)

At the start of the LEVIS project, all demonstrator partners participated in Task 1.2 (with report D1.3 as result). This task involved the development of an 'eco-design' tool and guideline (iEDGE toolkit) aimed to help the decision-making process.

The toolkit was used in WP1 of the LEVIS project in order to incorporate eco-design into the design process. Eco-design methodology is used during the first stages of a design process by identifying opportunities to improve integration of eco-design and circular economy principles into a new design. At the time the LCA was not yet performed and thus the iEDGE toolkit was performed by the partners without any LCA knowledge on their benchmark products. The tool therefore focused on providing decision-making guidance in the early (or pre) design stages. Now that the LCA results of the selected benchmark product has been completed, the question arises: How do these LCA results relate to the exercise and outcomes of Eco-Design toolkit?

By examining the link between these results and that of the iEDGE toolkit, we can identify the benefits of incorporating LCA into the (eco-)design process.

Table 22 shows the high-level requirements Yesilova identified as important for the battery box in the design phase. Apart from the requirements that are more concentrated to the structural performance of the product, the focus was not only on the projects objectives of simply having lightweight components, but also to consider other life cycle phases as production (lower energy consumption during production and EOL (easier dismantling). The LCA showed that the manufacturing phase has a relatively high effect compared to other phases, mostly from material usage (aluminium) and partly from the electricity consumption during the manufacturing of the components of the benchmark product, which was considered a high-level requirement.

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Table 22: *High level requirements battery box*

Importance rating	High-level requirements - (What) ↓
4	Increased recyclability
4	Lower emissions during production
5	Light Material Usage
5	Lower energy consumption during production
3	Lower transport costs
5	Safety
5	Lower Running Costs
4	Increased recyclability
5	Increased reusability
5	More energy

Figure 37 shows the improvement options that Yesilova suggested after the performance analysis using the iEDGE toolkit. All the improvements were focused on the safety and running costs of the product, which is interesting since, based on the input entered in the iEDGE toolkit, resulted in the indication that these factors were more important to improve than the environmental factors.

Design (life-cycle) strategies	No.	Improvement option	Application Description	Intended KPI effect	Design priorities			
					Feasibility	Desirability	Priotity	New design choice
1. Material selection	1.0	Emission reduction	Reduction of production emissions	CO2,CO,NOx,HC emissions	Feasible-long term	Desirable	Low Priority	No
	1.3	Energy Storage	Increased Energy Storage	Weight Reduction % mass, Energy Density (kWh/kg)	Feasible-long term	Desirable	Low Priority	No
4. Utilisation (First and Extended use)	4.0	Running cost	Decreasing running costs	running costs €, structural integrity	Feasible-short term	Desirable	High Priority	Yes
6. Added functional value	6.1	Safety	Increased Safety	Sealing performance, structural integrity	Feasible-short term	Desirable	High Priority	Yes

Figure 37: *Focus strategies by iEDGE toolkit battery box*

Looking at **Figure 38**, it can be seen that the benchmark product scores low on the transport and distribution and mining and production phases, which, according to the LCA data, is proven to be correct since the environmental impact resulting from the manufacturing phase is most significant for all impact categories.

Overall, it can be concluded that the iEDGE toolkit already helped identify some of the bottlenecks of the current design. However, some life cycle phases (e.g. transport and distribution) are overestimated in importance while others (material selection) may be underestimated (see **Figure 38**). Using the LCA could help the designers in the eco-design process by identifying critical life cycle phases and emissions (such as the fine particulate matter emissions for the battery box). Even though LCA is an investment in time, it could help steer the design team in the most effective design direction.

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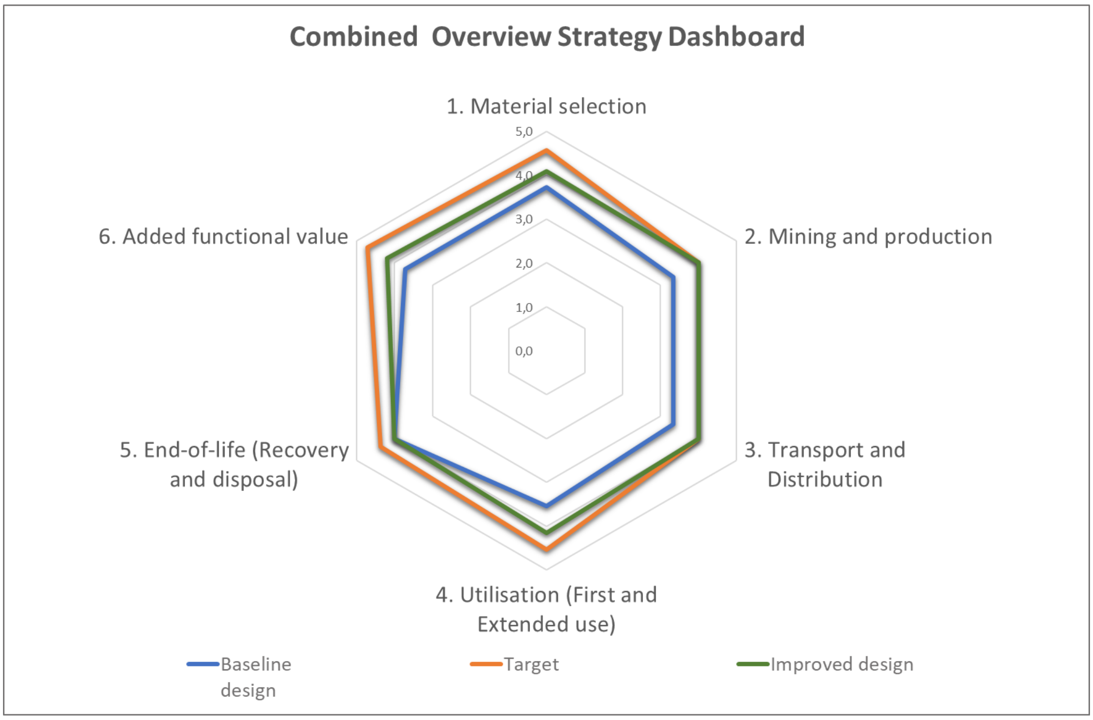

Figure 38: *Results eco-design toolkit battery box*

3.5.3. POTENTIAL FOR OBJECTIVES

The impact of the use phase on the whole life cycle impact is different for every impact category. It is therefore interesting to see what the impact would be if the mass would be reduced within the LEVIS objectives (20 to 40 percent). **Table 23** shows what would happen if the weight reduction requirements would be met and what the effect on the life cycle impact on a component level would be. In this scenario, the assumption is made that the energy consumption in the use phase would be considerably lower, but the production and EOL phase are unchanged.

Looking at this table, it is clear that the emission reduction objective of 25% of GHG emissions will be met only if, in addition to the decreasing of emissions during the use phase, there are also additional contributions from the rest of phases to the reduction of the GHG emissions. However, as has been stated before, the variables like lifespan, electricity grid mix, and recycling rate have a large influence on the potential relative emission savings of the LEVIS demonstrators. However, LEVIS still won't meet the objectives even when for example the electricity grid mix changes (see **Table 23**). This means that production and/or EOL emissions need to decrease as well for the LEVIS objectives to be met.

N.B: Please note that these numbers purely highlight the importance of all the life cycle phases. They are not in any way a prediction of the reduction in GHG emissions from the new design demonstrators. By light weighting through the use of new materials, one will inevitably have different emissions through all life cycle phases, with the potential of different effects on the corresponding impact categories. We expect that the final results from the LEVIS demonstrators (to be published in D6.2 towards the end of the project) will provide more concrete insights and we will be able to say more definitively whether, or to what extent, LEVIS is able to meet its environmental objectives.

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Table 23: *Battery box: Potential emission reduction effect of lightweight design in percentages (when it only affects use phase) for the electricity grid mix scenario.*

	EU-28		CN		US	
Mass reduction	**20%**	**40%**	**20%**	**40%**	**20%**	**40%**
Resource depletion						
Fossil depletion (%)	4	8	11	21	7	14
Damage to Human health						
Climate change (%)	5	8	10	19	5	11
Fine Particulate Matter Formation (%)	1	3	6	12	2	3
Damage to ecosystems						
Climate change (%)	5	8	10	19	5	11
Terrestrial Acidification (%)	2	3	6	12	2	3

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4. LCA BENCHMARK DEMO 2B – BATTERY MODULE

4.1. GOALS AND SCOPE DEFINITION

This chapter describes the goal and scope of the Life Cycle Analysis (LCA) of the LEVIS battery module benchmark product.

4.1.1. GENERAL DESCRIPTION OF THE BATTERY MODULE

The main function of the module is to store and distribute energy during the operation of the car. The module housing is a mechanical casing for the cells. The housing's main function is to thermally, mechanically, and electrically protect the cells and make sure there is electrical distribution through the busbar system. Every battery box has 10 modules per car.

The product details are shown in **Table 24**. The component identified as benchmark product is related to an EV which is produced in China. The electric vehicle is a D class type vehicle.

Table 24: *Product details benchmark battery module*

Product name	Battery Box
Model	Thunder power EV/TP
Manufacturer	Thunder Power
Country/countries of manufacturing	China
Year of manufacturing	2019

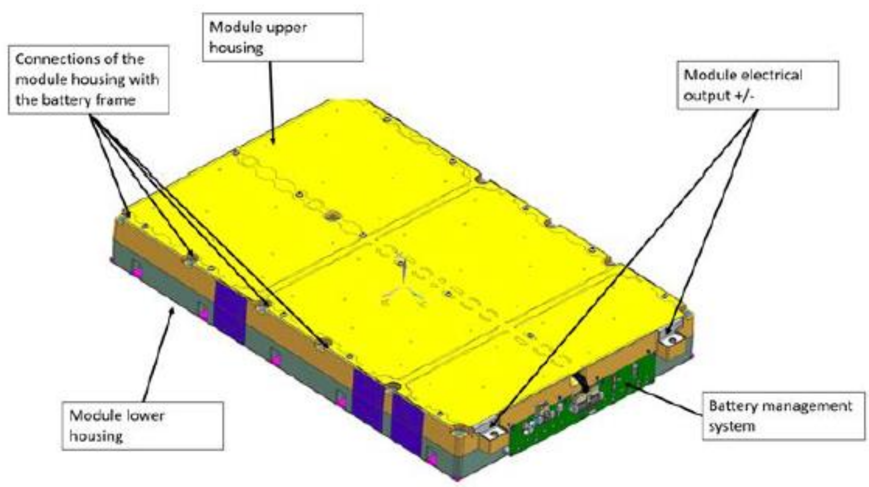

Figure 39: *Visual representation design battery module*

4.1.2. OBJECTIVES

This study aims to identify the absolute and relative environmental performance of a benchmark battery module and the LEVIS newly developed battery module. The goal of this study is to see whether the battery module meets the environmental objectives set at the start of the project. This means that the comparative statements will be made regarding the environmental performance of the two

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products. However, these statements are only included in “part 2” of the LCA reporting, since “part 1” only covers the environmental performance of the benchmark product.

Overarching project objectives

The project objectives regarding the environmental performance across all demonstrators are listed below:

1. The demonstrators are expected to have a 20-40% in weight reduction compared to the benchmark product.
2. The demonstrators should have at least a 25% reduction in global warming potential (GWP) at component level.
3. The demonstrators should have at least a 7% reduction in global warming potential (GWP) at vehicle level.

Demonstrator specific objectives

In relation to the first objective, one of the demo specific objectives defined is to have a weight reduction of 25%, which is in line with the project objective of 20-40%. The battery module also ought to have a minimum recycling rate of 80%.

WP5 does not have a recycling objective stated for the battery module. Instead, they will assess the quality grade of remoulded composite compared to the primary composite material to determine its reuse potential.

The LCAs performed in this study should determine whether the newly designed demonstrators meet the objectives or not. Even though the objectives of the LEVIS project focus on the global warming potential, this study also looks at other emissions and impacts across the life cycle stages and can be clustered across the following impact categories:

- Resource depletion
- Human Health
- Terrestrial ecosystems
- Marine ecosystems
- Freshwater ecosystems

A full list of impact (sub)categories can be found in the ANNEX section, which are split into so called Midpoint and Endpoint indicators (also see Section 4.3 for further explanations).

4.1.3. SYSTEM FUNCTION AND FUNCTIONAL UNIT (RESEARCH QUESTION)

The parameter to define the functionality of the component is called the functional unit and is key in LCA in order to make a measurable evaluation and comparison of the benchmark product and the demonstrator. The lifespan of the vehicle can be different per benchmark vehicle, but for the sake of this study, this is kept equal across all demonstrators. The functional unit is defined as below:

The functional unit for this study is the installation and usage of twelve battery modules which last the whole life of a D class electric vehicle driving a WLTP cycle, in a manner that maintains the functionality of the vehicle and safety of the occupants. The average lifespan is considered to be 160.000 km.

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4.1.4. SYSTEM BOUNDARIES

4.1.4.1. GENERAL SYSTEM DESCRIPTION

The life cycle phases (visualized in **Figure 40**) that are being considered for the battery module are the following:

- The extraction of all raw materials.
- The production and manufacturing of the parts.
- The transportation of the materials and parts to the manufacturing sites.
- The usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- Lastly, through the end-of-life of the components themselves.

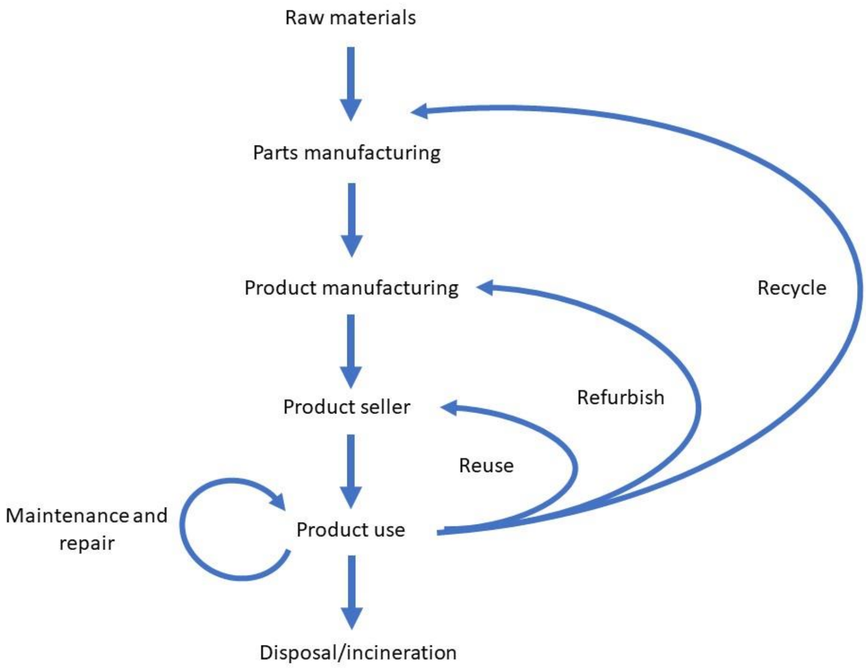

***Figure 40**: Life cycle phases of a product*

4.1.4.2. COVERAGE OF ENVIRONMENTAL INTERVENTIONS AND IMPACTS

As is mentioned in the "objectives" paragraph, the main targets of the LEVIS project relate to the global warming potential of the demonstrators. The results of this study will mainly focus on the emissions that are related to this impact category. However, all impact categories and associated emissions that are part of the ReCiPe 2016 (RIVM, 2011) impact assessment method are considered. Any "remarkable" results from the impact categories will also be discussed in the results section of the report.

4.1.4.3. TEMPORAL AND GEOGRAPHIC BOUNDARIES

This study mostly uses data extracted from the GaBi database. Other data comes from either literature studies or directly from the industrial plants (provided by the DEMO partners). All datasets that are used have to be valid until the end of the LEVIS project (2024). The geographical representativeness of the datasets is dependent on life cycle stage of the process. As default, the EU-28 (European Union, 28 countries) averages are used, unless specific knowledge of the region of production is known. For example, concerning the manufacturing of the battery module itself, China is used as geographical

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region. When multiple datasets for one process are available, a quick analysis on the specific datasets needs to be performed. The criteria on the choice datasets are the following:

Geographical representativeness:

1. Choose the dataset that is located in the specific region the process occurs.
2. If unknow or unavailable, use EU-28 (European) averages.
3. If unavailable, use the Global (GLO) averages.

Geographical representativeness:

- Choose the dataset which reference year falls under the 'years of manufacturing' of the benchmark vehicle.
- If unavailable or when multiple datasets fall under this requirement, choose the dataset with the most recent reference year.

4.1.4.4. TREATMENT OF RECYCLED MATERIALS

Allocation of the recycling and reuse of the materials is important in LCA. The method in this LCA study to account for this is to apply scrap credits to the steel and aluminium scrap that comes from all the production processes and end-of-life systems. This is called "value-corrected substitution" and is a method used in LCIA (Life Cycle Impact assessment) which tackles the downcycling issue in LCA when handling products with high scrap ratios.

During production and EOL, large volumes of scrap are produced and recycled. However, the material quality is often lower than that of the virgin material, which means that often the scrap material can't be replaced by virgin material on a one-by-one basis. The "value-corrected substitution" method uses the price ratio between different grades of scrap (based on their quality) and the virgin material. The price ratio for the materials used in the model are the following:

- ABS scrap price ratio: 0,264 (Plasticker, n.d.)
- Steel scrap price ratio: 0,21 (GaBi)

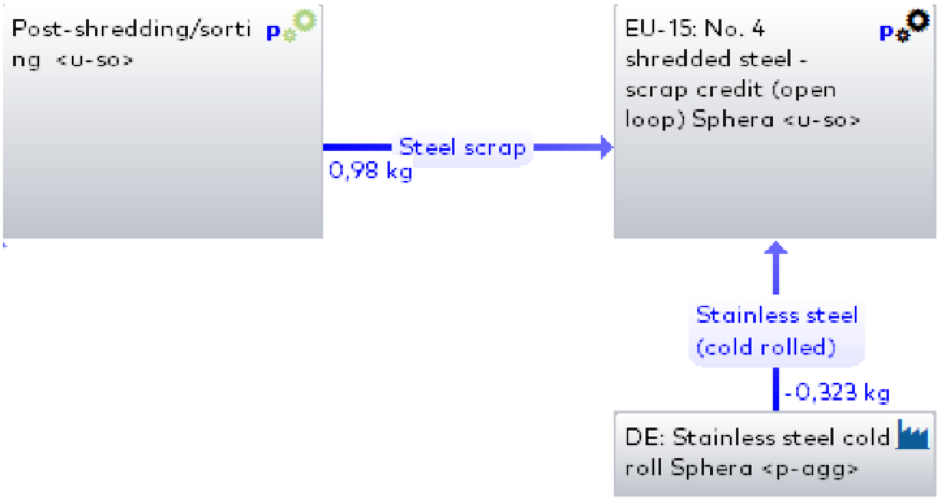

Figure 41: *Example value-corrected substitution method in EOL phase*

Figure 41 provides an example of how this method is used in LCA. In this example the shredded steel from the post-shredding/sorting process is directed to a process called "No. 4 shredded steel-scrap credit". This is the process containing the price ratio of the scrap and the virgin steel. The number (No. 4 in this example) relates to the quality of the scrap material. The second input in this process is the "DE: Stainless steel cold rolled", which is a negative input, which means that the environmental impact of the stainless steel is now environmental savings (negative emissions).

4.1.4.5. EXCLUSION AND CUT-OFF CRITERIA

This report is part of a comparative LCA. However, it was decided that, even though two systems are compared to each other, the identical processes are still accounted for in the LCA. Processes will be excluded if the mass or energy flows are less than 1% of the total. Mass and energy are used to estimate the environmental relevance, since it is not possible to determine the environmental relevance of a flow without having to perform a LCA in the first place.

4.1.5. DATA SOURCES AND ASSUMPTIONS

The data of the database from Sphera GaBi is used for the all the background processes of the life cycle of the demonstrators. This includes the production of steel and plastic granulate, but also the flow inputs as electricity and thermal energy. The most representable data regarding the real-life scenario is used to make an as accurate analysis as possible. The processes that are used to fabricate the parts themselves are derived from Mersen and the production area.

4.2. LIFE CYCLE INVENTORY

4.2.1. PRODUCTION

4.2.1.1. MATERIAL PRODUCTION AND REFINING

The following materials (**Table 25**) are based on the Bill of Materials (BOM). Although the secondary materials that are needed for the manufacturing processes are included in the entirety of the LCA, they are not specified in this table. All the materials are coupled with the datasets provided by the GaBi database. The column "region" relates to the geographical representativeness of the datasets. These datasets represent all the processes and steps involved over the supply chain of the cradle to gate inventory. Most of the data is based on industry data from a specific region, which is shown in the table.

Table 25: *Material use battery module*

Material	**Mass (%)**	**Region (database)**
Acrylonitrile-Butadiene-Styrene	59%	DE
Steel hot rolled coil (fasteners)	2%	Asia
Epoxy glass	3%	DE
Copper	36%	GLO

4.2.1.2. MANUFACTURING PROCESSES

The processes that are used to manufacture the battery module are listed in **Table 26** below:

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Table 26: *Processes battery module*

Processes	Database	Source	Region
Plastic injection moulding	GaBi	Yesilova	CN
Assembly battery module	GaBi	Privé	CN

4.2.2. USE PHASE

The (benchmark) demonstrators do not have a 'direct' use phase, in which they use energy by themselves. However, on a vehicle level, they do influence the energy consumption of the vehicle by their weight. In order to calculate the energy consumption associated with the benchmark demonstrator, the following formula is used:

$$EC_{benchmark} = \frac{ERV * m_{benchmark} * mileage_{use}}{10000}$$

Where;

ERV = Energy Reduction Value (kWh/(100kmx100kg));

$m_{Benchmark}$ = Vehicle mass reduction (kg)

$EC_{benchmark}$ = Energy consumption through mass (kWh)

$mileage_{use}$ = Lifetime vehicle (km)

The ERV (see **Table 27**) is extracted from the literature based on Del Pero, et al. (2020) and is based on the vehicle class and driving cycle. For this study, the World Light Test Procedure (WLTP) is used.

Table 27: *Benchmark vehicle demonstrators*

Demonstrator	Vehicle class	Milage (km)	ERV (kWh/100km*100kg)
Suspension Control Arm	B	160.000	0.56
Battery Holding Set	D	160.000	0.66
Cross Car Beam	C	160.000	0.58

4.2.3. END-OF-LIFE

The processes of the end-of-life phase are provided by either Mersen or PRIVE. During the End-of-Life phase of the battery box and the modules the battery pack is dismantled, and the metals, plastics and batteries are separated. The metals follow the following process steps:

1. Sorting aluminium by cutting the welded parts and separating all the parts according to the material type.
2. Shredding the parts into small pieces
3. Using mechanical and chemical cleaning processes
4. Melt the aluminium for secondary casting.

To account for the downcycling of the plastic scrap, a price ratio between plastic scrap from (ec.europa.eu, 2022) and virgin scrap (plasticker.de, 2022) is used.

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The melting and casting process is not taken into account during the analysis. This is because this is allocated to the secondary aluminium product.

There is some rubber waste from the sealing and gasketing, which is send to landfill. The batteries and their end-of-life processes are not taken into account for this analysis.

4.3. LIFE CYCLE IMPACT ASSESSMENT

ReCiPe 2016 is chosen as the primary assessment method for this study. This method is recognized by the EU (EUR 25167 EN - 2012) as a Life Cycle Impact Assessment (LCIA) method. The ReCiPe method can be used using three different cultural perspectives. These cultural perspectives represent different expectations such as timespan or the level of impact by future technology to avoid or mitigate future damages. The ReCiPe method differentiates the following three perspectives:

- Individualist: Short term view and optimistic about future technology
- Hierarchist: Default model. Used most often in scientific models and assumed to be the consensus model.
- Egalitarian: Long term view which is based on precautionary principle thinking.

For this study, the consensus model (Hierarchist) will be used as the preferred method. The Global Warming Potential (GWP) for the ReCiPe model is described as "Climate Change" in GaBi. Thus, the results of this study are all related to the effect of the components on Climate Change and is expressed kg CO2-eq as metric unit.

In the results, both the so called „Midpoint" and „Endpoint" indicators of the whole life cycle process are calculated. Midpoint indicators focus on a single environmental problem, while Endpoint indicators show the environmental impact of the Midpoint indicators on three higher aggregation level (RIVM, 2011):

- Damage to Human Health (DALY)
- Damage to ecosystems (species per year) containing:
  - Terrestrial ecosystems
  - Marine ecosystems
  - Freshwater ecosystems
- Resource depletion ($)

The unit "DALY" stands for Disability-Adjusted Life Years and takes into account the years lost to reduced quality of life due to illness and premature death. One DALY represents the loss of one year of a healthy life for one person. The unit "Species per year" stands for the number of species lost per year due to the environmental impact. While the unit dollars ($) of resource scarcity represents the extra costs involved to extract future mineral and fossil resources.

As explained in chapter 4.1.4.2, the (midpoint) impact categories which show „remarkable" results are discussed. The following impact categories were considered for in the results section:

- Climate Change (kg CO2 eq.): (Human made) emissions that have effect on the radiative forcing of the earth's atmosphere.
- Fine Particulate Matter Formation (kg PM2.5 eq.): Particles with a diameter of 2,5 µm or less which is suspended in the atmosphere. These particles have a negative effect on human health when inhaled into the lungs.

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- Fossil depletion (kg oil eq.): Extraction of non-renewable natural fossil resources.
- Terrestrial Acidification (kg SO2 eq.): Toxic substances which changes soil chemical properties, declines the pH level and decreases fertility of the soil.

4.3.1. CALCULATIONS TOOLS AND METHODS

GaBi Professional is used as the LCA software modelling tool to calculate the GHG emissions of the benchmark products. GaBi is also used as the database to quantify the flows that were unavailable by the LEVIS partners, in order to complete the Life Cycle Inventory. The final results are calculated by using the data derived from the LEVIS partners (foreground data, in-house processes) and cradle-to-gate background flows and processes. GaBi is then also used to perform the Life Cycle Impact Assessment and compute the final results of the study.

4.3.2. LIMITATIONS, DEVIATIONS AND LINKS TO OTHER WPS

Deviations from the Grant Agreement were made concerning the benchmark vehicles. Every demonstrator has a benchmark product that is used for a different type of vehicle, meaning that the original benchmark vehicle (1500 kg EV) is no longer relevant. The benchmark vehicles are described in chapter 4.2.2.

There was limited data available for the emissions and energy use for the production and EOL phase of the benchmark products. The LCA was largely reliant on datasets from databases in GaBi.

Links between Workpackages were mostly with WP1 (see chapter 4.5.2 & 4.1.1, eco-design and the description of the demonstrators). The LCA of the demonstrators themselves (not included in this report) will have a link with WP1 to WP6. The demonstrators are made partly from new composite materials from new processes, making the LCA less reliant on databases and more reliant on data from other partners and workpackages.

4.4. RESULTS

The results are presented and compared along three different life cycle phases; the production phase, the use phase and the end-of-life phase. The three phases consist of the following:

- Production phase: The extraction of the raw materials, the production and manufacturing of the parts and the transportation of the materials and parts to the manufacturing sites
- The Use phase: the usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- The End-of-Life phase: The processes needed to recover, recycle, or dispose of the product and its materials. It also consists of the credits gained due to the second-life of the materials through potential recycling or reuse.

4.4.1. WHOLE LIFE CYCLE IMPACT

The total environmental impact of the benchmark product is provided in **Table 50** & **Table 51** in Appendix 8.3. **Table 28** shows the environmental impact on the three impact levels (as mentioned in Section 4.3). In this table, we will look at the impact categories with the highest impact on their respective impact level (damage to human health, resource depletion and damage to ecosystems). The following impact categories are selected as having the highest impact on their impact level (see **Table 28**). This table also shows which life cycle phase has the most impact on set impact category.

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From the table, it is interesting to see that the use phase and production phase have similar effect on the climate change and fossil depletion impact categories. The EOL phase has high emission savings compared to the other demonstrators for the fine particulate matter formation and terrestrial acidification emissions. Chapter 4.4.4, explains in further detail on how this is the case.

Table 28: *Battery module: impact categories with highest percentage of total impact. Included is the indication of which life cycle phase shares the largest contribution to that particular impact category*

	Percentage of total impact to endpoint indicator	Relative influence of production	Relative influence of use phase	Relative influence of recycling	Relative influence of EOL
Resource depletion					
Fossil depletion	84%	64%	54%	-18%	<1%
Damage to Human health					
Climate change	53%	65%	56%	-22%	<1%
Fine Particulate Matter Formation	41%	182%	45%	-127%	<1%
Damage to ecosystems					
Climate change	60%	65%	56%	-22%	<1%
Terrestrial Acidification	17%	188%	46%	-134%	<1%

4.4.2. PRODUCTION

Figure 42 shows the CO2 eq. emissions (climate change impact category) that are emitted during the production phase. The left bar shows the total emissions during the production phase, while the bars to the right show the emissions per component. The three bars that have the highest influence are the materials that are used (ABS and copper) and the electricity that is needed for the plastic injection moulding. Interestingly, the relative impact of copper on the PMF impact category is a lot higher (see **Figure 43**). The impact of the electricity consumption is partly due to the fact that the injection moulding is performed in China with the Chinese electricity grid mix. The Chinese electricity grid (on average) has a high percentage of coal plants (IEA, 2021). Producing the parts locally on a grid mix with more green electricity production could reduce the emissions from this production process.

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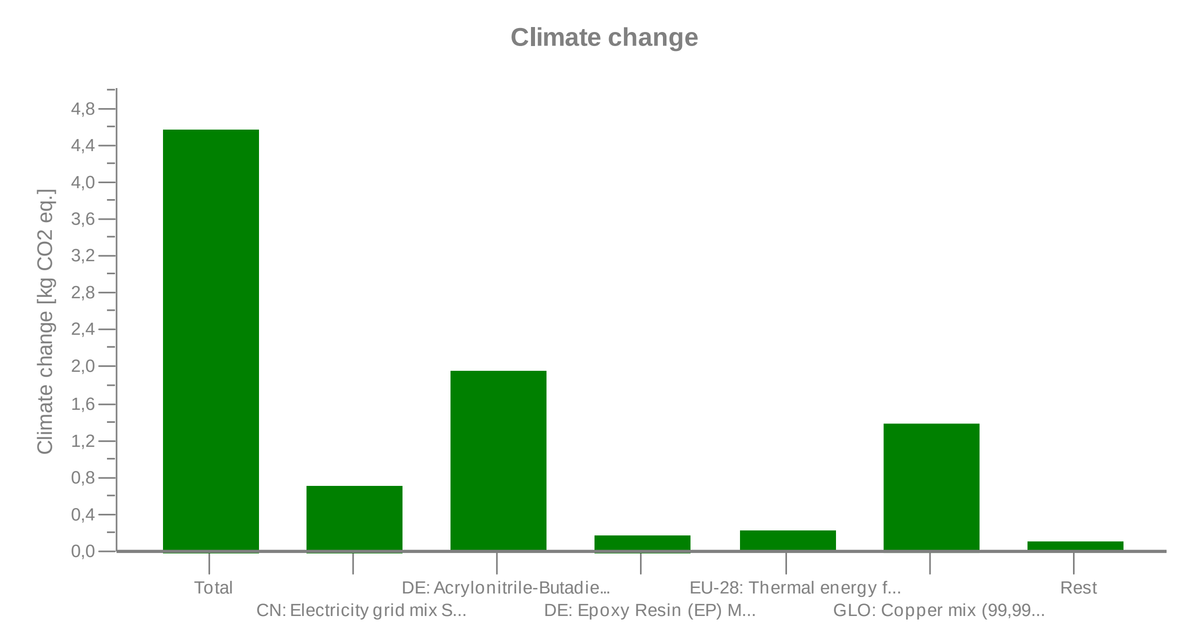

Figure 42: *Battery module: production impact on climate change*

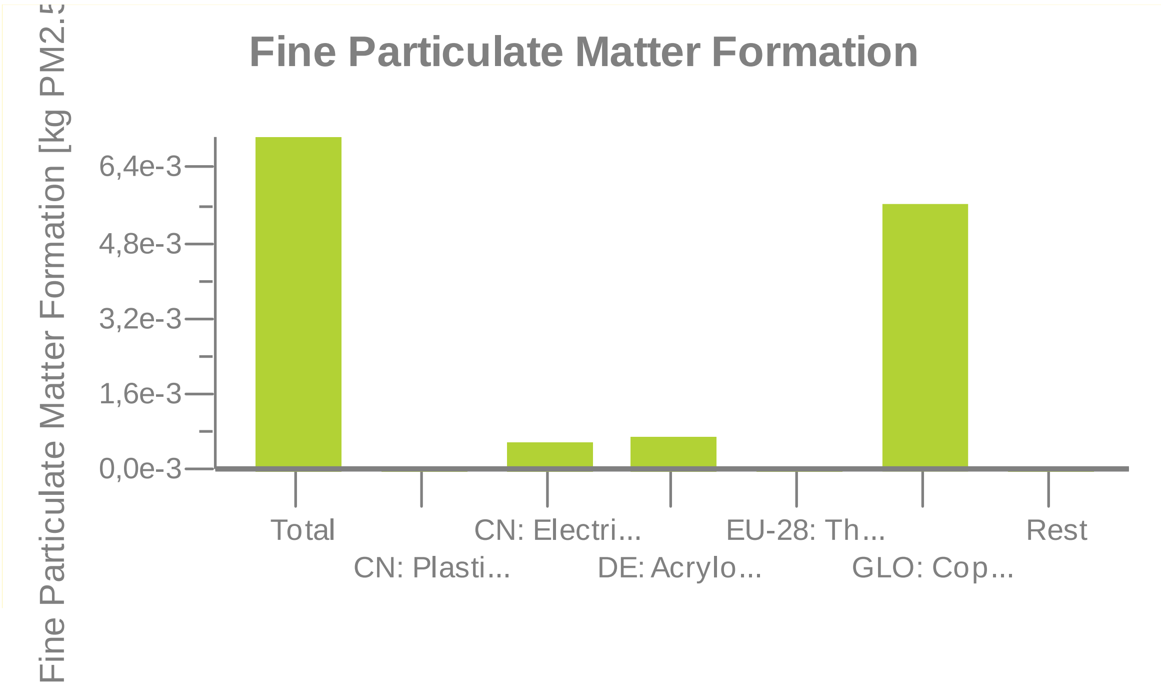

Figure 43: *Battery module: production impact on particulate matter formation*

4.4.3. USE

Table **29**, the primary energy demand for the use phase of the battery module is provided. This is the associated energy consumption for 1 kg of a class D electric vehicle driving 160.000 km in its lifetime. As can be seen from the table below, about two thirds of the primary energy demand come from non-renewable energy resources. Charging the EV with other energy grid mix could change this number and therefore the environmental impact in the use phase.

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Table 29: *Primary energy demand use phase battery module*

	Use phase
Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]	114
Primary energy from non-renewable resources (gross cal. value) [MJ]	74,6
Primary energy from renewable resources (gross cal. value) [MJ]	39,2

4.4.4. END-OF-LIFE

As can be seen from **Figure 44**, the environmental impact for the electricity use of the shredder used in the end-of-life phase is minimal compared to the other phases. Similar effect can be seen looking at other impact categories. The emission savings that comes from the recycling of the ABS and copper have the largest influence on the total emissions in the EOL phase. Looking at the FMP and terrestrial acidification emissions, it is clear that the recycling of the copper has by far the largest influence on the emission savings. The largest influence on improvement would be to increase the reuse, recovery and/or recycling rate and quality of plastic scrap.

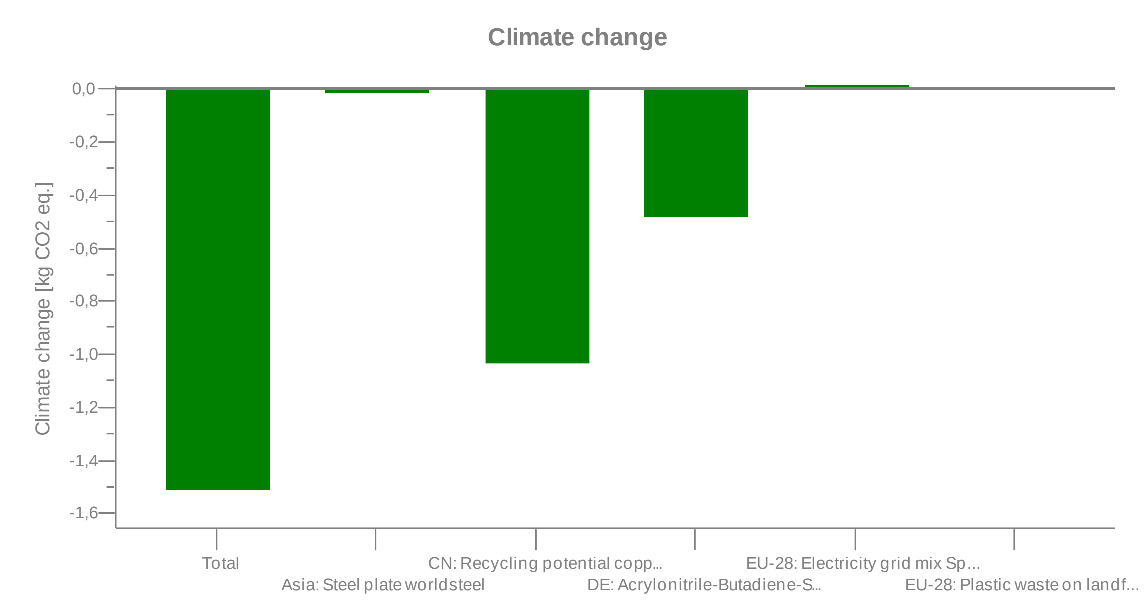

Figure 44: *Battery module: EOL impact on climate change*

4.4.5. SENSITIVIY ANALYSIS

The indicated System Function and Functional unit (section 4.1.3) reflects a specific scenario (a set of parameters and assumptions) against which results are calculated. As these parameters and assumptions contains a certain degree of variability and uncertainty it would be good practice to explore a few 'what if' scenarios. For this purpose, a sensitivity analysis is performed to evaluate what the influence is of these assumptions and parameters are on the conclusions of this report. For this study, three variables are chosen for the sensitivity analysis.

4.4.5.1. LIFESPAN

This study uses the general lifespan as a variable for the sensitivity analysis. The baseline lifespan defined (see scope definition) is 160.000 kilometres. This can be considered a conservative assumption, since research showed that the lifespan of EVs can be significantly longer (C. P. Aiken,

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2022). For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 160.000 km (baseline lifespan),
- 240.000 km (150% of baseline) and
- 300.000 km (as least conservative estimation)

***Table 30**: Results sensitivity analysis lifespan battery module.*

	160000 km		240000 km		300000 km	
Climate change [kg CO2 eq.]	4,36E-05	*100%*	3,73E-05	*85%*	3,47E-05	*79%*
Fine Particulate Matter Formation [kg PM2.5 eq.]	2,42E-08	*100%*	1,98E-08	*82%*	1,80E-08	*74%*
Fossil depletion [kg oil eq.]	1,89E-05	*100%*	1,60E-05	*85%*	1,49E-05	*79%*
Terrestrial Acidification [kg SO2 eq.]	7,63E-08	*100%*	6,25E-08	*82%*	5,70E-08	*75%*

The results of the sensitivity analysis are provided in **Table 30**. Keep in mind that these results are provided in kg CO2 eq. per kilometre driven. The table shows the environmental impact, and the emission savings when increasing the lifespan of the vehicle compared to the baseline. What is clear is that all the environmental impacts show almost equal savings, and the savings are quite significant.

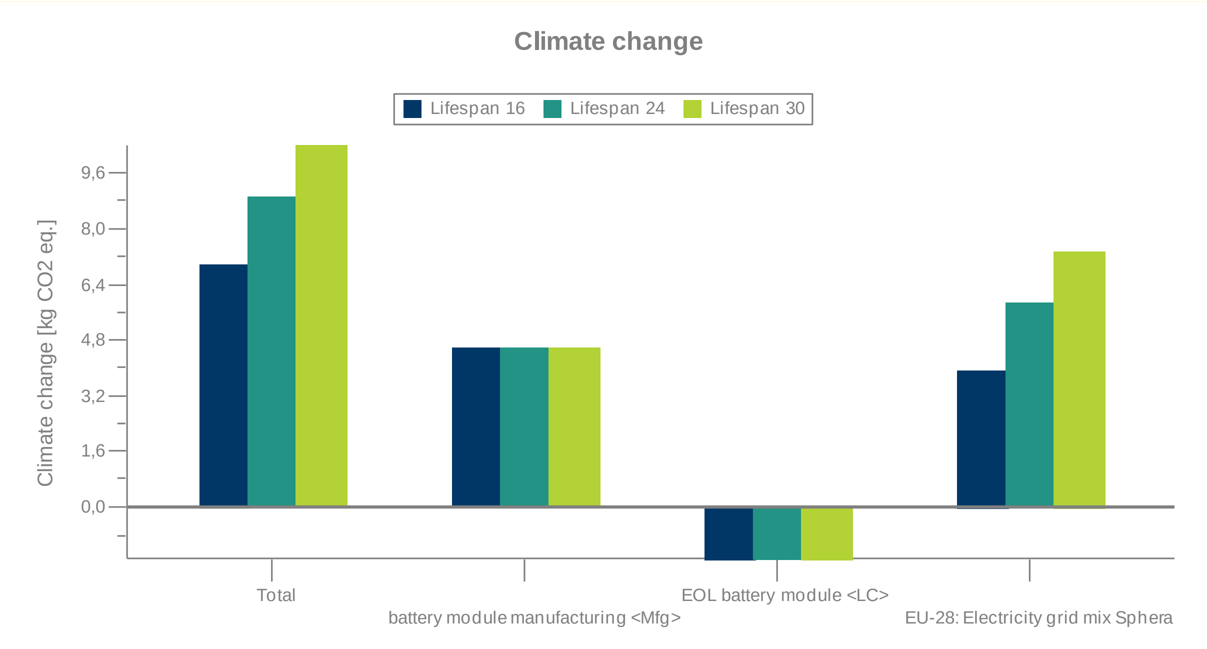

***Figure 45**: Results sensitivity analysis lifespan battery module. Climate change*

Figure 45 shows the <u>total</u> (so not per km) environmental impact on climate change. What is clear, is that the longer the lifespan of the EV, the higher the relative impact of the use phase of the product in comparison to the production and end-of life phase. Since the use phase impact (by electricity consumption) is solely driven by the mass of the product (see chapter 4.2.2), the potential environmental savings are also larger in the longer lifespan scenarios. This could have significant impact on the final results of the LEVIS project, which will be shown in the final LCA deliverable, D6.2.

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4.4.5.2. ELECTRICITY GRID MIX

This study uses the electricity grid mix for the use phase as a variable for the sensitivity analysis. The baseline is the EU-28 electricity grid mix. The two other two electricity grid mixes that are chosen are the Chinese (CN) and the United Stated (US) grid mixes. They are chosen, because they form a relatively large percentage of the total energy consumption in the world, for a single country. They are also chosen because they consist of quite different energy source mixes (see **Figure 48**). The Chinese grid mix relies most on coal power, while the US also on gas and nuclear. The EU-28 has the most diverse electricity grid mix.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 31**. Keep in mind that these are the results concerning the whole life cycle of the component, not just the use phase. It is clear from the results that the difference between electricity production can have a massive influence on the results of the study. This is especially applicable for the environmental impacts on terrestrial acidification and FPMF. As mentioned before, Chinese electricity grid mixes are currently mostly reliant on coal, which is a large contributor to acidification and FPM emissions.

***Table 31**: Results sensitivity analysis electricity grid mix battery module.*

	EU28		CN		US	
Climate change [kg CO2 eq.]	6,98E+00	100%	1,16E+01	166%	8,49E+00	122%
Fine Particulate Matter Formation [kg PM2.5 eq.]	3,87E-03	100%	8,95E-03	231%	3,81E-03	98%
Fossil depletion [kg oil eq.]	3,03E+00	100%	3,41E+00	113%	3,36E+00	111%
Terrestrial Acidification [kg SO2 eq.]	1,22E-02	100%	2,60E-02	213%	1,19E-02	98%

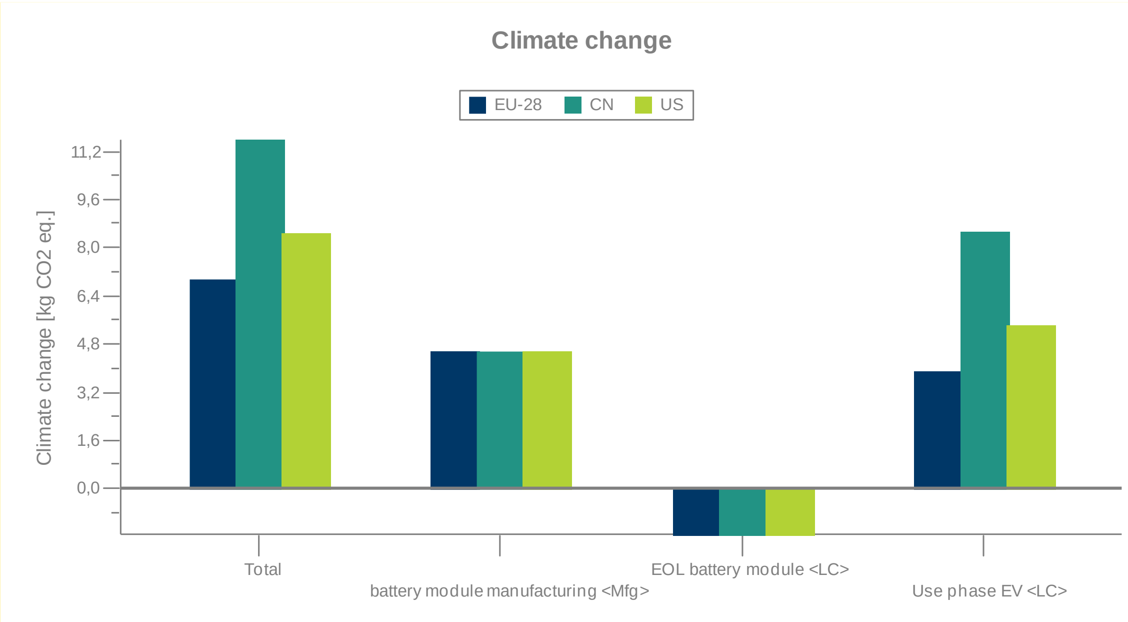

***Figure 46**: Results sensitivity analysis electricity grid mix battery module. Climate change.*

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Figure 46 and **Figure 47** show the impact on climate change of the three scenarios. A large spike can be seen in the use phase for the Chinese electricity grid mix, and a smaller one for the US electricity grid mix. This also increases the relative impact of the use phase of the product and implies that, similar to chapter 4.4.5.2, the potential impact of the weight reduction objective within the LEVIS project will have greater environmental savings in absolute numbers if the electric vehicles are used in regions with less environmentally friendly energy grid mixes. Consequently, any relative increase in the (electric) energy required for the production and end-of-life phases for the new designs would also translate into a higher absolute environmental impact.

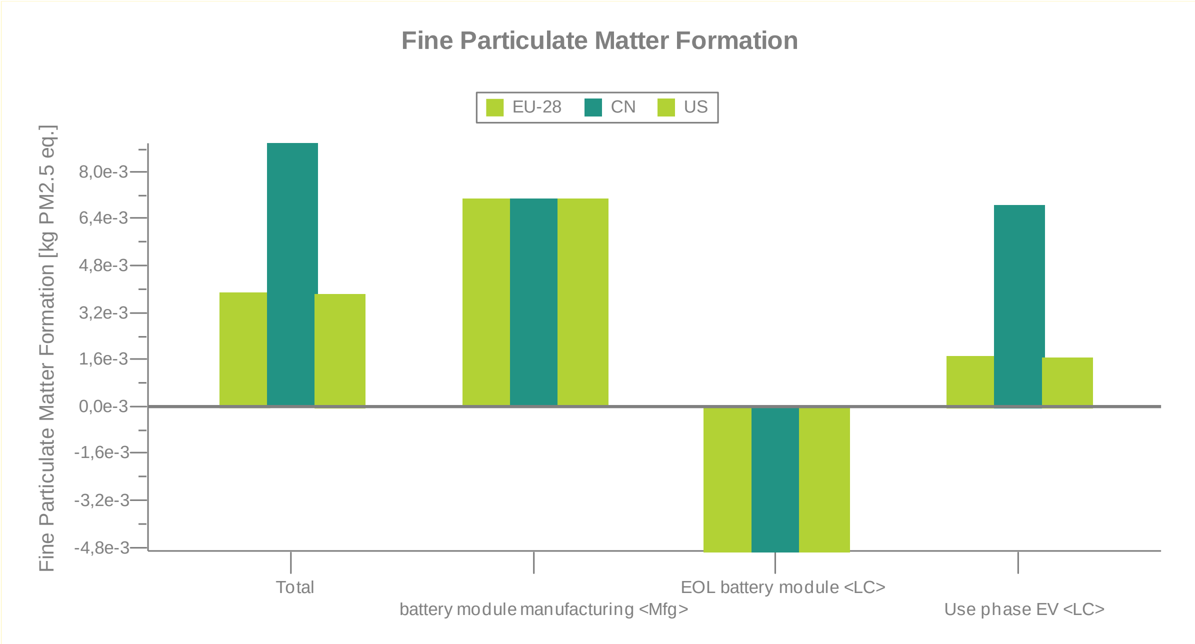

***Figure 47**: Results sensitivity analysis electricity grid mix battery module. Fine Particulate Matter Formation.*

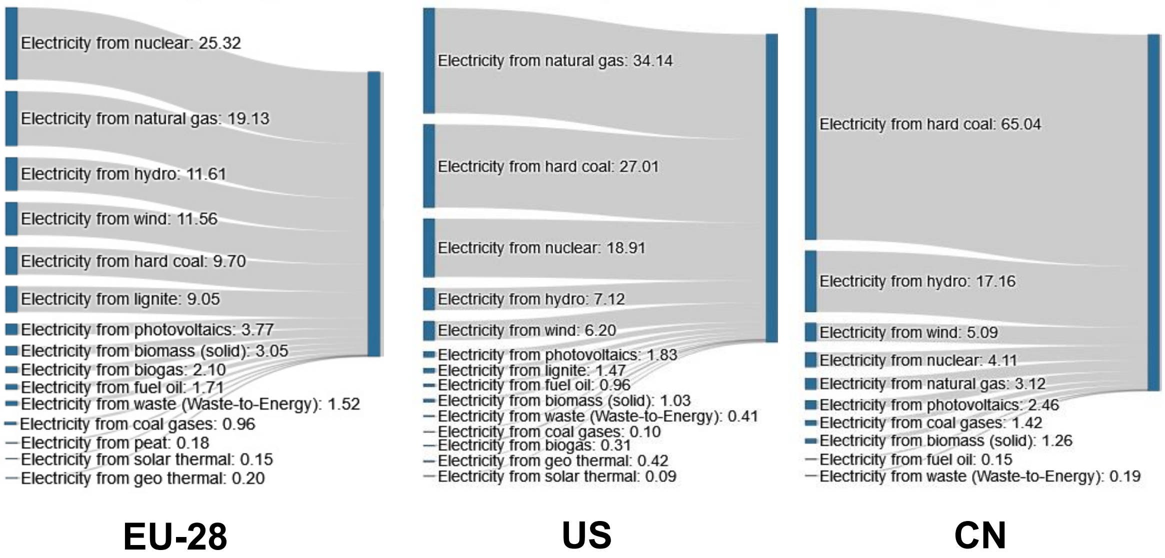

***Figure 48:** Electricity grid mixes in percentages for the European Union (28 countries), Unites States and China (Sphera Solutions GmbH, 2018).*

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4.4.5.3. RECYCLING RATE

This study uses the price ratio between scrap and virgin material described by GaBi as the recycling rate. A reasonably conservative baseline was chosen. Future improvements in end-of-life processes are not taken into account for the baseline study. For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 0,264 for ABS and 0,33 for steel as the baseline recycling rate,
- 50 more than the baseline and
- 100% more than the baseline.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 32** It is clear that the effect of the higher recycling rate is the highest for the impact categories which are largely determined by the material choice (ABS and aluminium) or production phase (see **Table 28**). The impact on fossil depletion is greatly reduced by having a higher recycling ratio, which can be explained by the fact that the fossil depletion emissions mostly occur during the production of the virgin material. These emissions are "saved" when the materials are recycled.

***Table 32**: Results sensitivity analysis recycling rate battery module.*

	Baseline		50% more recycling		100% more recycling	
Climate change [kg CO2 eq.]	6,98E+00	100%	6,49E+00	93%	6,01E+00	86%
Fine Particulate Matter Formation [kg PM2.5 eq.]	3,87E-03	100%	3,71E-03	96%	3,54E-03	91%
Fossil depletion [kg oil eq.]	3,03E+00	100%	2,71E+00	89%	2,39E+00	79%
Terrestrial Acidification [kg SO2 eq.]	1,22E-02	100%	1,17E-02	96%	1,11E-02	91%

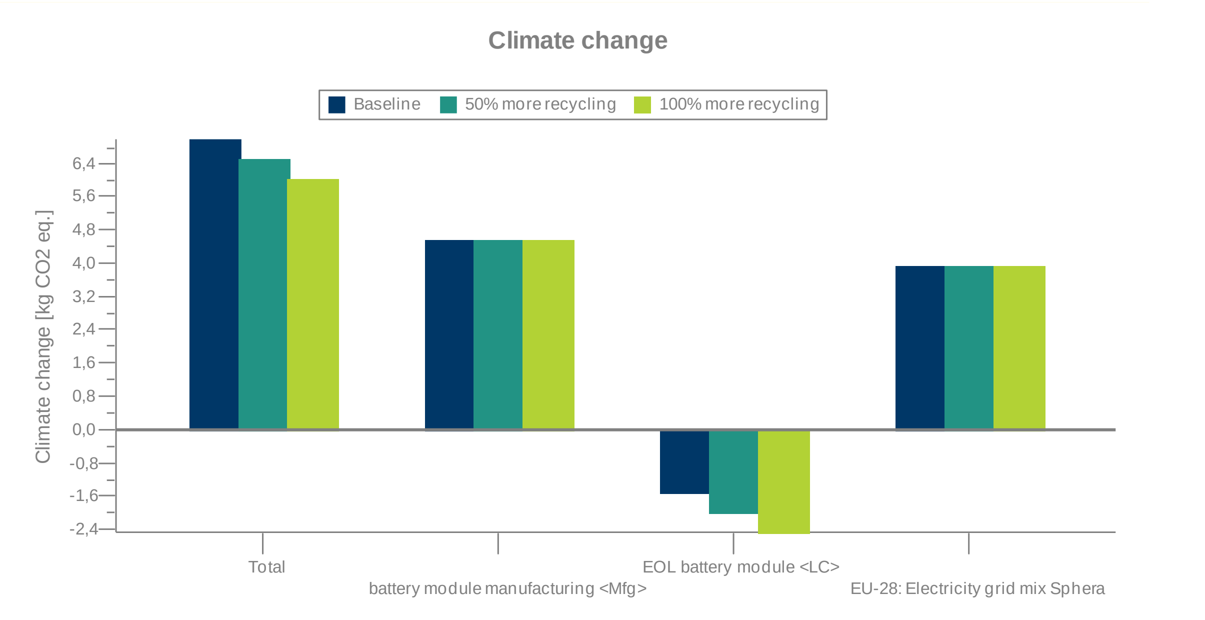

***Figure 49**: Results sensitivity analysis recycling rate battery module. Climate change.*

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Figure 49 and **Figure 50** show the impact on climate change and fossil depletion for the three scenarios. By comparing these figures, it possible to visualise how the relative impact of the EOL increases when the emissions are mostly coming from the production phase. Since the production emissions are mostly coming from the material usage, these emissions are also saved when the materials are being recycled in the EOL phase.

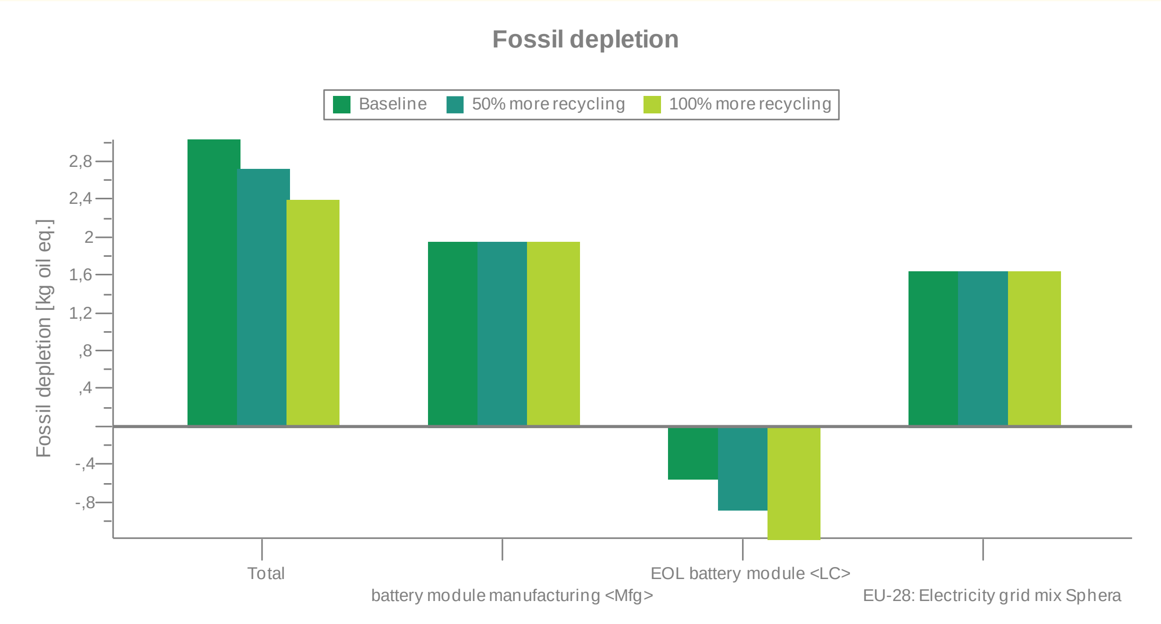

Figure 50*: Results sensitivity analysis recycling rate battery module. Fossil depletion.*

4.5. BENCHMARK EVALUATION CONCLUSIONS

4.5.1. MAIN CONCLUSIONS FROM RESULTS

The results of the LCA show that the life cycle phase which is dominant in its GHG emission output is the production phase. When concentrating more on the production phase, it is visible that the dominant factor for the emissions in this phase is the material selection. Since the new design of the demonstrator will use new lightweight composite materials, it is possible that this can have a large impact on the total impact on the life cycle of the battery module, but attention is required that impact is not shifted from one phase to another or to a different impact category as a direct result from the change in materials.

The end-of-life phase showed little so-called scrap credits savings for the plastics that were used, and a lot for the copper. It seems that there lies a huge potential for the LEVIS project in WP5 to have emission savings by recovery of plastics.

The LCIA indicates that multiple types of emissions have an impact on human health or ecosystems. In the case of the battery module, emissions from fine particulate matter almost had an equal share as the GHG emissions in the damage to human health impact category, meaning that these emissions cannot be ignored and should decrease as well as the GHG emissions.

The sensitivity analysis shows that changing variables can have a large influence on the results of the LCA. This also applies when taking into account the implications it can have for the end result of the LEVIS project, where the benchmark product is compared to the new design. The main take away from the sensitivity analysis is that the variables which increase the influence of the use phase (electricity grid mix and lifespan of the vehicle/product) can significantly influence the difference between the environmental impact of the benchmark product and the new design, since the new design's aim of light weighting mostly aims at lowering the use phase of the vehicle. The sensitivity analysis also shows that the impact of increasing the recycling rate is significant, especially for the indicators that are influenced by the material choice, which suggests that the effect of the LEVIS objectives to reuse and recycle the composite materials should be noticeable in the next LEVIS LCA report.

4.5.2. LINK TO ECO-DESIGN TOOLKIT RESULTS (D1.3)

At the start of the LEVIS project, all demonstrator partners participated in Task 1.2 (with report D1.3 as result). This task involved the development of an 'eco-design' tool and guideline (iEDGE toolkit) aimed to help the decision-making process.

The toolkit was used in WP1 of the LEVIS project in order to incorporate eco-design into the design process. Eco-design methodology is used during the first stages of a design process by identifying opportunities to improve integration of eco-design and circular economy principles into a new design. At the time the LCA was not yet performed and thus the iEDGE toolkit was performed by the partners without any LCA knowledge on their benchmark products. The tool therefore focused on providing decision-making guidance in the early (or pre) design stages. Now that the LCA of the selected benchmark product has been completed, the question arises: How do these LCA results relate to the exercise and outcomes of Eco-Design toolkit?

Table 33: *High level requirements iEDGE toolkit battery module*

Importance rating	High-level requirements - (What) ↓
5	REACH / RoHS Compliance
3	Recycled/Biosourced materials
3	Local purchasing
5	Low energy consumption processes
5	Reduce raw material consumption
4	Reusable packaging
3	Local purchasing
3	Higher repairability
5	Higher reliability
4	Modular design
4	Recovery of materials for new products
5	Easier dismantling
4	Integrated monitoring: Predictive maintenance.

By examining the link between these results and that of the iEDGE toolkit, we can identify the benefits of incorporating LCA into the (eco-)design process. **Table 33** shows the high-level requirements MERSEN identified as important for the battery module in the design phase. Apart from the requirements that are more concentrated to the structural performance of the product, the focus was not only at the projects objectives of simply having lightweight components, but also to consider other life cycle phases as transportation (reusable packaging) and EOL (easier dismantling). The LCA showed

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that the other life cycle phases have considerable effect and there is lot of room for improvement on especially the production phase regarding the material emissions.

Design (life-cycle) strategies	Improvement option	Application Description	Intended KPI effect	Design priorities: Selecting your case-specific eco-design principles			
				Feasibility	Impact risk level	Priotity	New design choice
1. Material selection	Selection of biosourced or recycled materials for casing	Module casing	% virgin material	Feasible-long term	Desirable	**Low Priority**	**No**
	Use composite materials	Module casing	Est. lifetime including second life (y)	Feasible-short term	Desirable	**High Priority**	**Yes**
	Reduce material quantity for all components	Module	Raw material consumption (g/parts)	Feasible-short term	Desirable	**High Priority**	**Yes**
2. Mining and production	Optimized and simplified design to allow low energy consumption	Laminated busbar	Total Electricity consumption	Feasible-short term	Desirable	**High Priority**	**Yes**
	Low material consomption during the processes	Module	Raw material consumption (g/parts)	Feasible-short term	Desirable	**High Priority**	**Yes**
5. End-of-life (Recovery and disposal)	Work on easy to disassemble components	Busbars and monitoring	% Recyclable materials (%) - Ecological	Feasible-short term	Desirable	**High Priority**	**Yes**
6. Added functional value	Add sensors in the casing	Detect failure or accelareted degradation	Est. lifetime including second life (y)	Feasible-long term	Desirable	**Low Priority**	**Yes**

***Figure 51**: Focus strategies and solutions iEDGE toolkit battery module*

Figure 51 shows the improvement options that MERSEN suggested after the performance analysis using the iEDGE toolkit. Many improvement options were mentioned which focus on the material selection, mining and production, and the EOL phase.

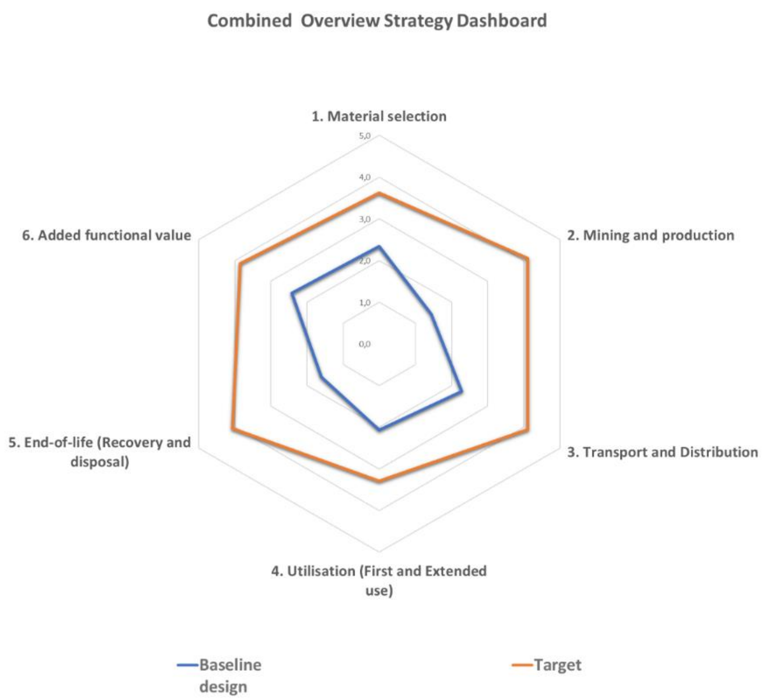

***Figure 52:** Results iEDGE toolkit battery module*

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Looking at **Figure 52**, at can be seen that the benchmark product scores low on the EOL and mining and production phases, which, according to the LCA data, is proved to be correct since the EOL recovery and emission savings is low compared to that of the other demonstrators.

Overall, it can be concluded that the iEDGE toolkit already helped identifying some of the bottlenecks of the current design. However, some life cycle phases (e.g. end-of-life) were correctly spotted as a critical life cycle phase (when looking at the recycling of ABS), others (material selection) may be underestimated in relative importance to the life cycle emissions (looking at Figure 52). Using the LCA could help the designers in the eco-design process by identifying critical life cycle phases and emissions (such as the fine particulate matter emissions for the battery module). Even though LCA is an investment in time, it could help steer the design team in the most effective design direction.

4.5.3. POTENTIAL FOR OBJECTIVES

The impact of the use phase on the whole life cycle impact is different for every impact category. It is therefore interesting to see what the impact would be if the mass would be reduced within the LEVIS objectives (20 to 40 percent). **Table 34** shows what would happen if the weight reduction requirements would be met and what the effect on the life cycle impact on a component level would be. In this scenario, the assumption is made that the energy consumption in the use phase would be considerably lower, but the production and EOL phase are unchanged.

Looking at this table, it is clear that the emission reduction objective of 25% of GHG emissions will be met only if, in addition to the decreasing of emissions during the use phase, there are also additional contributions from the rest of phases to the reduction of the GHG emissions. However, as has been stated before, the variables like lifespan, electricity grid mix, and recycling rate have a large influence on the potential relative emission savings of the LEVIS demonstrators. As is visualised as an example in **Table 34**, LEVIS will meet its objectives when the EVs would be charged in China or the US during their lifespan.

N.B: Please note that these numbers purely highlight the importance of all the life cycle phases. They are not in any way a prediction of the reduction in GHG emissions from the new design demonstrators. By light weighting through the use of new materials, you will inevitably have different emissions through all life cycle phases, with the potential of different effects on the corresponding impact categories. We expect that the final results from the LEVIS demonstrators (to be published in D6.2 towards the end of the project) will provide more concrete insights and we will be able to say more definitively whether, or to what extent, LEVIS is able to meet its environmental objectives.

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Table 34: *Battery module: Potential emission reduction effect of lightweight design in percentages (use phase effect only) for the electricity grid mix scenario.*

	EU-28		CN		US	
Mass reduction	**20%**	**40%**	**20%**	**40%**	**20%**	**40%**
Resource depletion						
Fossil depletion (%)	11	22	12	24	12	23
Damage to Human health						
Climate change (%)	12	23	15	29	12	26
Fine Particulate Matter Formation (%)	9	18	15	30	9	18
Damage to ecosystems						
Climate change (%)	12	23	15	29	12	26
Terrestrial Acidification (%)	9	18	15	30	9	18

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5. LCA BENCHMARK DEMO 3 – CROSS CAR BEAM

5.1. GOALS AND SCOPE DEFINITION

This chapter describes the goal and scope of the Life Cycle Analysis (LCA) of the LEVIS cross car beam benchmark product. This benchmark product (i.e., a vehicle component) is relevant to the new product LEVIS partner Tofas is developing.

5.1.1. GENERAL DESCRIPTION OF THE COMPONENTS

The Cross Car Beam (CCB) is a structural component located in the dashboard area. The primary function is to provide the structure for the dashboard and all the sub-systems that constitute the IP module (steering column, HVAC, air- bags, EE units). The structure is then fastened to the BIW. Only the steering column carrier (*Golden) is the part targeted in the LEVIS project.

The component identified as benchmark product is not related to an EV but is a structural component, meaning that the product is universally used in every vehicle. The product details can be found in **Table 35**.

Table 35: *Product details cross car beam*

Product name	Cross Car Beam
Manufacturer	TOFAS
Country/countries of manufacturing	TURKEY
Year of manufacturing	2016-2021
Amount of products sold yearly	166000
Serial no./product ID	3562

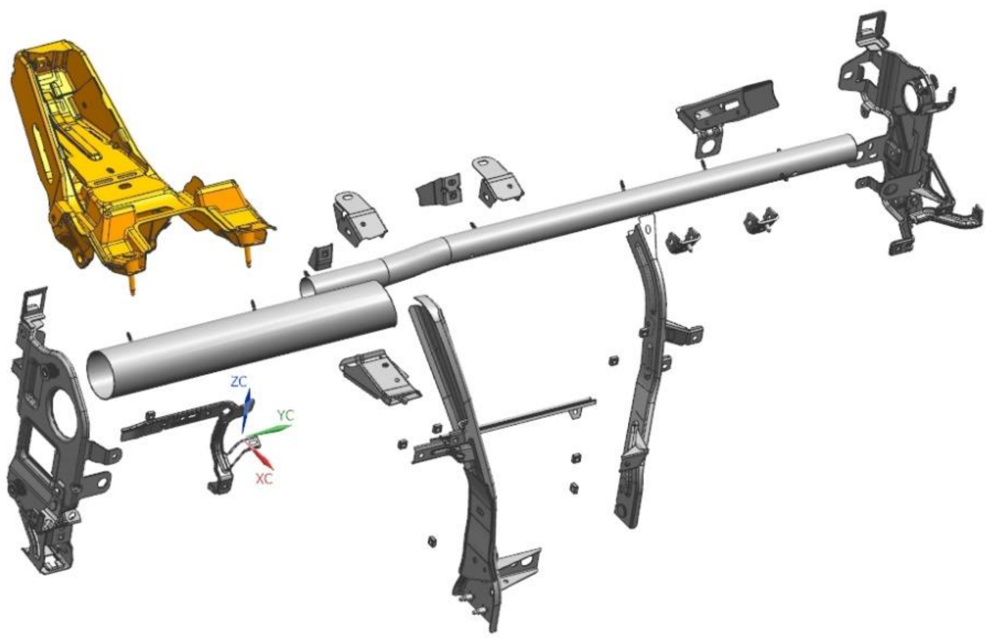

Figure 53: Visual representation of the cross car beam. Golden part (steering column carrier) is part of the LEVIS project.

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5.1.2. OBJECTIVES

This study aims to identify the absolute and relative environmental performance of a benchmark cross car beam steering column carrier group and the LEVIS newly developed cross car beam steering column carrier group. The goal of this study is to see whether the cross car beam steering column carrier group meets the environmental objectives set at the start of the project. This means that the comparative statements will be made regarding the environmental performance of the two products. However, these statements are only included in 'part 2' of the LCA reporting. Since 'part 1' only covers the environmental performance of the benchmark product.

Overarching project objectives

The project objectives regarding the environmental performance across all demonstrators are listed below:

- The demonstrators are expected to have a 20-40% in weight reduction compared to the benchmark product.
- The demonstrators should have at least a 25% reduction in global warming potential (GWP) at component level.
- The demonstrators should have at least a 7% reduction in global warming potential (GWP) at vehicle level.

Demonstrator specific objectives

In relation to the first objective, one of the demo specific objectives defined is to have a weight reduction of 20-40%, which is in line with the project objective of 20-40%.

WP5 stated that the hybrid CFRP/metal components will be firstly debonded, where at least 80% of the debonded CFRP will be remoulded. The metal part will be 100% recycled, which means that at least 80% of the CFRP/metal components will be recycled.

There is also a specific objective that the reduction of environmental impact of the product is made by using recovery and reuse of the carbon fibres. Since this is not possible to quantify by means of a LCA, a survey concerning the effects and results of the iEDGE toolkit will be held to determine whether these objectives were met.

The LCAs performed in this study should determine whether the newly designed demonstrators meet the objectives or not. Even though the objectives of the LEVIS project focus on the global warming potential, this study also looks at other emissions and impacts across the life cycle stages and can be clustered across the following impact categories:

- Resource depletion
- Human Health
- Terrestrial ecosystems
- Marine ecosystems
- Freshwater ecosystems

A full list of impact (sub)categories can be found in the ANNEX section, which are split into so called Midpoint and Endpoint indicators (also see Section 5.3 for further explanations).

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5.1.3. SYSTEM FUNCTION AND FUNCTIONAL UNIT

The parameter to define the functionality of the component is called the functional unit and is key in LCA in order to make a measurable evaluation and comparison of the benchmark product and the demonstrator. The lifespan of the vehicle can be different per benchmark vehicle, but for the sake of this study, this is kept equal across all demonstrators. The functional unit is defined as below:

> *The functional unit for this study is the installation and usage of a cross car beam which last the whole life of a C class electric vehicle driving a WLTP cycle, in a manner that maintains the functionality of the vehicle and safety of the occupants. The average lifespan is considered to be 160.000 km.*

5.1.4. SYSTEM BOUNDARIES

5.1.4.1. GENERAL SYSTEM DESCRIPTION

The life cycle phases (visualized in **Figure 54**) that are being considered for the cross car beam are the following:

- The extraction of all raw materials.
- The production and manufacturing of the parts.
- The transportation of the materials and parts to the manufacturing sites.
- The usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- Lastly, through the end-of-life of the components themselves.

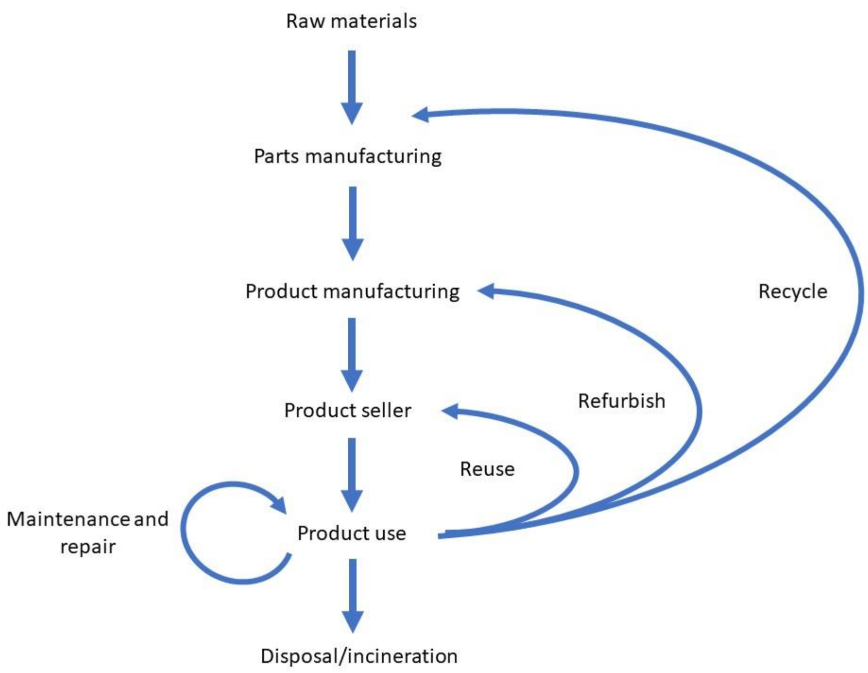

Figure 54: *Life cycle phases of a product*

5.1.4.2. COVERAGE OF ENVIRONMENTAL INTERVENTIONS AND IMPACTS

As is mentioned in the "objectives" paragraph, the main targets of the LEVIS project relate to the global warming potential of the demonstrators. The results of this study will mainly focus on the emissions that are related to this impact category. However, all impact categories and associated emissions that are part of the ReCiPe 2016 (RIVM, 2011) impact assessment method are considered. Any

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"remarkable" results from the impact categories will also be discussed in to results section of the report.

5.1.4.3. TEMPORAL AND GEOGRAPHIC BOUNDARIES

This study mostly uses data extracted from the GaBi database. Other data comes from either literature studies or directly from the industrial plants (provided by the DEMO partners). All datasets that are used have to be valid until the end of the LEVIS project (2024). The geographical representativeness of the datasets is dependent on life cycle stage of the process. As default, the EU-28 (European Union, 28 countries) averages are used, unless specific knowledge of the region of production is known. For example, concerning the manufacturing of the cross car beam itself, Turkey is used as geographical region. When multiple datasets for one process are available, a quick analysis on the specific datasets needs to be performed. The criteria on the choice datasets are the following:

Geographical representativeness:

1. Choose the dataset that is located in the specific region the process occurs.
2. If unknow or unavailable, use EU-28 (European) averages.
3. If unavailable, use the Global (GLO) averages.

Geographical representativeness:

- Choose the dataset which reference year falls under the 'years of manufacturing' of the benchmark vehicle.
- If unavailable or when multiple datasets fall under this requirement, choose the dataset with the most recent reference year.

5.1.4.4. TREATMENT OF RECYCLED MATERIALS

Allocation of the recycling and reuse of the materials is important in LCA. The method in this LCA study to account for this is to apply scrap credits to the steel and aluminium scrap that comes from all the production processes and end-of-life systems. This is called "value-corrected substitution" and is a method used in LCIA (Life Cycle Impact assessment) which tackles the downcycling issue in LCA when handling products with high scrap ratios.

During production and EOL, large volumes of scrap are produced and recycled. However, the material quality is often lower than that of the virgin material, which means that often the scrap material can't be replaced by virgin material on a one-by-one basis. The "value-corrected substitution" method uses the price ratio between different grades of scrap (based on their quality) and the virgin material. The price ratio for the materials used in the model is the following:

- Steel scrap price ratio: 0,33 (GaBi)

Figure 55 provides an example of how this method is used in LCA. In this example the shredded steel from the post-shredding/sorting process is directed to a process called "No. 4 shredded steel-scrap credit". This is the process containing the price ratio of the scrap and the virgin steel. The number (No. 4 in this example) relates to the quality of the scrap material. The second input in this process is the "DE: Stainless steel cold rolled", which is a negative input. Which means that the environmental impact of the stainless steel are now environmental savings (negative emissions).

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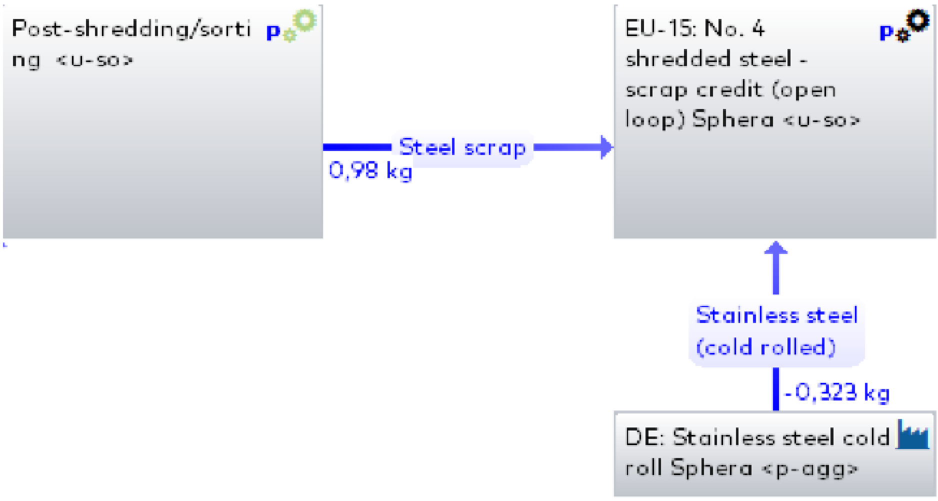

Figure 55: *Example value-corrected substitution method in EOL phase*

5.1.4.5. EXCLUSION AND CUT-OFF CRITERIA

This report is part of a comparative LCA. However, it was decided that, even though two systems are compared to each other, the identical processes are still accounted for in the LCA. Processes will be excluded if the mass or energy flows are less than 1% of the total. Mass and energy are used to estimate the environmental relevance, since it is not possible to determine the environmental relevance of a flow without having to perform a LCA in the first place.

5.1.5. DATA SOURCES AND ASSUMPTIONS

The data of the database from Sphera GaBi is used for the all the background processes of the life cycle of the demonstrators. This includes the production of steel ingots, sheets and plastic granulate, but also the flow inputs as electricity and cooling water. The most representable data regarding the real-life scenario is used to make an as accurate analysis as possible. The processes that are used to fabricate the parts themselves are derived from Tofas and the production area.

5.2. LIFE CYCLE INVENTORY

5.2.1. PRODUCTION

5.2.1.1. MATERIAL PRODUCTION AND REFINING

The following materials (**Table 36**) are based on the Bill of Materials (BOM). Although the secondary materials that are needed for the manufacturing processes are included in the entirety of the LCA, they are not specified in this table. All the materials are coupled with the datasets provided by the GaBi database. These datasets represent the cradle to gate inventory of the materials. As can be seen, the cross car beam is made solely from steel, whereas 56% is made from cold rolled steel and 44% from hot rolled steel.

The materials of the CCB are made in Turkey. However, steel with Turkey as the country of origin was not available in the GaBi database. For this study, a European country with an electricity grid mix most similar to Turkey, which was available in the GaBi database was chosen (Germany).

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Table 36: *Material use cross car beam*

Material		Mass % of Product	Mass % of Material	Country
Steel		100%		
	Stainless steel cold roll		56%	DE
	Steel hot rolled coil		44%	DE

5.2.1.2. MANUFACTURING PROCESSES

The processes that are used to manufacture the cross car beam are listed in **Table 37** below:

The process “steel stamping” is extracted from the GaBi database. The process “MIG welding” is extracted from literature studies.

Table 37: *Processes cross car beam*

Processes	Database	Source	Country
Steel stamping	GaBi	Sphera	DE
MIG welding	-	(Rajemi, 2019)	GLO

5.2.2. USE

The (benchmark) demonstrators do not have a ‘direct’ use phase, in which they use energy by themselves. However, on a vehicle level, they do influence the energy consumption of the vehicle by their weight. In order to calculate the energy consumption associated with the benchmark demonstrator, the following formula is used:

$$EC_{benchmark} = \frac{ERV * m_{benchmark} * mileage_{use}}{10000}$$

Where;

ERV = Energy Reduction Value (kWh/(100kmx100kg));

$m_{Benchmark}$ = Vehicle mass reduction (kg)

$EC_{benchmark}$ = Energy consumption through mass (kWh)

$mileage_{use}$ = Lifetime vehicle (km)

The ERV (see **Table 38**) is extracted from the literature based on Del Pero, et al. (2020) and is based on the vehicle class and driving cycle. For this study, the World Light Test Procedure (WLTP) is used.

Table 38: *Benchmark vehicle demonstrators*

Demonstrator	Vehicle class	Milage (km)	ERV (kWh/100km*100kg)
Suspension Control Arm	B	160.000	0.56
Battery Holding Set	D	160.000	0.66
Cross Car Beam	C	160.000	0.58

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5.2.3. END-OF-LIFE

The end-of-life process is similar to the suspension control arm. The processes are provided by Tofas. The end-of-life phase of the cross-car beam follows the same path as the rest of the vehicle since the CCB is often not dismantled and separated from the vehicle after the use phase. The vehicle is shredded into small pieces, after which the different materials, in this case mostly steel, are sorted and recycled if possible. The model does not account for the remelting of the steel scrap since this is allocated to the second life product.

5.3. LIFE CYCLE IMPACT ASSESSMENT

ReCiPe 2016 is chosen as the primary assessment method for this study. This method is recognized by the EU (EUR 25167 EN - 2012) as a Life Cycle Impact Assessment (LCIA) method. The ReCiPe method can be used using three different cultural perspectives. These cultural perspectives represent different expectations such as timespan or the level of impact by future technology to avoid or mitigate future damages. The ReCiPe method differentiates the following three perspectives:

- Individualist: Short term view and optimistic about future technology
- Hierarchist: Default model. Used most often in scientific models and assumed to be the consensus model.
- Egalitarian: Long term view which is based on precautionary principle thinking.

For this study, the consensus model (Hierarchist) will be used as the preferred method. The Global Warming Potential (GWP) for the ReCiPe model is described as "Climate Change" in GaBi. Thus, the results of this study are all related to the effect of the components on Climate Change and is expressed kg CO2-eq as metric unit.

In the results, both the so called „Midpoint" and „Endpoint" indicators of the whole life cycle process are calculated. Midpoint indicators focus on a single environmental problem, while Endpoint indicators show the environmental impact of the Midpoint indicators on three higher aggregation level (RIVM, 2011):

- Damage to Human Health (DALY)
- Damage to ecosystems (species per year) containing:
    - Terrestrial ecosystems
    - Marine ecosystems
    - Freshwater ecosystems
- Resource depletion ($)

The unit "DALY" stands for Disability-Adjusted Life Years and takes into account the years lost to reduced quality of life due to illness and premature death. One DALY represents the loss of one year of a healthy life for one person. The unit "Species per year" stands for the number of species lost per year due to the environmental impact. While the unit dollars ($) of resource scarcity represents the extra costs involved to extract future mineral and fossil resources.

As explained in chapter 5.1.4.2, the (midpoint) impact categories which show „remarkable" results are discussed. The following impact categories were considered for in the results section:

- Climate Change (kg CO2 eq.): (Human made) emissions that have effect on the radiative forcing of the earth's atmosphere.

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- Human toxicity (kg 1,4-dichlorobenzene eq.): Toxic substances that are emitted in the environment that damage human health.
- Fine Particulate Matter Formation (kg PM2.5 eq.): Particles with a diameter of 2,5 µm or less which is suspended in the atmosphere. These particles have a negative effect on human health when inhaled into the lungs.
- Fossil depletion (kg oil eq.): Extraction of non-renewable natural fossil resources.

5.3.1. CALCULATIONS TOOLS AND METHODS

GaBi Professional is used as the LCA software modelling tool to calculate the GHG emissions of the benchmark products. GaBi is also used as the database to quantify the flows that were unavailable by the LEVIS partners, in order to complete the Life Cycle Inventory. The final results are calculated by using the data derived from the LEVIS partners (foreground data, in-house processes) and cradle-to-gate background flows and processes. GaBi is then also used to perform the Life Cycle Impact Assessment and compute the final results of the study.

5.3.2. LIMITATIONS, DEVIATIONS AND LINKS TO OTHER WPS

Deviations from the Grant Agreement were made concerning the benchmark vehicles. Every demonstrator has a benchmark product that is used for a different type of vehicle. Meaning that the original benchmark vehicle (1500 kg EV) is no longer relevant. The benchmark vehicles are described in chapter 5.2.2.

There was limited data available for the emissions and energy use for the production and EOL phase of the benchmark products. The LCA was largely reliant on datasets from databases in GaBi.

Links between workpackages were mostly with WP1 (see chapter 5.5.2 & 5.1.4.1, eco-design and the description of the demonstrators). The LCA of the demonstrators themselves (not included in this report) will have a link with WP1 to WP6. The demonstrators are made partly from new composite materials from new processes, making the LCA less reliant on databases and more reliant on data from other partners and workpackages.

5.4. RESULTS

The results are presented and compared along three different life cycle phases; the production phase, the use phase and the end-of-life phase. The three phases consist of the following:

- Production phase: The extraction of the raw materials, the production and manufacturing of the parts and the transportation of the materials and parts to the manufacturing sites
- The Use phase; the usage and energy consumption of the associated mass of the component through the use phase of the electric vehicle.
- The End-of-Life phase: The processes needed to recover, recycle, or dispose of the product and its materials. It also consists of the credits gained due to the second-life of the materials through potential recycling or reuse.

5.4.1. WHOLE LIFE CYCLE IMPACT

The total environmental impact of the benchmark product is provided in **Table 52** & **Table 53** in Appendix 8.4. **Table 39** shows the environmental impact on the three impact levels (as mentioned in Section 5.3). In this table, we will look at the impact categories with the highest impact on their respective impact level (damage to human health, resource depletion and damage to ecosystems). The following impact categories are selected as having the highest impact on their impact level (see **Table**

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39). This table also shows which life cycle phase has the most impact on set impact category. Keep in mind that the EOL (end-of-life) phase also accounts for the recycling credits, which means that the EOL phase will almost always have negative emissions (emission savings).

From the table, it is interesting to see that the use phase and production phase have similar effect on the fossil depletion and the climate change impact categories. However, in the case of the PMF and human toxicity emissions, the production phase has considerably more effect. The large emission savings by the EOL (recycling) phase suggests that this mostly comes from the material use of the product, which is steel.

Table 39: *Cross car beam: impact categories with highest percentage of total impact. Included is the indication of which life cycle phase shares the largest contribution to that particular impact category*

	Percentage of total impact to endpoint indicator	Relative influence production	Relative influence use phase	Relative influence Recycling	Relative influence EOL
Resource depletion					
Fossil depletion	90%	48%	63%	-12%	1%
Damage to Human health					
Climate change	43%	61%	53%	-15%	1%
Fine Particulate Matter Formation	22%	105%	30%	-35%	<1%
Human toxicity, cancer	31%	162%	0%	-62%	<1%
Damage to ecosystems					
Climate change	72%	61%	53%	-15%	1%

5.4.2. PRODUCTION

Figure 56 shows the CO2 eq. emissions (climate change impact category) that are emitted during the production phase. The left bar shows the total emissions during the production phase, while the bars to the right show the emissions per component. There seems to be a correlation between the quantity of material used per emission impact. This is proved by **Figure 57**, which shows that almost all emissions come from the materials that are used (steel), and only a small part comes from the production processes and the related energy that is used from it. The other important emission impact categories show similar distributions. Interesting to note is that there seem to be less emissions per kg material used from hot rolled steel compared to cold rolled steel. This is especially true for the impact category “Human toxicity, cancer” (**Figure 58**).

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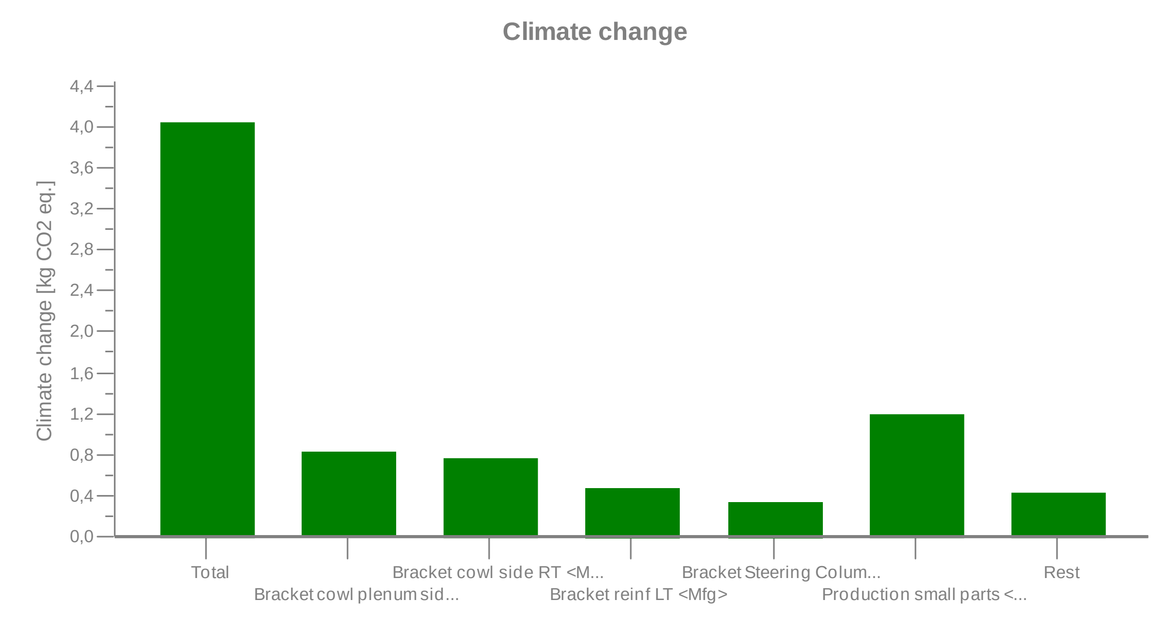

Figure 56: *Cross car beam: Production impact on climate change*

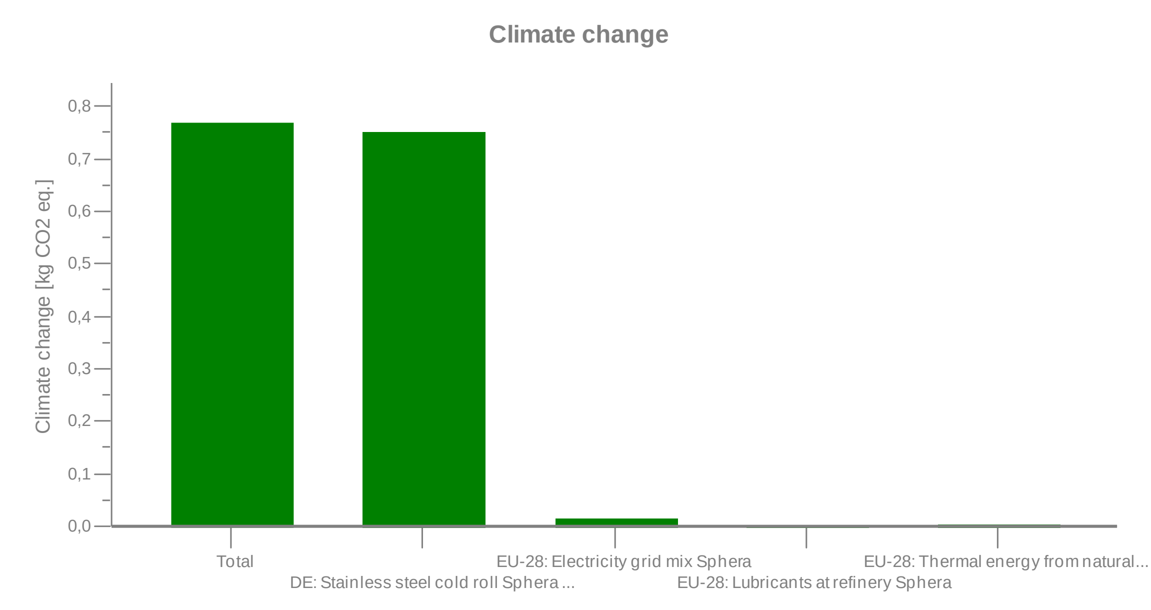

Figure 57: *Cross car beam: Impact climate change from the production of a single component*

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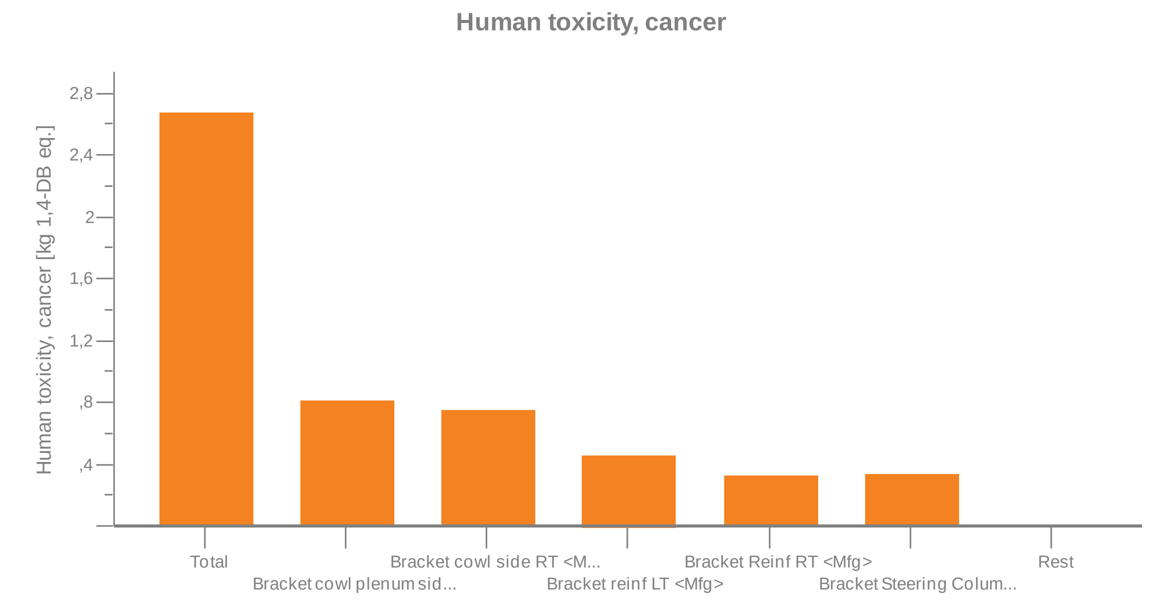

***Figure 58**: Cross car beam:Production impact on human toxicity*

5.4.3. USE

In **Table 40**, the primary energy demand for the use phase of the cross car beam is provided. This is the associated energy consumption for 1 kg of a class C electric vehicle driving 160.000 km in its lifetime. As can be seen from the table below, about two thirds of the primary energy demand come from non-renewable energy resources. Charging the EV with other energy grid mix could change this number and therefore the environmental impact in the use phase.

***Table 40:** Primary energy demand use phase cross car beam*

	Use phase
Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]	100
Primary energy from non-renewable resources (gross cal. value) [MJ]	65,6
Primary energy from renewable resources (gross cal. value) [MJ]	34,5

5.4.4. END-OF-LIFE

As can be seen from **Figure 59**, the environmental impact for the electricity use of the shredder used in the end-of-life phase is minimal compared to the other phases. Similar effects can be seen looking at other impact categories. Since steel has a high recycling rate, the emission savings (in figure XX it is shown as DE: Stainless steel cold r…) are significant.

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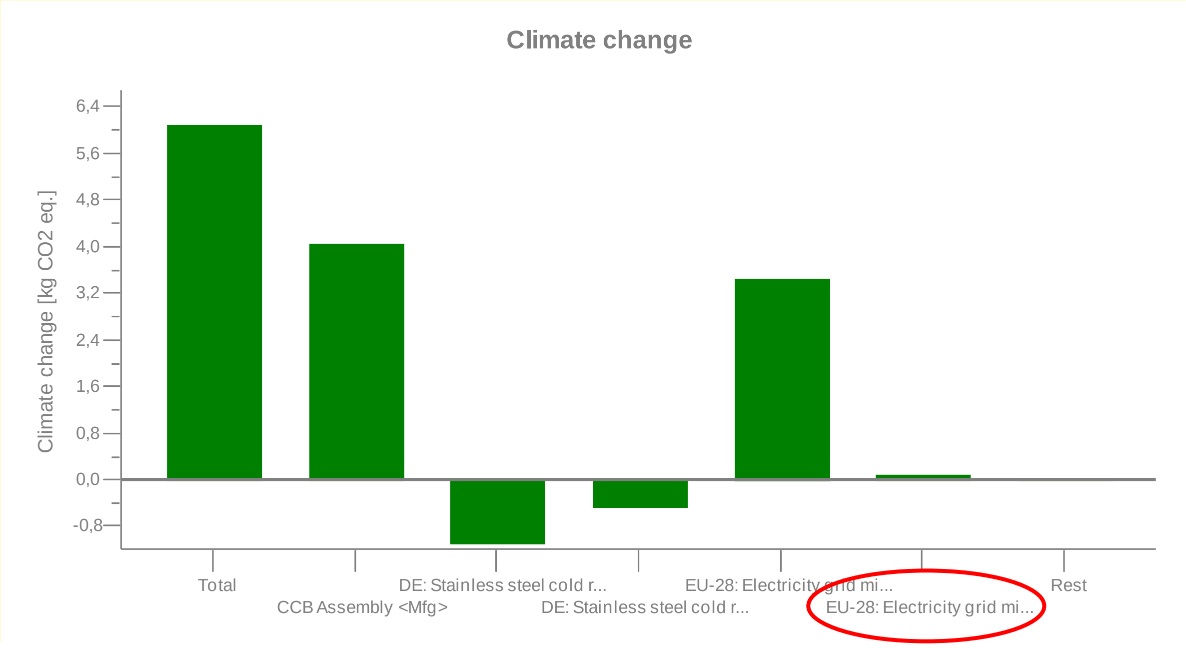

Figure 59: *Impact on climate change life cycle cross car beam. Red circle is the environmental effect of the energy usage for the EOL phase.*

5.4.5. SENSITIVIY ANALYSIS

The indicated System Function and Functional unit (section 5.1.3) reflects a specific scenario (a set of parameters and assumptions) against which results are calculated. As these parameters and assumptions contain a certain degree of variability and uncertainty it would be good practice to explore a few 'what if' scenarios. For this purpose, a sensitivity analysis is performed to evaluate the influence of these assumptions and parameters on the conclusions of this report. For this study, three variables are chosen for the sensitivity analysis.

5.4.5.1. LIFESPAN

This study uses the general lifespan as a variable for the sensitivity analysis. The baseline lifespan is defined (see scope definition) is 160.000 kilometres. This can be considered a conservative assumption, since research showed that the lifespan of EVs can be significantly longer (C. P. Aiken, 2022). For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 160.000 km (baseline lifespan),
- 240.000 km (150% of baseline) and
- 300.000 km (as least conservative estimation)

The results of the sensitivity analysis are provided in **Table 41**. Keep in mind that these results are provided in kg CO_2 eq. per kilometre driven. The table shows the environmental impact, and the emission savings when raising the lifespan of the vehicle compared to the baseline. What is clear is that the largest “savings” can be found in the human toxicity and fine particulate matter impact categories. This is logical, since these emissions come mostly from the production phase, which stays unaltered when raising the lifespan of the vehicle. As a result, the relative contribution per driven kilometre reduces.

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***Table 41**: Results sensitivity analysis lifespan cross car beam.*

	160000 km		240000 km		300000 km	
Climate change [kg CO2 eq.]	3,79E-05	*100%*	3,25E-05	*86%*	3,03E-05	*80%*
Fine Particulate Matter Formation [kg PM2.5 eq.]	2,74E-08	*100%*	2,15E-08	*78%*	1,91E-08	*70%*
Fossil depletion [kg oil eq.]	1,33E-05	*100%*	1,18E-05	*89%*	1,13E-05	*85%*
Human toxicity, cancer [kg 1,4-DB eq.]	7,13E-06	*100%*	4,75E-06	*67%*	3,80E-06	*53%*

Figure 60 and **Figure 61** show the total (so not per km) environmental impact on climate change and human toxicity respectively, which again illustrates that the impact on climate change has more effect in the use phase than human toxicity.

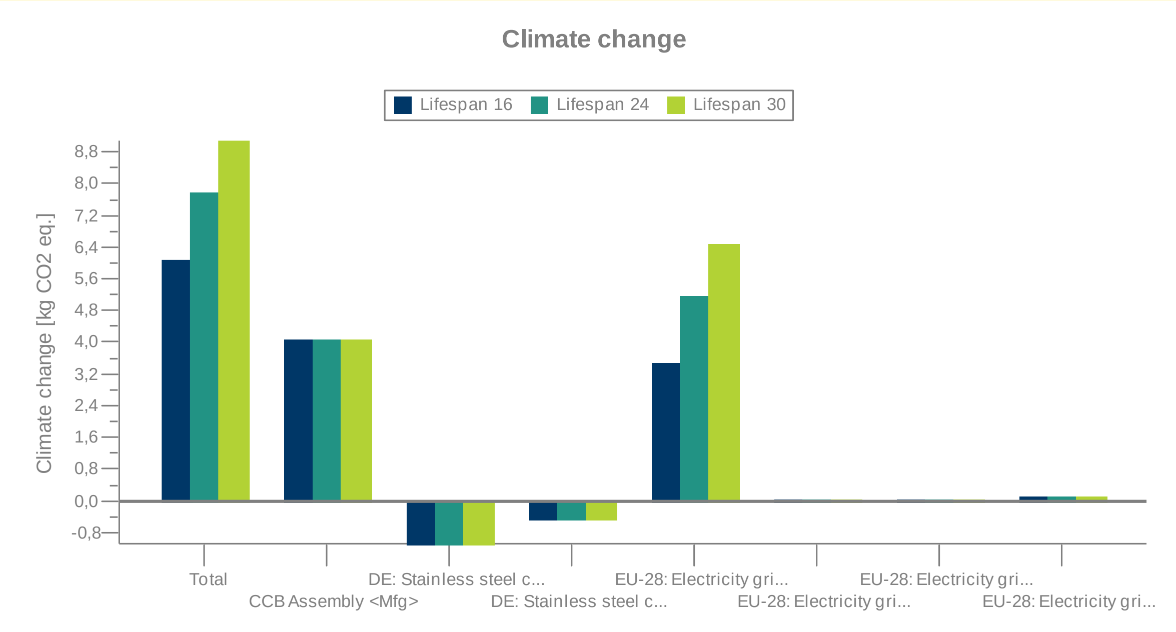

***Figure 60:** Results sensitivity analysis lifespan cross car beam. Climate change.*

The longer the lifespan of the EV, the higher the relative impact of the use phase of the product. Since the use phase impact is solely driven by the mass of the product (see chapter 5.2.2), the potential environmental savings are also larger in the longer lifespan scenarios. It could be argued that a longer lifespan may also have a carryover effect in avoided or postponed impact from replacement needs. As such, the sensitivity analysis confirms that a longer lifespan could have significant impact on the final results of the LEVIS project, which will be explored and evaluated further in the final LCA deliverable, D6.2. This could have significant impact on the final results of the LEVIS project, which will be shown in the final LCA deliverable, D6.2.

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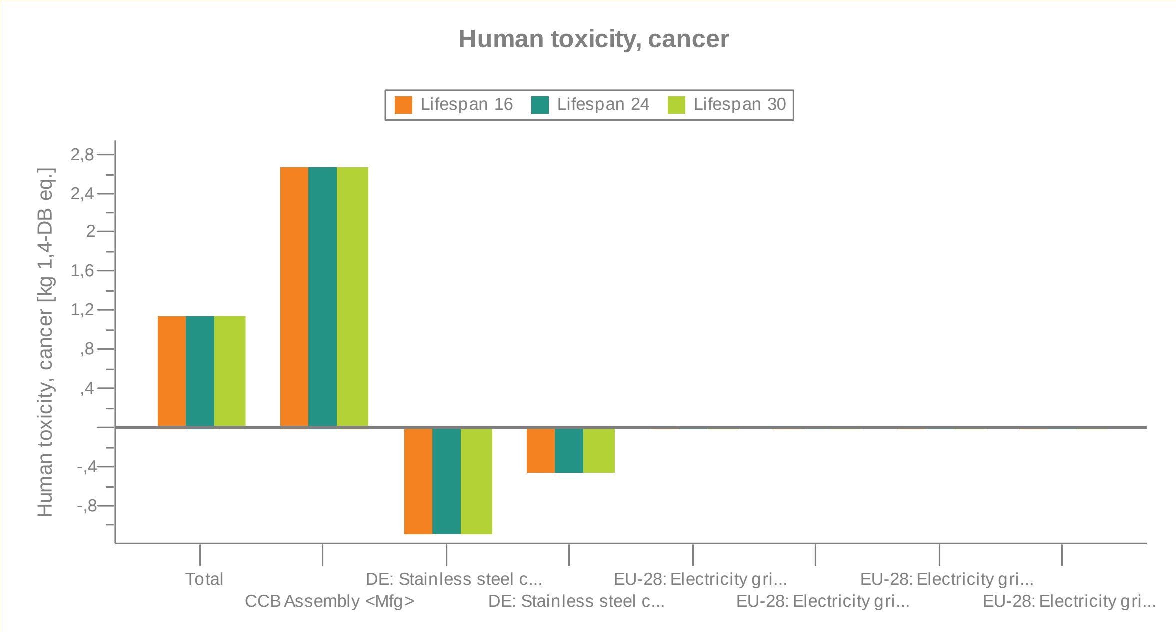

Figure 61*: Results sensitivity analysis lifespan cross car beam. Human Toxicity, cancer.*

5.4.5.2. ELECTRICITY GRID MIX

This study uses the electricity grid mix for the use phase as a variable for the sensitivity analysis. The baseline is the EU-28 electricity grid mix. The two other two electricity grid mixes that are chosen are the Chinese (CN) and the United Stated (US) grid mixes. They are chosen, because they form a relatively large percentage of the total energy consumption in the world, for a single country. They are also chosen because they consist of quite different energy source mixes (see **Figure 64**). The Chinese grid mix relies most on coal power, while the US also on gas and nuclear. The EU-28 has the most diverse electricity grid mix.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 42**. Keep in mind that these are the results concerning the whole life cycle of the component, not just the use phase. It is clear from the results that the difference between electricity production can have a massive influence on the results of the study. This is especially applicable for the environmental impacts on climate change and FPMF. As mentioned before, Chinese electricity grid mixes are currently mostly reliant on coal, which is a large contributor to GHG and FPM emissions.

Table 42: *Results sensitivity analysis electricity grid mix cross car beam.*

	EU28		CN		US	
Climate change [kg CO2 eq.]	6,07E+00	100%	1,01E+01	166%	7,40E+00	122%
Fine Particulate Matter Formation [kg PM2.5 eq.]	4,39E-03	100%	8,85E-03	202%	4,34E-03	99%
Fossil depletion [kg oil eq.]	2,13E+00	100%	2,47E+00	116%	2,42E+00	114%
Human toxicity, cancer [kg 1,4-DB eq.]	1,14E+00	100%	1,14E+00	100%	1,14E+00	100%

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Figure 62 and **Figure 63** shows the impact on climate change of the three scenarios. A large spike can be seen in the use phase for the Chinese electricity grid mix, and a smaller one for the US electricity grid mix. This also increases the relative impact of the use phase of the product. This means that, similar to the chapter 5.4.5.1, the potential impact of the weight reduction objective within the LEVIS project, will have greater environmental savings in absolute numbers if the electric vehicles are used in regions with less environmentally friendly energy grid mixes. Consequently, any relative increase in the (electric) energy required for the production and end-of-life phases for the new designs would also translate into a higher absolute environmental impact.

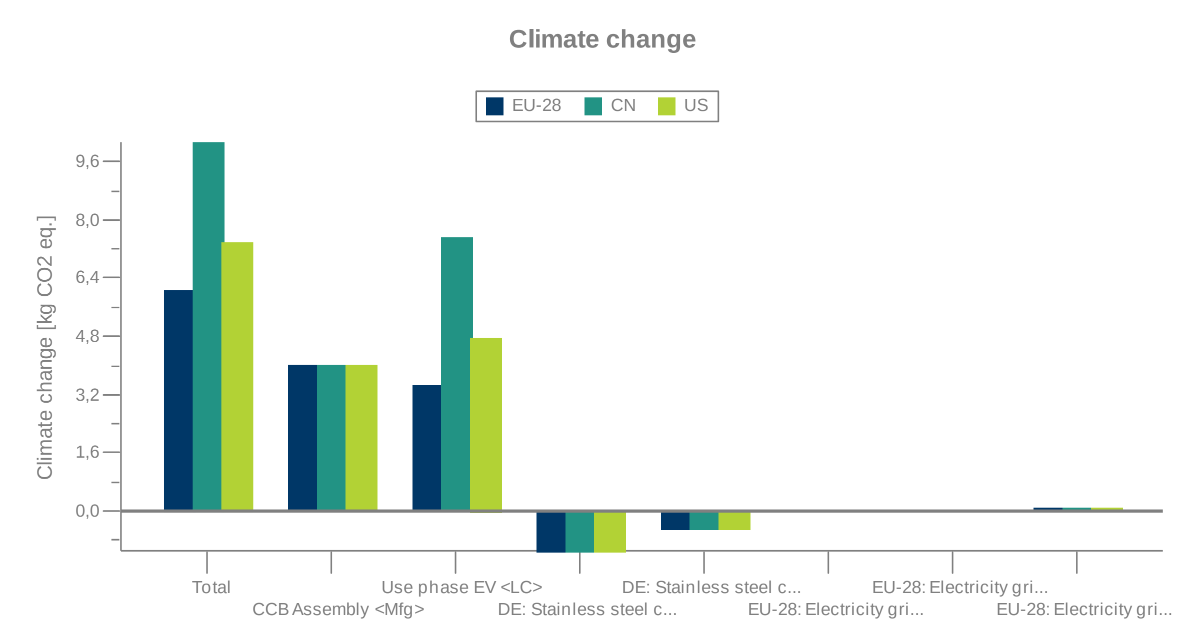

***Figure 62**: Results sensitivity analysis electricity grid mix cross car beam. Climate Change.*

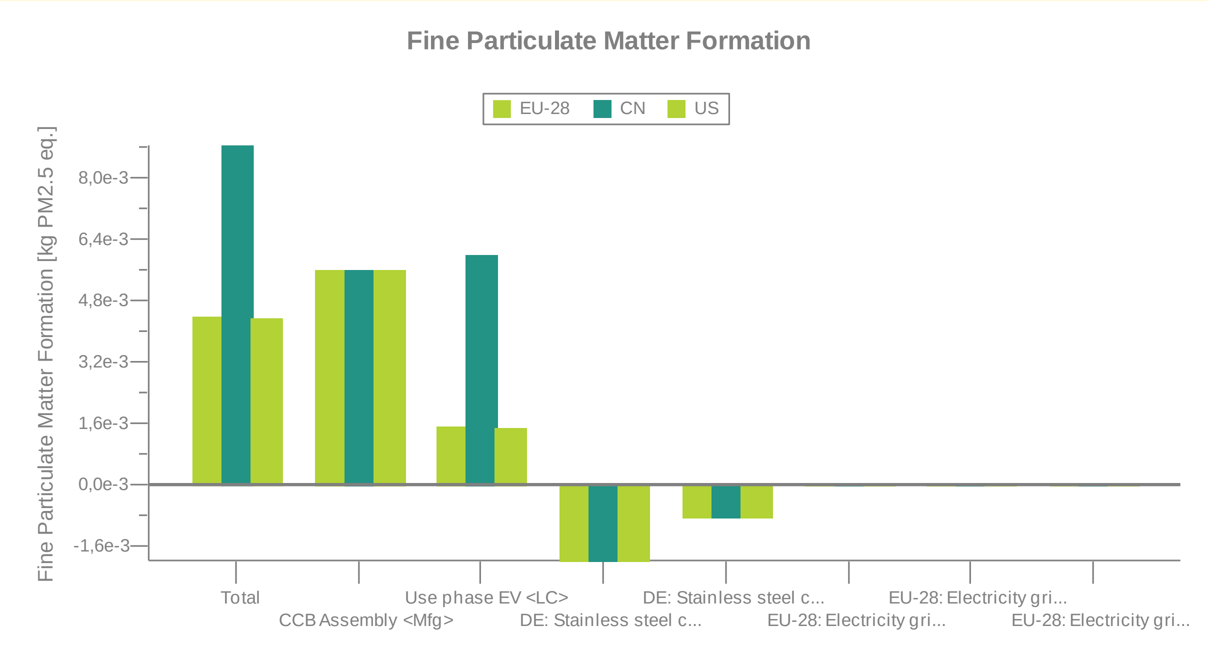

***Figure 63:** Results sensitivity analysis electricity grid mix cross car beam. Fine Particulate Matter Formation.*

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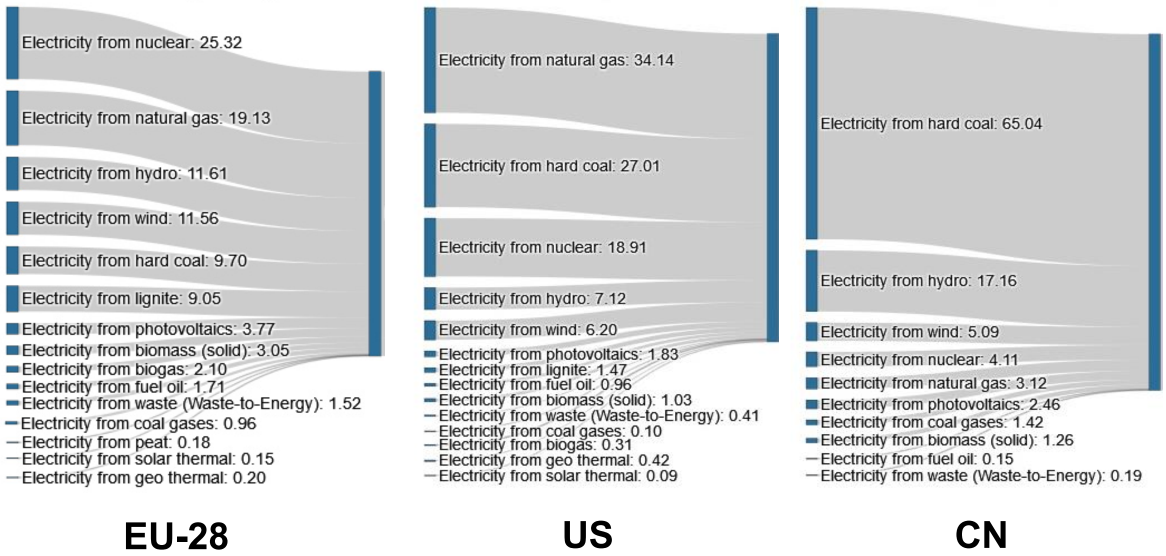

***Figure 64:** Electricity grid mixes in percentages for the European Union (28 countries), Unites States and China (Sphera Solutions GmbH, 2018).*

5.4.5.3. RECYCLING RATE

This study uses the price ratio between scrap and virgin material described by GaBi as the recycling rate. A reasonably conservative baseline was chosen. Future improvements in end-of-life processes are not taken into account for the baseline study. For this sensitivity analysis the following alternative parameters are explored for comparison of impact on results:

- 0,33 for steel as the baseline recycling rate,
- 50 more than the baseline and
- 100% more than the baseline.

The results of the sensitivity analysis for the different electricity grid mixes are provided in **Table 43**. It is clear that the impact of the higher recycling rate is the most for the impact categories which are largely determined by the material choice, steel (see **Table 39**). The impact on human toxicity is greatly reduced by having a higher recycling ratio, which can be explained by the fact that the human toxicity emissions mostly occur during the production of the virgin material.

Figure 65 and **Figure 66** show the impact on climate change and human toxicity for the three scenarios. By comparing these figures, it is easy to visualise how the relative impact of the EOL increases when the emissions are mostly coming from the production phase. Since the production emissions are mostly coming from the material usage, these emissions are also saved when the materials are being recycled in the EOL phase.

***Table 43**: Results sensitivity analysis recycling rate cross car beam.*

	Baseline		50% more recycling		100% more recycling	
Climate change [kg CO2 eq.]	6,51E+00	100%	5,95E+00	91%	5,48E+00	84%
Fine Particulate Matter Formation [kg PM2.5 eq.]	5,17E-03	100%	4,16E-03	80%	3,30E-03	64%

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Fossil depletion [kg oil eq.]	2,26E+00	100%	2,11E+00	93%	1,97E+00	87%
Human toxicity, cancer [kg 1,4-DB eq.]	1,65E+00	100%	1,09E+00	66%	6,20E-01	38%

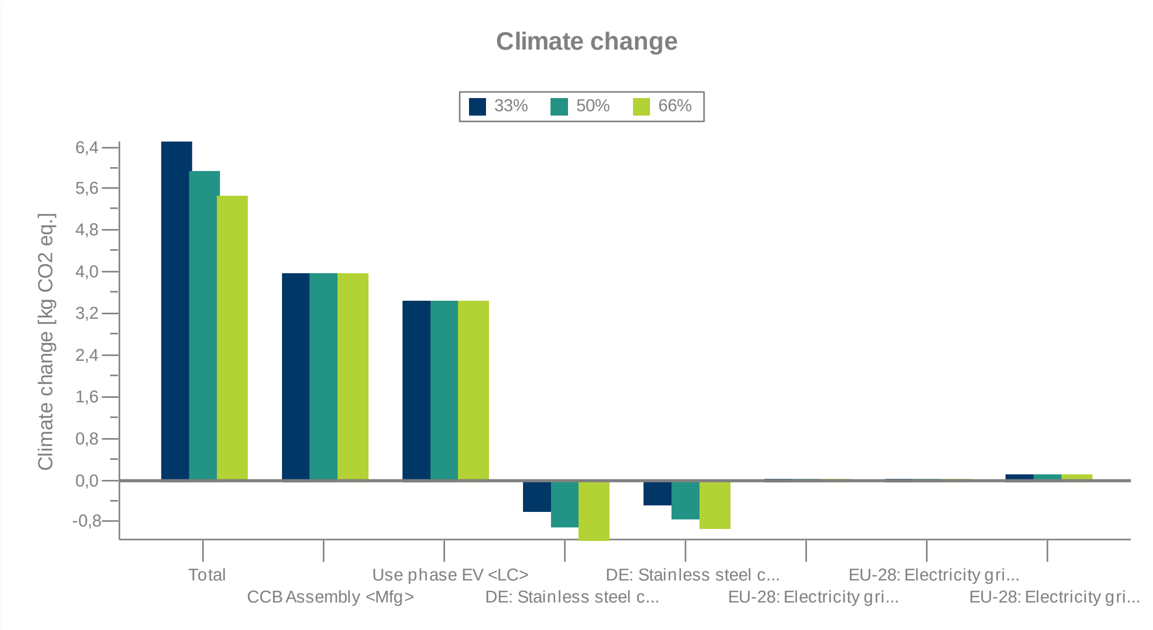

***Figure 65**: Results sensitivity analysis recycling rate cross car beam. Climate change.*

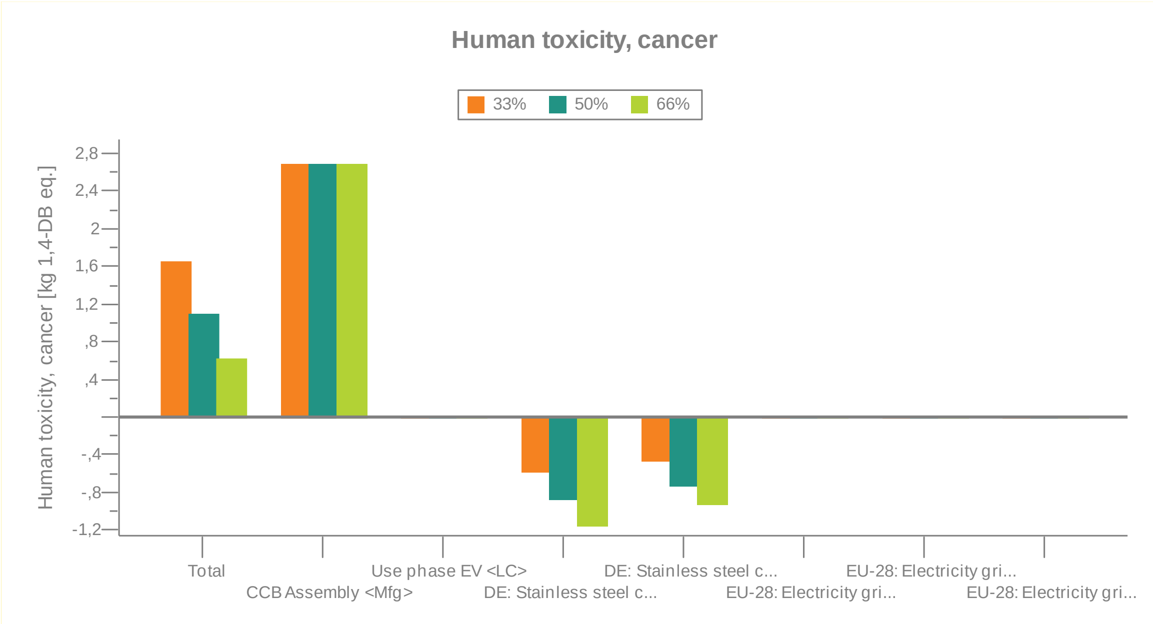

***Figure 66**: Results sensitivity analysis recycling rate cross car beam. Human toxicity, cancer.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006888.

5.5. BENCHMARK EVALUATION CONCLUSIONS

5.5.1. MAIN CONCLUSIONS FROM RESULTS

The results of the LCA show that there is not one life cycle phase which is dominant in its GHG emission output, meaning that improvement can be found on different levels. However, when concentrating more on the production phase, it is visible that the dominant factor for the emissions in this phase is the material selection (steel). Since the new design of the demonstrator will use new lightweight composite materials, it is possible that this can have a large impact on the total impact on the life cycle of the cross car beam, but attention is required that impact is not shifted from one phase to another or to a different impact category as a direct result from the change in materials.

The LCIA indicates that multiple types of emissions have an impact on human health or ecosystems. In the case of the cross car beam, it showed that the cross car beam emissions from fine particulate matter and the human toxicity impact both had a large share in the damage they've dealt to human health as does the GHG emissions, meaning that these emissions cannot be ignored and should decrease as well as the GHG emissions. These emissions are most dominant in the production phase by the material that is used (steel).

The sensitivity analysis substantiates that changing variables can have a large influence on the results of the LCA. This also applies when taking into account the implications it can have for the end result of the LEVIS project, where the benchmark product is compared to the new design. The main take away from the sensitivity analysis is that the variables which increase the influence of the use phase (electricity grid mix and lifespan of the vehicle/product) can significantly influence the difference between the environmental impact of the benchmark product and the new design, since the new designs aim of light weighting mostly aims at lowering the use phase of the vehicle. The sensitivity analysis also shows that the impact of increasing the recycling rate is significant, especially for the indicators that are influenced by the material choice, which suggests that the effect of the LEVIS objectives to reuse and recycle the composite materials should be noticeable in the next LEVIS LCA report.

5.5.2. LINK TO ECO-DESIGN TOOLKIT RESULTS (D1.3)

At the start of the LEVIS project, all demonstrator partners participated in Task 1.2 (with report D1.3 as result). This task involved the development of an 'eco-design' tool and guideline (iEDGE toolkit) aimed to help the decision-making process.

The toolkit was used in WP1 of the LEVIS project in order to incorporate eco-design into the design process. Eco-design methodology is used during the first stages of a design process by identifying opportunities to improve integration of eco-design and circular economy principles into a new design. At the time the LCA was not yet performed and thus the iEDGE toolkit was performed by the partners without any LCA knowledge on their benchmark products. The tool therefore focused on providing decision-making guidance in the early (or pre) design stages. Now that the LCA of the selected benchmark product has been completed, the question arises: How do these LCA results relate to the exercise and outcomes of Eco-Design toolkit?

By examining the link between these results and that of the iEDGE toolkit, we can identify the benefits of incorporating LCA into the (eco-)design process.

Table 44 shows the high-level requirements TOFAS identified as important for the cross car beam in the design phase. Apart from the requirements that are more concentrated to the structural performance of the product, the focus was not only at the projects objectives of simply having less GHG emissions, but also to consider other emissions which damage human health. The LCIA showed that other impact categories had considerable impact on human health.

Table 44: *High level requirements iEDGE toolkit cross car beam*

Importance rating	High-level requirements - (What) ↓
5	Lighter Steering Column
5	Strength
5	Crash Safety
4	Less impact on climate change
5	Less emissions damaging human health
5	Less Energy
5	NVH Performance

Figure 67 shows the improvement options that TOFAS suggested after the performance analysis using the iEDGE toolkit. All the improvement options were focused around using composite materials, which influences the two largest contributors of impact of the benchmark product, the material choice, and the energy consumption in the use phase. Interestingly, they also predicted this would have a possible impact on the PMF emissions. Since this is a large contributor to the damage to human health impact category, this can have a large impact on their high-level requirement, "Less emissions damaging health".

Design (life-cycle) strategies	No.	Improvement option	Application Description	Intended KPI effect	Design priorities			
					Feasibility	Desirability	Priotity	New design choice
1. Material selection	1.2	Using composite material	For the steering column instead of Steel, Composite material can be used	Weight (gr), kw/km, PMF emissions	Feasible-short term	Desirable	High Priority	Yes
4. Utilisation (First and Extended use)	4.0	Using composite material	For the steering column instead of Steel, Composite material can be used	Euro, Weight (gr), kw/km, CO2 eq.	Feasible-short term	Desirable	High Priority	Yes
5. End-of-life (Recovery and disposal)	5.0	Using composite material	For the steering column instead of Steel, Composite material can be used	PMF emissions, CO2 eq.	Feasible-short term	Desirable	High Priority	Yes

Figure 67: *Focus strategies and proposed solutions iEDGE toolkit cross car beam*

Looking at **Figure 68**, it can be seen that it is expected that the new design would have a better overall performance compared to the benchmark product. Interestingly, also the EOL phase of the benchmark product, which is made from fully recyclable steel, was rated low. The EOL phase could be improved of course by using recovery, reuse or by having a lower downcycling rate.

Overall, it can be concluded that the iEDGE toolkit already helped identifying some of the bottlenecks of the current design. However, some life cycle phases (e.g., transport and distribution) are overestimated in importance while others (material selection) may be underestimated (looking at **Figure 68**). Using the LCA could help the designers in the eco-design process by identifying critical life cycle phases and emissions (such as the human toxicity and fine particulate matter for the cross car beam). Even though LCA is an investment in time, it could help steer the design team in the most effective design direction.

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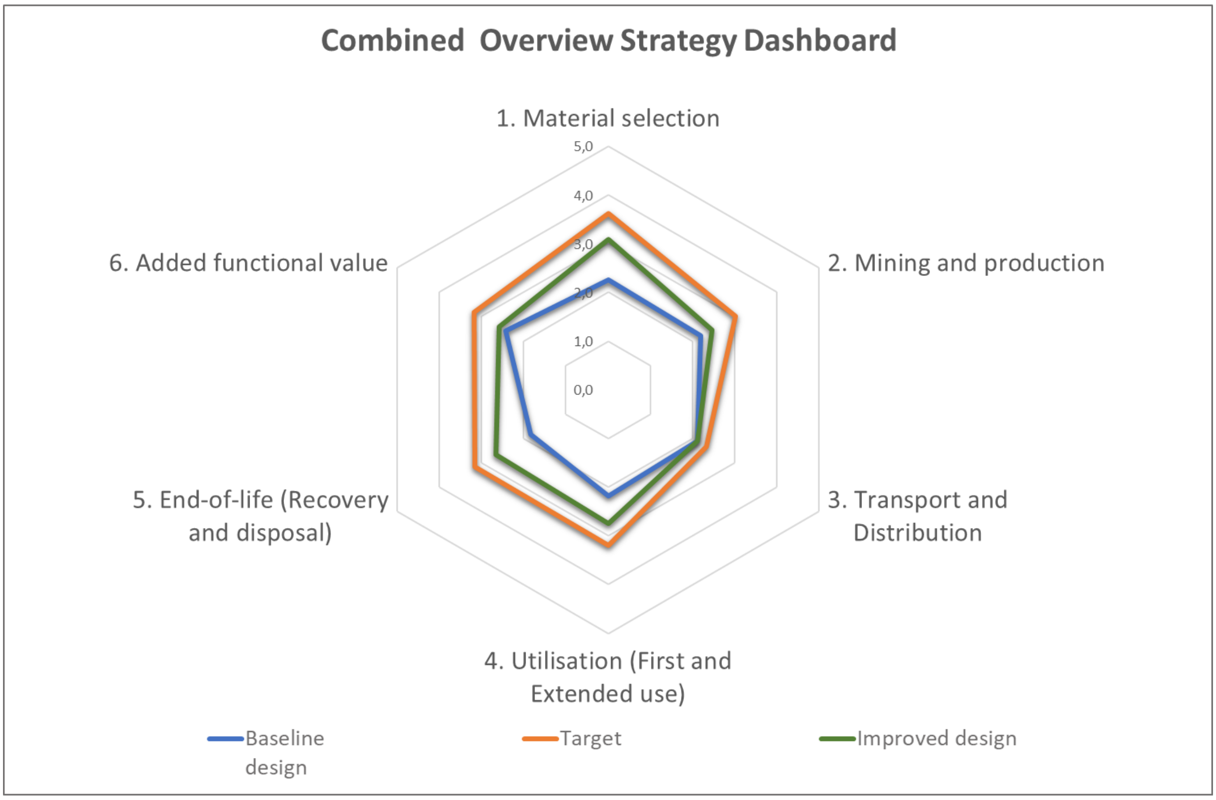

Figure 68: *Results iEDGE toolkit cross car beam*

5.5.3. POTENTIAL FOR OBJECTIVES

The impact of the use phase on the whole life cycle impact is different for every impact category. It is therefore interesting to see what the impact would be if the mass would be reduced within the LEVIS objectives (20 to 40 percent). **Table 45** shows what would happen if the weight reduction requirements would be met and what the effect on the life cycle impact on a component level would be. In this scenario, the assumption is made that the energy consumption in the use phase would be considerably lower, but the production and EOL phase are unchanged.

Looking at this table, it is clear that the emission reduction objective of 25% of GHG emissions will be met only if, in addition to the decreasing of emissions during the use phase, there are also additional contributions from the rest of phases to the reduction of the GHG emissions. However, as has been stated before, the variables like lifespan, electricity grid mix, and recycling rate have a large influence on the potential relative emission savings of the LEVIS demonstrators. As is visualised as an example in **Table 45**, LEVIS will meet its objectives when the EVs would be charged in China during their lifespan.

N.B: Please note that these numbers purely highlight the importance of all the life cycle phases. They are not in any way a prediction of the reduction in GHG emissions from the new design demonstrators. By Lightweighting through the use of new materials, you will inevitably have different emissions through all life cycle phases, with the potential of different effects on the corresponding impact categories. We expect that the final results from the LEVIS demonstrators (to be published in D6.2 towards the end of the project) will provide more concrete insights and we will be able to say more definitively whether, or to what extent, LEVIS is able to meet its environmental objectives.

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Table 45: *Cross car beam: Potential emission reduction effect of lightweight design (when it only affects use phase) for the electricity grid mix scenario.*

	EU-28		CN		US	
Mass reduction	**20%**	**40%**	**20%**	**40%**	**20%**	**40%**
Resource depletion						
Fossil depletion (%)	13	26	14	27	13	27
Damage to Human health						
Climate change (%)	12	23	14	28	12	24
Fine Particulate Matter Formation (%)	7	13	12	25	6	12
Human toxicity, cancer (%)	0	0	0	0	0	0
Damage to ecosystems						
Climate change (%)	12	23	14	28	12	24
Terrestrial Acidification (%)	9	18	15	30	9	18

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6. CROSS DEMO CONCLUSIONS

The LCA results across the different demonstrator benchmark products show both similarities and differences when comparing each other. It is clear from the results, that the material selection has a large influence on the overall impact of the product, often more so than the particular production processes involved or the transportation of the materials during the production of the components.

There is, however, a slight difference on relative impact between the benchmark demonstrators when looking at the different phases. This is shown in **Figure 69**. The figure shows the impact on climate change per kg of produced benchmark product on the three different life cycle phases (production, use phase and EOL). The cross-car beam and the suspension control arm have very similar LCA results, which is logical since both these products are made mostly of steel. The battery box and module on the other hand are very different, with the battery box having a large impact during the production phase, and the battery module having very limited emission savings from material recovery in the EOL phase. This is with both products (battery box and module), due to the materials selection of the benchmark demonstrators. Aluminium produces more GHG emissions per kg than steel, and the plastics from the module are more difficult to recycle than the metals from the other benchmark demonstrators.

A similar impact profile can be seen when looking at the damage to human health impact (**Figure 70**). The main difference is that the damage to human health of the steel products (suspension control arm & cross car beam) is comparatively slightly higher than when looking solely at the impact on climate change. This does not mean that from a LCIA perspective the choice of aluminium and ABS is not a good choice by definition. Were the battery box made of steel, it would have been much heavier which would have resulted in its own adverse environmental effects (more GHG emissions, land use, ionizing radiation emissions, etc.), by having a much larger energy consumption in the use phase.

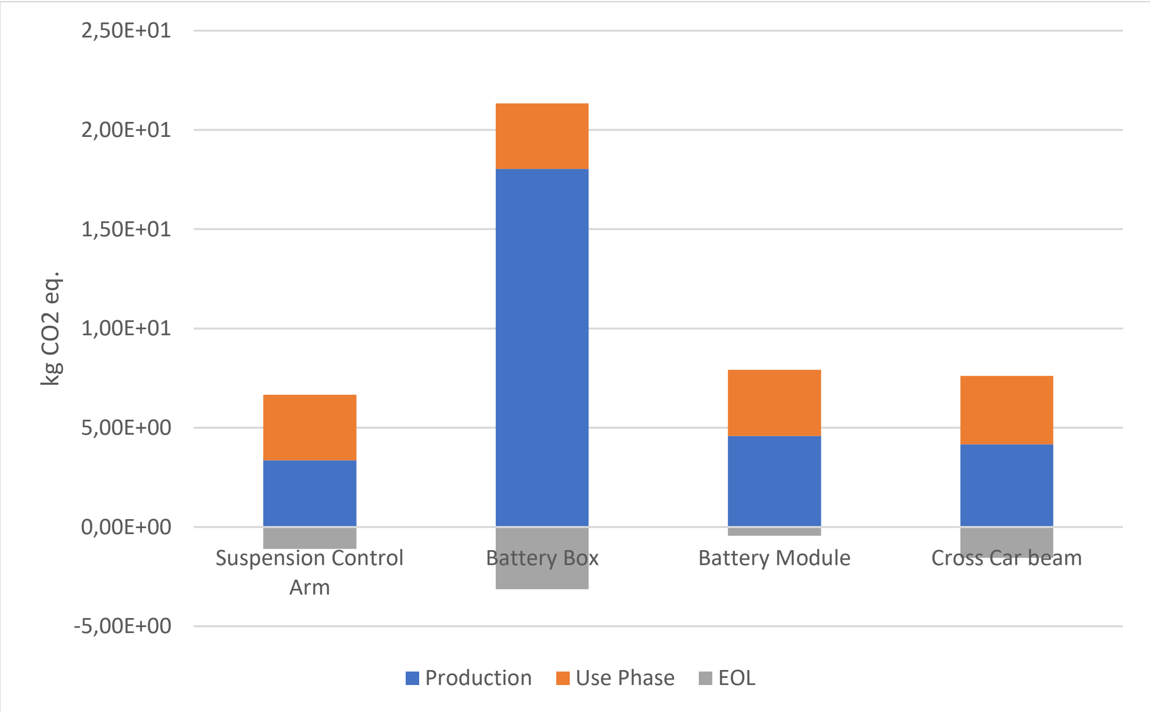

Figure 69: *Comparison impact on climate change benchmark demonstrators*

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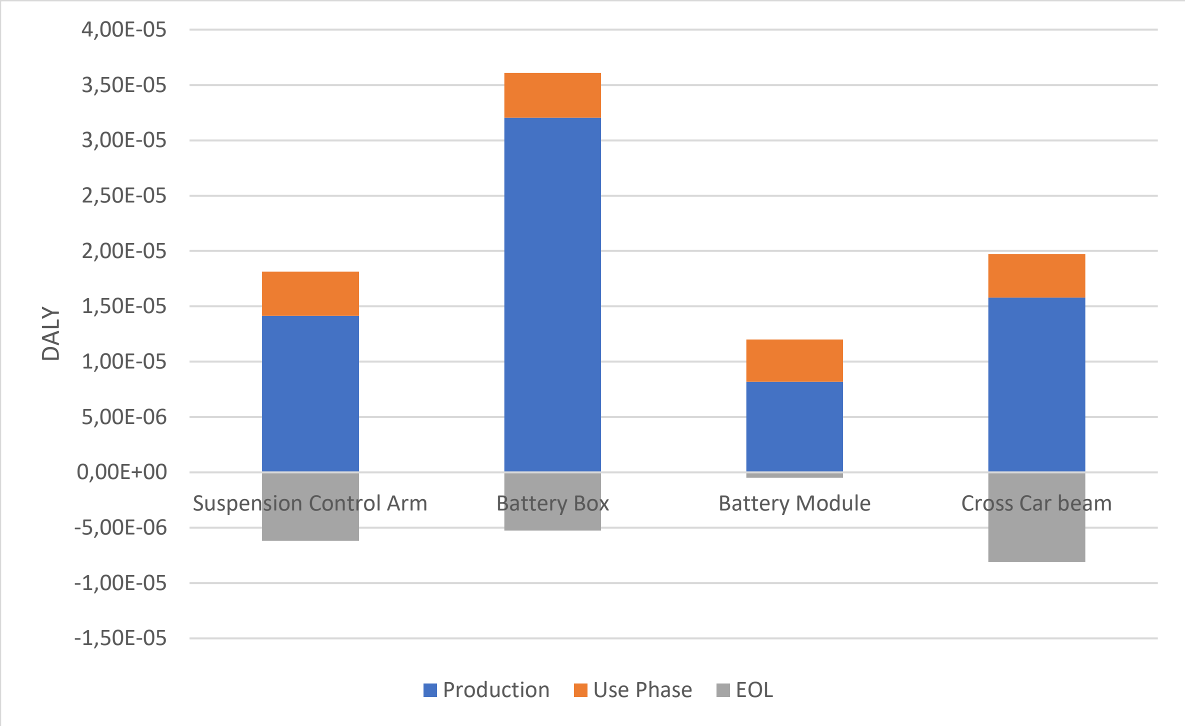

Figure 70: *Comparison damage to human health benchmark demonstrators*

When comparing the results of the sensitivity analysis across the benchmark demonstrators, similar results can be seen. They all showed significant decreases in emissions when raising the lifespan of the vehicles and increasing the recycling rate, while the emissions increased when the EVs were charged in China or the US. The impact of the lifespan and electricity grid mix was especially large for impact categories where the use phase was the main contributor, which were the fine particulate matter formation and human toxicity. This was similar for the recycling rate and the influence of the material choice, which showed reductions on the same impact categories. The sensitivity analysis also strengthened the argument for a potential carryover effect through avoided or postponed need for replacement, due to extended lifespan for example. The changing variables have significant influence on the results of this LCA and will likely have a significant impact on the conclusions of the deliverable D6.2, where the comparison will be made between benchmark products and the new LEVIS designs and carryover effects in line with circular economy principles are further explored.

When comparing the LCA results of the benchmark demonstrators with the results of the iEDGE toolkit which the demo partners performed in WP1, some similarities can be found. The LCA results suggested that the there are multiple harmful emissions damaging human health and ecosystems apart from GHG emissions (impact on climate change). Looking at the requirements the demo partners set showed that in most cases the partners already were aware of this, since they specifically mentioned to reduce emissions damaging human health.

One of the most important aspects were the similarities and differences between the focus suggestions of the iEDGE toolkit and the results of the benchmark LCA. Important LCA results for all the demonstrators were for example the high influence of the material selection on the environmental impact. This was shown as a suggested focus area for the all the demonstrators in the iEDGE toolkit.

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Another noticeable similarity was also found between the battery module having a low recycling rate, and having the EOL phase as suggested focus. There were also some differences between the LCA results of the partners and the iEDGE suggestions. The cross car beam for example had the EOL suggested as focus in the iEDGE toolkit, while the steel of the cross car beam is easily recyclable. Similarly, the battery box had the utilisation as a focus suggestion, while the main environmental impact comes from the production phase (particularly the material production).

This report also made a very rough estimation on the environmental impact on the use phase if the demonstrators were 20 to 40% lighter (as stated in the objectives). It could be concluded that lowering the use phase impact alone is not enough to meet the LEVIS objectives. Of course, in reality the different materials are expected to have a considerable effect on the production phase and EOL as well. However, it can be concluded that there is no margin for the composites to have a higher environmental impact than the benchmark materials.

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8. ANNEX

8.1. LIFE CYCLE EMISSIONS SUSPENSION CONTROL ARM

The values are provided in scientific number format, meaning that the “E” is equal to “10^” (for example, 5,51E+02 = 5,51*10^2 s= 551).

***Table 46**: Environmental impact life cycle benchmark suspension control arm. Midpoint indicators.*

ReCiPe Midpoint indicator	Value	Unit
Climate change	6,20E+00	kg CO2 eq.
Fine Particulate Matter Formation	6,20E+00	kg PM2.5 eq.
Fossil depletion	5,21E-03	kg oil eq.
Freshwater Consumption	2,30E+00	m3
Freshwater ecotoxicity	5,20E-02	kg 1,4 DB eq.
Freshwater Eutrophication	7,86E-04	kg P eq.
Human toxicity, cancer	1,92E-05	kg 1,4-DB eq.
Human toxicity, non-cancer	1,63E+00	kg 1,4-DB eq.
Ionizing Radiation	2,89E-01	kBq Co-60 eq. to air
Land use	2,66E-01	Annual crop eq.·y
Marine ecotoxicity	3,32E-01	kg 1,4-DB eq.
Marine Eutrophication	3,60E-03	kg N eq.
Metal depletion	1,24E-04	kg Cu eq.
Photochemical Ozone Formation, Ecosystems	1,11E-01	kg NOx eq.
Photochemical Ozone Formation, Human Health	8,79E-03	kg NOx eq.
Stratospheric Ozone Depletion	8,73E-03	kg CFC-11 eq.
Terrestrial Acidification	1,67E-06	kg SO2 eq.
Terrestrial ecotoxicity	1,55E-02	kg 1,4-DB eq.

***Table 47:** Environmental impact life cycle benchmark suspension control arm. Endpoint indicators.*

ReCiPe Endpoint indicators	Value	Unit
Resource depletion		
Fossil depletion	3,18E-01	[$]
Metal depletion	2,56E-02	[$]
Human Health		
Climate change Human Health	5,76E-06	[DALY]
Fine Particulate Matter Formation	3,28E-06	[DALY]
Freshwater Consumption, Human Health	5,57E-08	[DALY]
Human toxicity, cancer	5,42E-06	[DALY]
Human toxicity, non-cancer	6,58E-08	[DALY]
Ionizing Radiation	2,26E-09	[DALY]
Photochemical Ozone Formation, Human Health	7,95E-09	[DALY]
Stratospheric Ozone Depletion	8,88E-10	[DALY]
Terrestrial ecosystems		
Terrestrial Acidification	3,29E-09	[species.yr]

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Terrestrial ecotoxicity	3,90E-11	[species.yr]
Photochemical Ozone Formation, Ecosystems	1,13E-09	[species.yr]
Land use	2,95E-09	[species.yr]
Climate change Terrest Ecosystems	1,74E-08	[species.yr]
Marine ecosystems		
Marine ecotoxicity	3,78E-13	[species.yr]
Marine Eutrophication	2,05E-13	[species.yr]
Freshwater ecosystems		
Freshwater Consumption, Terrest Ecosystems	2,77E-10	[species.yr]
Freshwater ecotoxicity	5,46E-13	[species.yr]
Freshwater Eutrophication	1,29E-11	[species.yr]
Freshwater Consumption, Freshw Ecosystems	3,09E-14	[species.yr]
Climate change Freshw Ecosystems	4,75E-13	[species.yr]

8.2. LIFE CYCLE EMISSIONS BATTERY BOX

Table 48: *Environmental impact life cycle benchmark battery box. Midpoint indicators.*

ReCiPe Midpoint indicators	Value	Unit
Climate change	1,84E+01	kg CO2 eq.
Fine Particulate Matter Formation	2,21E-02	kg PM2.5 eq.
Fossil depletion	4,98E+00	kg oil eq.
Freshwater Consumption	2,08E-01	m3
Freshwater ecotoxicity	1,40E-03	kg 1,4 DB eq.
Freshwater Eutrophication	1,45E-05	kg P eq.
Human toxicity, cancer	8,03E-03	kg 1,4-DB eq.
Human toxicity, non-cancer	1,39E+00	kg 1,4-DB eq.
Ionizing Radiation	2,63E-01	kBq Co-60 eq. to air
Land use	2,87E-01	Annual crop eq.·y
Marine ecotoxicity	1,42E-02	kg 1,4-DB eq.
Marine Eutrophication	1,42E-04	kg N eq.
Metal depletion	4,81E-02	kg Cu eq.
Photochemical Ozone Formation, Ecosystems	3,43E-02	kg NOx eq.
Photochemical Ozone Formation, Human Health	3,41E-02	kg NOx eq.
Stratospheric Ozone Depletion	3,48E-06	kg CFC-11 eq.
Terrestrial Acidification	6,11E-02	kg SO2 eq.
Terrestrial ecotoxicity	1,99E+01	kg 1,4-DB eq.

Table 49: *Environmental impact life cycle benchmark battery box. Endpoint indicators.*

ReCiPe Endpoint indicator	Value	Unit
Resource depletion		
Metal depletion	6,43E-01	$
Fossil depletion	1,11E-02	$
Human Health		

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Climate change Human Health	1,71E-05	DALY
Fine Particulate Matter Formation	1,39E-05	DALY
Freshwater Consumption, Human Health	3,48E-07	DALY
Human toxicity, cancer	2,67E-08	DALY
Human toxicity, non-cancer	3,16E-07	DALY
Ionizing Radiation	2,24E-09	DALY
Photochemical Ozone Formation, Human Health	3,10E-08	DALY
Stratospheric Ozone Depletion	1,85E-09	DALY
Terrestrial ecosystems		
Terrestrial Acidification	1,30E-08	species.yr
Terrestrial ecotoxicity	2,27E-10	species.yr
Photochemical Ozone Formation, Ecosystems	4,42E-09	species.yr
Land use	2,55E-09	species.yr
Climate change	5,15E-08	species.yr
Marine ecosystems		
Marine ecotoxicity	1,49E-12	species.yr
Marine Eutrophication	2,35E-13	species.yr
Freshwater ecosystems		
Freshwater Consumption, Terrest Ecosystems	2,03E-09	species.yr
Freshwater ecotoxicity	9,73E-13	species.yr
Freshwater Eutrophication	9,72E-12	species.yr
Freshwater Consumption, Freshw Ecosystems	4,14E-13	species.yr
Climate change Freshw Ecosystems	1,41E-12	species.yr

8.3. LIFE CYCLE IMPACT BATTERY MODULE

Table 50: *Environmental impact life cycle benchmark battery module. Midpoint indicators.*

ReCiPe Midpoint indicators	Value	Unit
Climate change	7,40E+00	kg CO2 eq.
Fine Particulate Matter Formation	8,37E-03	kg PM2.5 eq.
Fossil depletion	3,01E+00	kg oil eq.
Freshwater Consumption	6,12E-02	m3
Freshwater ecotoxicity	3,88E-03	kg 1,4 DB eq.
Freshwater Eutrophication	2,53E-05	kg P eq.
Human toxicity, cancer	8,34E-03	kg 1,4-DB eq.
Human toxicity, non-cancer	2,70E+00	kg 1,4-DB eq.
Ionizing Radiation	2,47E-01	kBq Co-60 eq. to air
Land use	5,38E-01	Annual crop eq.·y
Marine ecotoxicity	5,38E-02	kg 1,4-DB eq.
Marine Eutrophication	1,78E-04	kg N eq.
Metal depletion	5,53E-01	kg Cu eq.
Photochemical Ozone Formation, Ecosystems	1,15E-02	kg NOx eq.
Photochemical Ozone Formation, Human Health	1,14E-02	kg NOx eq.
Stratospheric Ozone Depletion	3,92E-06	kg CFC-11 eq.

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Terrestrial Acidification	2,71E-02	kg SO2 eq.
Terrestrial ecotoxicity	1,06E+02	kg 1,4-DB eq.

Table 51: *Environmental impact life cycle benchmark battery module. Endpoint indicators.*

ReCiPe Endpoint indicator	Value	Unit
Resource depletion		
Fossil depletion	6,61E-01	$
Metal depletion	1,28E-01	$
Human Health		
Climate change Human Health, default	6,87E-06	DALY
Fine Particulate Matter Formation	5,26E-06	DALY
Freshwater Consumption, Human Health	6,58E-08	DALY
Human toxicity, cancer	2,77E-08	DALY
Human toxicity, non-cancer	6,16E-07	DALY
Ionizing Radiation	2,10E-09	DALY
Photochemical Ozone Formation, Human Health	1,04E-08	DALY
Stratospheric Ozone Depletion	2,08E-09	DALY
Terrestrial Ecosystems		
Terrestrial Acidification	5,65E-12	species.yr
Terrestrial ecotoxicity	2,96E-13	species.yr
Photochemical Ozone Formation, Ecosystems	5,65E-12	species.yr
Land use	2,96E-13	species.yr
Climate change Terrest Ecosystems	5,65E-12	species.yr
Marine ecosystems		
Marine ecotoxicity	5,82E-12	species.yr
Marine Eutrophication	2,45E-13	species.yr
Freshwater ecosystems		
Freshwater Consumption, Terrest Ecosystems	3,47E-10	species.yr
Freshwater ecotoxicity	2,69E-12	species.yr
Freshwater Eutrophication	1,70E-11	species.yr
Freshwater Consumption, Freshw Ecosystems	5,29E-14	species.yr
Climate change Freshw Ecosystems, default	5,66E-13	species.yr

8.4. LIFE CYCLE IMPACT CROSS CAR BEAM

Table 52: *Environmental impact life cycle benchmark cross car beam. Midpoint indicators.*

ReCiPe Midpoint indicators	Value	Unit
Climate change	6,51E+00	kg CO2 eq.
Fine Particulate Matter Formation	6,50E+00	kg PM2.5 eq.
Fossil depletion	5,17E-03	kg oil eq.
Freshwater Consumption	2,26E+00	m3
Freshwater ecotoxicity	4,56E-02	kg 1,4 DB eq.
Freshwater Eutrophication	8,35E-04	kg P eq.
Human toxicity, cancer	1,35E-05	kg 1,4-DB eq.

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Human toxicity, non-cancer	1,65E+00	kg 1,4-DB eq.
Ionizing Radiation	3,19E-01	kBq Co-60 eq. to air
Land use	2,68E-01	Annual crop eq.·y
Marine ecotoxicity	3,32E-01	kg 1,4-DB eq.
Marine Eutrophication	3,84E-03	kg N eq.
Metal depletion	1,22E-04	kg Cu eq.
Photochemical Ozone Formation, Ecosystems	1,28E-01	kg NOx eq.
Photochemical Ozone Formation, Human Health	8,47E-03	kg NOx eq.
Stratospheric Ozone Depletion	8,42E-03	kg CFC-11 eq.
Terrestrial Acidification	1,55E-06	kg SO2 eq.
Terrestrial ecotoxicity	1,54E-02	kg 1,4-DB eq.

Table 53: *Environmental impact life cycle benchmark cross car beam. Endpoint indicators.*

ReCiPe Endpoint indicator	Value	Unit
Resource depletion		
Fossil depletion	2,46E-01	$
Metal depletion	2,96E-02	$
Human Health		
Climate change Human Health	6,04E-06	DALY
Fine Particulate Matter Formation	3,25E-06	DALY
Freshwater Consumption, Human Health	4,85E-08	DALY
Human toxicity, cancer	5,47E-06	DALY
Human toxicity, non-cancer	7,28E-08	DALY
Ionizing Radiation	2,28E-09	DALY
Photochemical Ozone Formation, Human Health	7,67E-09	DALY
Stratospheric Ozone Depletion	8,22E-10	DALY
Terrestrial Ecosystems		
Terrestrial Acidification	3,26E-09	species.yr
Terrestrial ecotoxicity	4,53E-11	species.yr
Photochemical Ozone Formation, Ecosystems	1,09E-09	species.yr
Land use	2,94E-09	species.yr
Climate change Terrest Ecosystems	1,82E-08	species.yr
Marine ecosystems		
Marine ecotoxicity	4,04E-13	species.yr
Marine Eutrophication	2,03E-13	species.yr
Freshwater ecosystems		
Freshwater Consumption, Terrest Ecosystems	2,36E-10	species.yr
Freshwater ecotoxicity	5,80E-13	species.yr
Freshwater Eutrophication	9,08E-12	species.yr
Freshwater Consumption, Freshw Ecosystems	2,68E-14	species.yr
Climate change Freshw Ecosystems	4,98E-13	species.yr

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