POLITECNICO DI TORINO

MASTER's Degree in ENERGY AND NUCLEAR ENGINEERING

MASTER's Degree Thesis

REDUCING THE ENVIRONMENTAL IMPACT IN THE ELECTRIC POWER TRAIN MOUNTS DESIGN PROCESS

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JULY 2022

Summary

Achieving a sustainable automotive industry requires a systemic view that implies addressing the circularity, reduction, and decarbonization of materials apart from the electrification efforts being implemented by the industry. The main focus of this work consists in the calculation of the environmental impact of the current design of the power train mounts of the XC40 electric vehicle in Volvo Cars Europe. The main objective is to evaluate the most impactful stages of the process and propose different scenarios under which the carbon footprint and other relevant effects can be reduced. The thesis is developed applying the Life Cycle Assessment (LCA) methodology, under a cradle-to-gate approach, which encompasses from the material extraction to the assembly of the parts in Volvo's facility in Ghent. Accordingly, the value chain is broken down into four different phases which include raw material extraction, manufacturing of the pieces, logistics (packaging and transportation), and assembly of the power train. The work demonstrates the importance of approaching circularity and sustainability from an early stage in design process, as the most effective method to reduce the environmental footprint. This method is referred to as the impact based design. Additionally, it provides a regulatory background that justifies the relevance of the study.

The data collection methodology consisted in gathering information on the elementary flows that are present in each of the four different phases. For this purpose, an extensive literature review was carried along with interviews to Volvo Cars suppliers. The Ecoinvent 3.7 database was used as the main source of information to obtain data on transportation and raw material extraction regards.

The calculations were performed using the free access OpenLCA software and the ReCiPe midpoint (H)V1.13 impact assessment method. The results obtained show the relevance of raw materials in the environmental impact of the value chain. Specifically aluminum, since it corresponds to 93% of the total power train weight. Aluminum accounts for 69% of the total carbon dioxide emissions, which is equivalent to 291.83 kg of CO2e. Moreover, it demonstrates that the electricity generation source for the aluminum production is the most significant characteristic in the climate impact and fossil depletion categories due to the fact that most of

the parts are produced in China. Furthermore, the sensitivity analysis highlights the environmental impact reduction potential of increasing the aluminum recycled content. Finally, the study presents a techno-economic analysis that reflects on the economic implications of adopting more sustainable alternatives. Moreover, it provides a preliminary discussion of the expansion of the European emissions trading system to the maritime sector and the introduction of the carbon border tax on imported aluminum goods.

Acknowledgements

I would like to thank Volvo Cars for this unique opportunity and the Power Train Mounts Team for the guidance and suppport provided during this thesis. Special thanks to Charlotta Nedström for her feedback and continuous help to gather the necessary data for the implementation. Thanks to Professor Giovanni Blengini for his inputs and advice.

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Acronyms

AC
: Aluminum Cast

AoPs
: Area of Protection

AW
: Aluminum Wrought

AWD
: All Wheel Drive

BEV
: Battery Electric Vehicle

CN
: China

DCB
: Dichlorobenzeen

DE
: Germany

EA
: European Aluminum

EFAD
: Electric Front Axle Drive

EGD

European Green Deal

ERAD

Electric Rear Axle Drive

ETS

Emissions Trading System

EU

European Union

EV

Electric Vehicle

FWD

Front Wheel Drive

GDP

Gross Domestic Product

GF

Glass fiber

GHG

Green House Gas

GWP

Global Warming Potential

HDPC

High Pressure Die Casting

HDPE

High Density Polyethylene

IAI

International Aluminum Institute

ICE
  Internal Combustion Engine

IMDS
  International Material Data System

IRAC
  International Agency for Research on Cancer

ISO
  International Organization for Standardization

LCA
  Life Cycle Assessment

LCIA
  Life Cycle Impact Assessment

LHM
  Left Hand Mount

LHS
  Left Hand Side

LHV
  Lower Heating Value

LLTB
  Left Lower Torque

NO
  Norway

NR
  Natural Rubber

NZE
  Net Zero Emissions

PA
  Polyamide

PWT
: Powertrain

RHM
: Right Hand Mount

RHS
: Right Hand Side

RLTB
: Right Lower Torque

RPM
: Rotation per minute

RWD
: Rear Wheel Drive

SDGs
: Sustainable Development Goals

VOC
: Volatile Organic Compounds

WBCSD
: World Business Council for Sustainable Development

WDP
: Water Depletion Potential

WEF
: World Economic Forum

Chapter 1

Introduction

This chapter sets the context in which the master thesis will be developed and presents the scope of the study.

1.1 Background

The European Union (EU) has committed to become the first climate neutral continent by 2050. In 2019, the European commission presented the European Green Deal (EGD), which comprises an ambitious set of initiatives to direct the transformation towards climate neutrality. Starting with the European Climate Pact that intends to engage different stakeholders in becoming part of the action plan [1]. In 2021, the European Parliament and member states reached an agreement on the European Climate Law which contains the new target of achieving a 55% emissions reduction by 2030 (2030 Climate Target Plan) compared to 1990 levels and provides a roadmap towards the fulfillment of the 2050 target including the participation of the most relevant sectors across the EU economy [2].

The automotive industry is one of the most important sectors in the EU economy, representing 7% of the European gross domestic product (GDP). However, it also accounts for 10% of the greenhouse gas (GHG) emissions worldwide and around 20% of European CO_2 emissions [3]. This makes the industry a key component for achieving the Paris agreement target of carbon neutrality and stay within the limit of 1.5 C global warming temperature [4]. Furthermore, it is forecasted that due to the increased demand of battery electric Vehicles, materials would account for more than 60% of the industry's emissions by 2040 [5]. Consequently, mobility and transportation are one of the main focuses of the climate action plans. The green deal includes a target of achieving 55% reduction of emissions coming from cars by 2030 and zero emission coming from new cars by 2035. In the same way, the European Commission is supporting the market for zero and low emissions vehicles and a carbon emission trading system for road transport will be put in place starting in 2026. Increasing environmental regulations and sustainability concerns have led major car manufacturers to take an important shift in the production of fossil-fuel based vehicles and start focusing on electric proposals. However, electrification is not the only way to decarbonizing the sector. The industry must consider the emissions during the manufacturing stage and adopt a circularity approach within the business model [4]. The Circular Cars Initiative, presented in Davos 2020 by the World Economic Forum (WEF) and the World Business Council for Sustainable Development (WBCSD), aims to bring together different stakeholders involved in the automotive industry to implement actions focused on mitigating emissions from the production phase [4]. That involves a more efficient use of natural resources and increasing the sustainability of the value chain. Additionally, it is a clear strategy that contributes with the Sustainable Development Goals (SDG) of responsible consumption and production, Industry innovation and infrastructure, and partnership for the goals.

Sustainability makes part of Volvo Cars core values along with safety. Therefore, the firm plans to become a net-zero company by 2040. As part of the plan, the company prompts to phase out the internal combustion engine (ICE) by 2030 and capture the benefits of circular economy principles. Some of the company's main goals include:

- Reduce CO2 emissions per car in supply chain by 2025.
- Reducing the GHG emissions from raw materials usage by 25 per cent per average vehicle from 2018 to 2025
- Using 25% recycled materials in new cars by 2025.
- Increase the use of recycled and bio-based materials.
- Create a climate neutral retailer network by 2040.

1.2 Scope and goal

This master thesis aims to identify and analyze the environmental impact of the design and assembling processes of the electric drive transmission system that compose three of Volvo's battery electric vehicles (BEVs) (Polestar 2, XC 40, and C 40). The study implements a life cycle assessment methodology adopting a cradle-to-gate approach to calculate the climate impact of the powertrain mounts of the vehicle. Consequently, a sensitivity analysis will be conducted to identify potential emissions reduction opportunities, based on the operations of Volvo Cars in Gothenburg and Ghent. Moreover, it proposes a cost-effective alternative to achieve the decarbonization of the powertrain parts and implement a circular strategy.

The importance of the study relies on identifying the most meaningful environmental impacts and their causes. The results will enable the Powertrain Mounts area to implement actions aimed to improve the sustainability of the design and assembling processes. This study requires the participation of the Powertrain Mount suppliers as well as the packaging, transportation, and assembly responsible from Volvo Cars.

1.3 Limitations

The complete information from all the suppliers was not available as it was not possible to establish contact with all of them. As a result, some reasonable assumptions were considered based on the literature review and available data from other suppliers.

Chapter 2

Literature Review

This chapter presents the reader with a description of the available literature regarding the mechanical components of a BEV powertrain system and the methodology used to assess their environmental impact.

2.1 Powertrain mounts

The powertrain of a car is a system made of different elements in charge of transferring the power from the engine to the wheels, in order to propel the car [6]. During this process, noise and vibrations are produced. These can be a consequence of radial forces acting in the stator´s housing, torque ripple and irregularities on the road [7]. There are different configurations for powertrains according to literature, and each of them have three rotational and longitudinal degrees of freedom [7][8]. The powertrain mounts are the set of parts responsible for supporting the weight of the engine and distributing it uniformly among the load points on the vehicle´s structure. Besides attaching the motor to the vehicle´s frame and holding the powertrain in place, the main function of the mounts is to isolate the vehicle from the engine´s noise and mitigate the vibrations. As a result, the mounts are crucial components when addressing the drivability of a vehicle. The position of the motor and of the powertrain components is of great importance as they have a major effect on the dynamic features of the vehicle [8]. Increasing the power output of the motor and decreasing the weight of the car´s structure, cause a rising stress on the performance of the engine mounts due to the vibratory and noise effects [9]. The design of the powertrain mounts is proprietary of each car manufacturer, although they are similar in concept, they are different in the detailed structural design. However, all the parts most comply with different properties:

- Damping

- Stiffness
- Safety
- Durability
- Manufacturing characteristics

The XC 40 powertrain is composed of two main systems, the Electric Front Axle Drive (EFAD) and the Electric Rear Axle Drive (ERAD). Each system is made up of different mechanic parts shown in Table 2.1

Table 2.1: Electric Drive Transmission System mounts

Amount of parts	Part name
1	RLTB Link
1	RHS Body Bracket
1	LHS Body Bracket
1	RHM Bracket
1	LHM Bracket
1	Crossmember
2	Small bushings
4	Big bushings
2	Mounts (RHM/LHM)
1	LLTB
1	RLTB
1	RLTB Bracket

Figure 2.1 shows the different parts that make up the EFAD of the XC 40´s transmission mounts system.

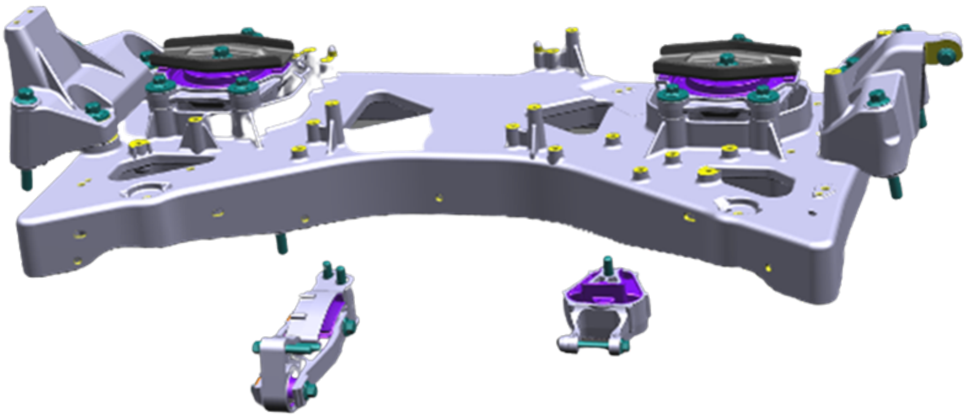


Figure 2.1: Schematic drawing of the EFAD system

Each part has a specific function within the powertrain system. As a result, the physical and mechanical properties of each piece are evaluated and tested several times before undergoing the mass production process. The material of the parts is chosen based on mechanical specifications, cost, sustainability requirements, and safety standards. The most common materials used to produce the mount parts are aluminum alloys, due to their high resistance to corrosion and recyclability, and natural rubber, as it presents the best damping and isolation characteristics. A general review of the materials used for the mounts is presented later in this chapter.

Table 2.2 presents the powertrain mounts that compose the XC 40 vehicle and provides a short description of their functions.

2.2 The electric transmission

The transmission system of a car is in charge of transferring the rotating power originated in the motor to the wheels, in the correct amount. This means, the transmission system adjusts the engine power according to the operating range of the vehicle. In conventional cars, it is usually made of a gearbox containing different sizes of gears that allows the car to adjust the rotating ratio between the motor and the wheels by adjusting the revolutions per minute (RPM) and torque according to its speed.

Most electric vehicles (EVs) work with an AC motor connected to a single-speed gearbox, all the gears are interconnected and rotate at the same time. Since the absence of the multiple gears reduces the friction, the speed transition is smoother.

Table 2.2: XC40 Powertrain mounts

PWT Part	Description
LH/RH Engine Mount Brackets	The engine mount brackets are attached to the engine mounts in the left- and right-hand side of the crossmember. They are the link between the engine mounts and the engine housing structure
LH/RH Engine Mounts	The left and right engine mounts are responsible for attaching the engine structure to the crossmember
Crossmember	The crossmember design was initially thought for an ICE vehicle. This part links the electric transmission to the vehicle´s frame. Its shape aims to balance longitudinal and lateral forces in case of crashing. Thus, making it a key element concerning safety. It should be strong enough to avoid deformations.
RHS Body Bracket	The right-hand side body bracket serves as an anchor point between the crossmember and the vehicle´s frame on the right side.
LHS Body Bracket	The left-hand side body bracket serves as an anchor point between the crossmember and the vehicle´s frame on the left side. It balances the engine and transmission to have a good balance control when the vehicle is in motion.
LLTB	The left lower torque bracket attaches the structure of the motor to the frame of the vehicle. Its main purpose is to reduce the vibrations coming from the powertrain.
RLTB	The right lower torque bracket has the function of attaching the structure of the motor to the frame of the vehicle. Should be stiff to reduce the vibrations.
Small bushings	The small bushing is placed inside the RLTB Bracket holding the RLTB link. The engine is attached to this piece. It is responsible for isolating the engine vibrations and noise caused by speed and prevent the engine bounce.
RLTB Bracket	The RLTB holds the right-hand side of the engine structure. It is attached to the RLTB link by the small bushing assembled within.
RLTB Link	The RLTB link attaches the RLTB bracket and the RLTB torque rod.

Moreover, EVs are able to generate a consistent value of torque at different RPM (beyond 10000) within a specific range [10]. Consequently, the efficiency of the EVs is higher than that of the ICE.

There are four different types of transmission systems depending on the requirements they meet:

- All wheel drive (AWD) powers both front and rear axle. Engine is positioned either in front or center. However, it is also possible to locate engine in the back of the car.

- Front wheel drive (FWD) prioritizes the front axle, while rear axle is not powered. Engine is mainly located in front either in longitudinal or transverse direction.

- Standard drive is in which engine is positioned in front of the car and powers the rear axle.

- Rear wheel drive (RWD) is focused on rear axle which is powered by the engine located in rear [8].

2.3 Volvo XC40 BEV

The Volvo XC 40 is Volvo Cars first fully electric vehicle powered by two twin electric motors with a maximum motor power of 170 kW at a maximum speed of 160 km/h. The total engine power is 408 hp with a total peak torque of 660 Nm, able to accelerate from 0 to 100 km in 4.9 seconds [11]. The mounts of the EFAD weigh 21.287 kg. The model being analyzed by this thesis is an all-wheel drive vehicle.

2.4 Life Cycle Assessment

The Life Cycle Analysis is a standardized methodology, created in the early 1990´s (ISO 14040-44), for analyzing and quantifying the environmental impact of a product or a service along their life cycle [12]. The technique applies a four-step methodology which consists in breaking down a system into smaller operation units or subprocesses to then define a functional unit that represents the elemental unit for which the impact will be calculated, create an inventory analysis containing the raw materials and fuels used as inputs and the resultant waste/emissions, evaluate the impact of each subprocess, and analyze the results obtained. Figure 2.2 shows the LCA methodology according to the ISO 14040-44 standard.

2.4.1 State of the art

Various LCA´s can be found in literature for BEV. However, most of them focus on the electric motor and the battery pack performance, only a few publications are based on the powertrain components. [13], developed a generic scalable life cycle inventory based on a wide range electric traction model (20-200 kW; 48-477 Nm). The model is able to estimate the mass of different materials in the motor, with a 79% precision, depending on the torque and power inputs. The study analysis includes the main parts connected to the electrical motor such as the stator´s and endbells´ housing, terminal connection points, shaft, rotor, magnets, endplates, bearings, and other components defined as passive parts. It is divided into two stages that include the design and production stages. The purpose of the inventory is to serve as a complementary database for missing information when performing

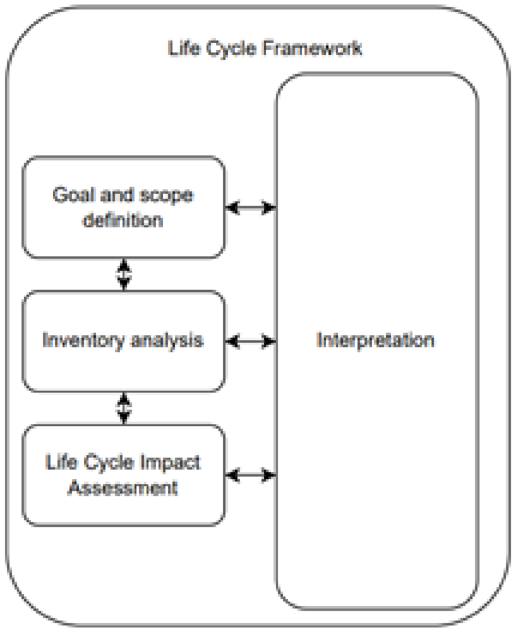


Figure 2.2: Life Cycle Assessment Methodology

LCA for BEV models of different characteristics. For practical matters, the study aims to link the gate-to-gate inventory with the existing processes of the life cycle of the parts found in the Ecoinvent 3 database to have a complete cradle-to-gate approach. Primary and secondary data were used in the building of the design and manufacturing description, including information from seven electric traction vehicles.

For the three power inputs that were analyzed in the study, 20 kW, 80 kW, and 200 kW, the results show that aluminum and electrical steel together represent around 60% of the material composition of the powertrain.

In the second version of the study [14], the manufacturing processes for steel, copper, plastics and insulation, magnets, and aluminum are described, and the elementary and product flows listed. According to the aluminum die casting method showed, the production of 1 kg of final product releases 0.4 g of aluminum fumes into the atmosphere along with 1 g of volatile organic compounds (VOC), as a consequence of oil-based lubricants. Although most of the direct emissions correspond to the burning of fossil fuels used in the melting process. A large part of metal scrap is recovered and remelted. However, around 60 g of aluminum cannot be recovered for recycling and results in waste.

A third study [15] performs a sensitivity analysis on the LCA of electric vs ICE vehicles and describes the importance of adopting a wide environmental impact analysis instead of solely focusing on CO2 emissions due to the misleading decisions it may cause.

Similarly, Volvo Cars has implemented a LCA to evaluate the carbon footprint of the fully electric C 40 [16], Volvo´s second fully electric car. The assessment considers a cradle-to-grave approach and compares the results to the fully electric XC 40 and XC 40 ICE vehicles. According to the report, the biggest improvement in CO2 reduction seems to be made when charging the vehicles with wind energy instead of the generic European Union electricity mix (from the GaBi database). The study coincides with the literature review by evidencing that the accumulated emissions from the raw materials extraction and processing are higher for a BEV than an ICE. However, during the use phase, the emissions per km are lower for a BEV. This shift of CO2 equivalent emissions from use phase to material extraction, is one of Volvo´s main motivations for the development of this master thesis.

Regarding the materials production phase, aluminum appears to be responsible for around 30% of the carbon footprint of all materials. This value matches the results obtained in [13]. Since the study is based on a complete vehicle rather than its subsystems, a simplified categorization of the materials is used. Thus, the report does not make a distinction among aluminum alloys. Data for components manufacturing processes is not taken into consideration either. A final comparison chart is included where it can be observed that the XC 40 emissions for the mining stage are 1% lower than that of the C 40. This is mainly due to the aluminum usage, which reinforces the fact that aluminum is one of the biggest responsible for the emissions accounted to passenger vehicles.

2.4.2 Raw material's extraction

Aluminum

Aluminum is the predominant material in the powertrain mounts manufacturing. Different aluminum alloys are used to produce each of the parts. The brackets and crossmember are entirely made from alloys such as Alu 46000 and Alu 43500. On the other hand, the torque rod and small bushings integrate other types of alloys in their composition (Alu 6082 and Alu 6005). These alloys are made of approximately 86-90% of aluminum, on a weight basis, and additives such as silicon, magnesium and iron. Different manufacturing techniques are used for the alloys production, which give them distinct physical properties. The production processes and the material's composition used in the powertrain mounts described in section

2.1 are shown in Table 3.2. A further description on the properties of each alloy can be found in the appendix section.

Table 2.3: Characteristics of aluminum alloys

Material Code	Material Formula	Alu wt%	Production Process	Properties Info
Alu 46000	AlSi9Cu3(Fe)	79.9-89.25	HPDC[1]	Appendix A1
Alu 43500 T7	AlSi10MgMn	86.45-90.45	HPDC	Appendix A2
Alu 44300	AlSi12(Fe)(a)	84.37-89.05	HPDC	Appendix A3
Alu 6082 T6	AlSi1MgMn	95.2-98.3	Extrusion	Appendix A4
Alu 6061 T6	AlMg1SiCu	95.85-99.33	Extrusion[2]	Appendix A5
Alu 6005 T6	AlSiMg(a)	96-98.8	Extrusion	Appendix A6

The alloys are made from aluminum ingots, which are produced from bauxite ore through differentiate processes. Figure 2.3 offers a brief description of the value chain of an aluminum ingot. This method involves four main steps:

1. Bauxite ore mining
2. Production of alumina
3. Molten aluminum obtainment via electrolysis
4. Ingot casting [19]

The aforementioned processes are energy intensive and have a high environmental impact potential. According to the analysis made by the International Aluminum Institute (IAI), the average aluminum ingot production, from cradle-to-gate, has a carbon footprint of 18 tonne CO2 eq per tonne of primary aluminum [20]. Other publication shows that the primary aluminum ingot production has a mean climate impact of 18.4 tonne of CO2 eq/tonne of Al [19]. While the average is around 18 tonne of CO2 eq/tonne of Al, the cradle-to-gate GWP for the primary aluminum ingot production oscillates between 5.92 kg of CO2e/kg Al for a smelter in Iceland to 41.1 kg of CO2e/kg Al for a smelter in the Middle East [21].Besides having a notorious carbon footprint, aluminum production has an important effect on human health, it has been classified as a carcinogenic activity by the International Agency for Research on Cancer (IARC) [22].

[1] *HPDC – in the High Pressure Die Casting process, the fused aluminum is forced into a mould cavity, using compressive power, until the metal is solidified [17].*

[2] *In the Extrusion process, aluminum is pushed through a die slot, using a hydraulic cylinder, at either room or elevated temperatures. Thus, aluminum takes the shape of the vent. [18]*

This thesis takes the Ecoinvent 3.7.1 database to analyze the aluminum casting production process and modifies it according to the descriptions found in the literature review.

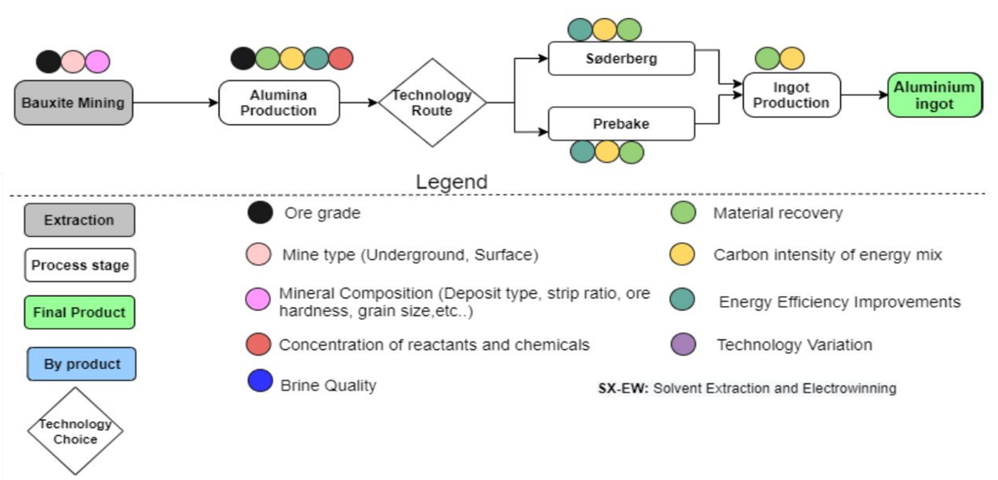


Figure 2.3: Value chain of Aluminum Ingot production [19]

Natural Rubber

Different powertrain parts such as bushings, mounts, and brackets contain natural rubber because of its mechanical properties. Natural rubber is also known as latex in its raw state and it is harvested from the rubber tree (Hevea brasiliensis). It contains dry rubber particles, mainly polyisoprene (C5H8), a smaller percentage of non-rubber content, and around 60% of water [23]. According to [24], 1 kg of dry rubber contains 88% of carbon. Table 2.4 shows the different additives that are used to mix with natural rubber blocks with the objective of upgrading its physical properties.

Table 2.4: Natural rubber compounds

Material group	Examples	Mixed in	Impact to compound
Polymers	NR, EPDM	The compound batch	Chemical resistance, basic high and low temp. Mechanical and dynamic properties Durability
Fillers	Carbon black, Silica, Clay, Chalk	The compound batch	Hardness Dynamic properties Durability
Softeners	Oil, synthetic softener	The compound batch	Hardness Low temp. properties
Anti-ageing		The compound batch	Reduce viscosity
Process aids	Wax	The compound batch	Vulcanization properties
Cure system	Sulphur, accelerators	Final mixing	Fine tuning Vulcanization properties

Different publications explain that the majority of green house gas (GHG) emissions resulting from fresh latex production are low. Thus, latex emissions are mainly associated to fertilizers, pesticides and fuel used for vehicles. According to the research from [25], the CO2 emissions of fresh latex production range between 55.6 – 168.9 kg CO2e/tonne. The publication is based on latex farms in Malaysia. It categorizes the farms, according to their size, into three different groups: small, medium and large and compares the emission factor of the groups. The resuslts show that all the farms have a similar climate impact of 93, 94, and 98 kg CO2e/tonne fresh latex, respectively. Although fresh latex contains a carbon bound, the CO2 intake from the trees is higher. Resulting in negative carbon emission from the natural rubber production.
The natural rubber composition analyzed in this thesis is a compound of the revised literature review and the Ecoinvent 3.7.1 database for latex production, which includes raw material extraction and transportation to the processing plant.

PA 6.6 30% GF

PA 6.6 30% GF refers to polyamide filled with 30% of glass fiber. It has very high strength, dimensional stability, creep strength and rigidity. The accretion of glass fiber adds high impact resistance under a continuous high temperature operation during long periods [26]. Its main properties are shown in Appendix D.3 (Ref). Polyamide is produced by combining adipic acid and hexamethylene diamine [27]. The main global polyamide producers and exporters are Germany, The United States, China, and Italy [28]. As the polyamide is produced from oil derivates, it has a significant environmental impact. According to the LCA analysis done by PwC on the PA 6.6 30% GF production of SOLVAY, the GWP is 6.7 ton CO_{2eq}/tonne of product [29].

Steel

Although aluminum is the main metal used in the powertrain parts, there are some components such as the stopper, damper and nut, that are made from steel. There are two types of steel alloys that are broadly used: QSTE 380 and GJL-200. QSTE is a high-strength steel used for the manufacturing of longitudinal beams and frames (Appendix). GJL-200 is a cast iron with a lamellar Graphite microstructure (Appendix). The steel industry generates an important amount of emissions throughout its value chain, during the extraction, crushing, grinding, calcining and casting. The research done by Vladimir Strezov et. al. analyzed the environmental impact of a steel company that has 1.2 M ton annual production in Australia. The result illustrates that the steel industry GWP is 909 kg CO2 eq/tonne of product. However, it does not mention the scope of the analysis [30].

Another report mentions that the cradle to gate GWP of iron is 1.5 ton CO2 eq/tonne of product. According to the results, the refining process is responsible for 75% of GWP, while the rest belongs to the mining and purification processes [31]. Another life cycle analysis of the steelmaking process in Shandong Province, China resulted in 358.54 kg CO2eq/tonne of molten steel [32]. Regarding the steel production in Europe, the carbon footprint of the Integrated Steel Mill in Italy is calculated to be 1.59 tonne CO2eq/tonne of steel, according to [33].

2.5 Circular Economy

The circular economy concept consists in growing apart from the business-as-usual system and creating one based on three main tenets: avoid waste and pollution, reuse materials, and regenerate natural systems [34]. It is forecasted that circular economy measures would be responsible for achieving the remaining 45% global emissions reduction, after renewables have been adopted [35]. Moreover, steel and aluminum, two broadly used elements in the automotive industry, make part of the materials responsible for more than 60% of the industry´s CO2 emissions [35]. The fact that BEV's are shifting emissions from the use phase to the material production phase [36] reinforces the idea that circularity must be a design driven principle. This thesis is focused on proposing design guidelines that can contribute with the implementation of circularity within Volvo Cars and enhance transparency throughout the value chain.

Chapter 3

Methodology

This chapter is dedicated to explaining the main steps taken in the development and implementation of the study.

3.1 Life Cycle Assessment

A LCA was implemented using the OpenLCA software to calculate the environmental impact of the mounts design process. The study was developed by following the LCA methodology and analyzing the effect on multiple indicators.

Functional Unit

The impact of the design and assembling process of the electric drive transmission system will be assessed in terms of 1 powertrain. Nevertheless, each stage is analyzed selecting the functional unit that best represents the corresponding process. Each adopted functional unit will be mentioned in the Life Cycle Impact Assessment chapter.

System Boundaries

The study is focused on the design process of the powertrain mounts within a cradle-to-gate approach,(also known as Ecoprofile [12]) which encompasses different steps of the value chain such as the extraction of raw materials, manufacturing, logistics (packaging and transportation), and the assembly of the parts in Volvo Cars Factory in Ghent, Belgium. The approach was selected according to the phases where Volvo Cars can have a direct impact. Figure 3.1 shows the system boundaries defined to conduct this thesis.

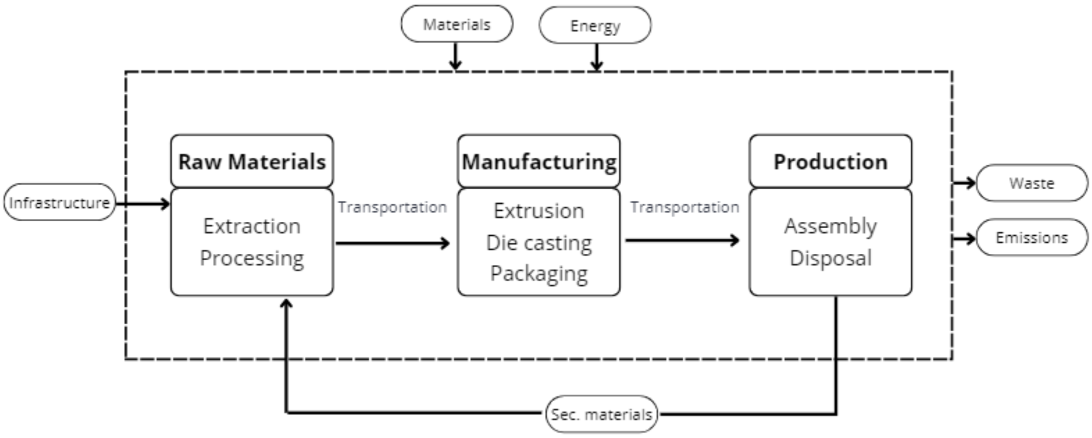


Figure 3.1: System boundaries for powertrain mounts production analysis

Data collection

The information required for the development of this thesis was obtained through different sources, taking care of the quality. Primary data for materials' content, manufacturing techniques, energy consumption, and logistics was collected directly from Volvo Cars departments, the International Material Data System (IMDS), and the powertrain mounts suppliers. An inventory sheet was created and shared with the suppliers for them to fill out with the corresponding information.

Secondary information such as extraction, refining of raw materials, infrastructure, and energy sources for production was obtained from the literature review and the Ecoinvent 3.7.1 dataset.

In order to create the inventory used in OpenLCA, the information was gathered through a variety of methods. Figure 3.2 shows the different sources used to collect the materials, energy, waste, and emissions involved.

A breakdown of the inventory is given in the following section according to the processes described in the system boundary.

3.2 LC Inventory

The inventory includes the elementary flows (raw materials and elements) and other resources included in each of the aforementioned phases of the powertrain mounts production.

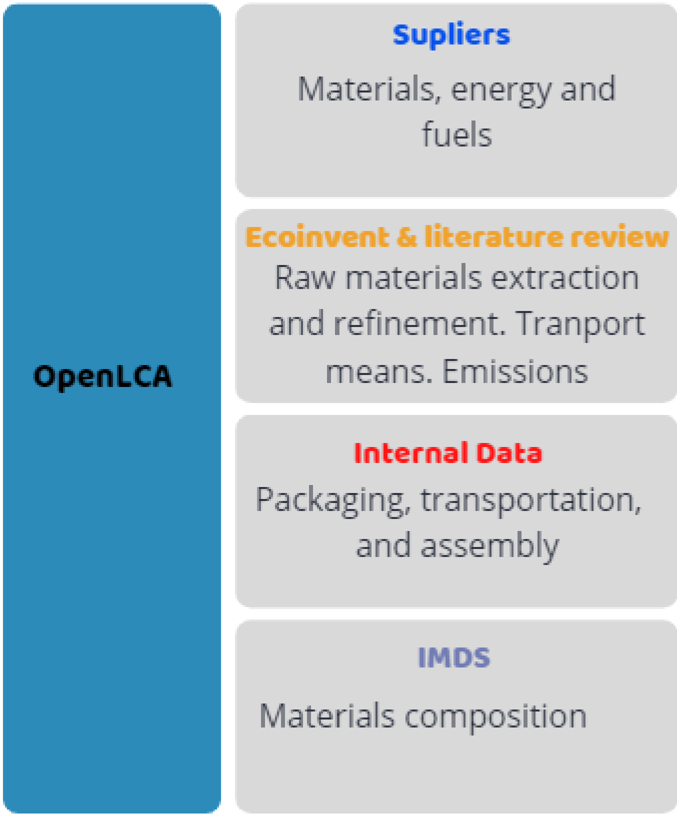


Figure 3.2: Data collection sources for inventory creation

Powertrain mounts

The powertrain mounts are made of different materials among which are aluminum alloys, natural rubber, steel, and glass-fiber reinforced polyamids. Table 3.1 shows the materials and weights of the different components that make up the powertrain elements. As shown in Figure 3.3, aluminum represents the highest content of the total powertrain weight (93%), followed by steel (4%). More specifically, Aluminum alloy 43500 T7 accounts for around 57% of the total material component.

Table 3.1: Powertrain mounts composition

Part name	Components	Material	Weight (g)
LH/RH Engine Mounts	Stopper	QSTE 380	456
	Upper Core	Alu 46000	125
	Mass Damper	GJL 200	304
	Housing	Alu 46000	760
	Main Spring	NR	241
Engine Mounts Brackets	RHM/LHM Bracket	Alu 46000	918/1133
	Snubber	PA 6.6 30% GF	94
Crossmember		43500 T7	12200
RHS Body Bracket	Body	Alu 44300	1566
LHS Body Bracket	Body	Alu 44300	1500
LLTB	Bolt	SCM 435	4
	Inner Core	Alu 6082 T6	229
	Link	Alu 44300	343
	Big Bush	NR	167
RLTB	Inner Core	Alu 6082 T6	251
	Housing	Alu 44300	345
	Big Bush	NR	114
Small bushings	Core	AlMg1SiCu	78.1
	Rubbers	NR	26
RLTB Bracket	Core	Alu 6005 T6	202
RLTB Link	Nut	40Cr (TBD)	17
	Extrusion	Alu 6005 T6	214

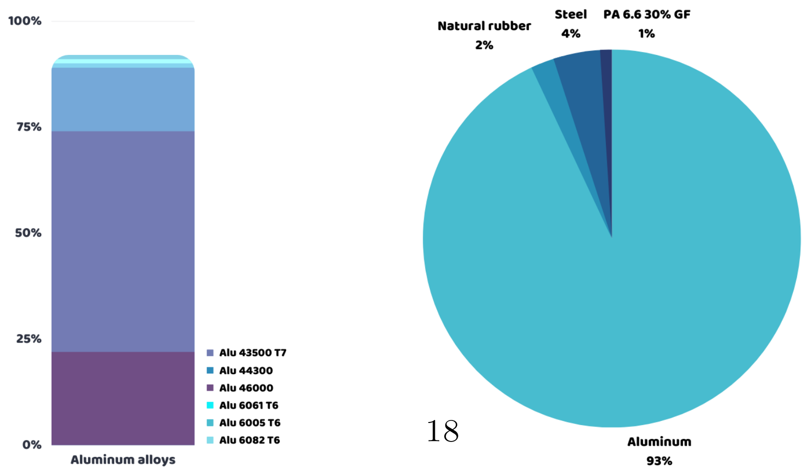


Figure 3.3: Materials' content in the powertrain mounts

Raw materials Inventory

This section shows the elementary and process flows considered during the extraction and refinement of the raw materials used in the creation of the mounts.

Aluminum - As described in Table 3.1, six different aluminum alloys are used depending on their applications and properties. The information for the aluminum alloys composition was taken from IMDS and the datasheets found in Appendix A. These were used to complement and modify the aluminum data available in the Ecoinvent 3.7.1 library, based on 99% pure aluminum. The average between the lower and upper weight percentage values for the additives (Appendix A) was taken as a reference to adjust the material formulation of the alloys. Table 3.2 shows the composition of the aluminum alloys used by the different suppliers and the provider information from Ecoinvent 3.7.1. According to the information provided by the suppliers, some alumimum alloys are made from secondary aluminum production. Consequently, additional processes for recycled aluminum were created in OpenLCA. The provider selection was made according to the production information from the suppliers.

Table 3.2: Aluminum alloys composition in kg

<table>
<tr><th>Element</th><th>AW 46000</th><th>AW 44300</th><th>AW 43500</th><th>AW 6005</th><th>AW 6061</th><th>AW 6082</th><th>Provider</th></tr>
<tr><td>Aluminum</td><td>85.65</td><td>87.81</td><td>89.52</td><td>98.94</td><td>98.37</td><td>97.88</td><td>aluminium production, primary, liquid, prebake | aluminium, primary, liquid | APOS, U - CN</td></tr>
<tr><td>Silicon</td><td>9.50</td><td>12.00</td><td>10.25</td><td>0.70</td><td>0.60</td><td>1.00</td><td>market for silicon, metallurgical grade | silicon, metallurgical grade | APOS, U - GLO</td></tr>
<tr><td>Ferium</td><td>8.50</td><td>0.68</td><td>0.10</td><td>0.18</td><td>0.35</td><td>0.25</td><td>market for pig iron | pig iron | APOS, U - RoW</td></tr>
<tr><td>Copper</td><td>3.00</td><td>0.04</td><td>0.02</td><td>0.15</td><td>0.28</td><td>0.05</td><td></td></tr>
<tr><td>Manganese</td><td>0.28</td><td>0.08</td><td>0.60</td><td>0.25</td><td>0.08</td><td>0.70</td><td>market for manganese | manganese | APOS, U - GLO</td></tr>
<tr><td>Magnesium</td><td>0.35</td><td>0.00</td><td>0.38</td><td>0.55</td><td>1.00</td><td>0.90</td><td>market for magnesium | magnesium | APOS, U - GLO</td></tr>
<tr><td>Cromium</td><td>0.08</td><td>0.00</td><td>0.00</td><td>0.15</td><td>0.20</td><td>0.13</td><td>market for chromium | chromium | APOS, U - GLO</td></tr>
<tr><td>Nickel</td><td>0.28</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>market for nickel concentrate, 16% Ni | nickel concentrate, 16% Ni | APOS, U - GLO</td></tr>
<tr><td>Zinc</td><td>0.60</td><td>0.08</td><td>0.04</td><td>0.10</td><td>0.13</td><td>0.10</td><td>market for zinc | zinc | APOS, U - GLO</td></tr>
<tr><td>Tin</td><td>0.08</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>market for tin | tin | APOS, U - GLO</td></tr>
<tr><td>Lead</td><td>0.18</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>market for lead | lead | APOS, U - GLO</td></tr>
<tr><td>Titanium</td><td>0.10</td><td>0.08</td><td>0.08</td><td>0.05</td><td>0.08</td><td>0.05</td><td>market for titanium, primary | titanium, primary | APOS, U - GLO</td></tr>
</table>

Natural Rubber - The inventory for natural rubber was created by using the Latex flow found in Ecoinvent 3.7.1 and additional chemicals such as softeners, fillers, and anti-aging materials to obtain the required specifications. The specific natural rubber composing was taken from the IMDS from Volvo Cars. However, this information is confidential and therefore cannot be disclosed. Table 3.3 contains the composition of natural rubber used in OpenLCA.

Table 3.3: Natural rubber composition in kg

<table>
<tr><th>Material</th><th>Value</th><th>Provider</th></tr>
<tr><td>Latex</td><td>0.9583</td><td>market for latex | latex| APOS, U-RER</td></tr>
<tr><td>Para-phenylene diamine</td><td>——</td><td>market for para-phenylene diamine | para-phenylene diamine| APOS, U-RER</td></tr>
<tr><td>Phenol</td><td>——</td><td>market for phenol | phenol| APOS, U-RER</td></tr>
<tr><td>Zinc oxide</td><td>——</td><td>market for zinc oxide | zinc oxide| APOS, U-GLO</td></tr>
</table>

Polyamid 6.6 30% GF - Table 3.4 shows the process used to account for the use of polyamide reinforced with 30% of glass fiber. Taken from the existing process in Ecoinvent 3.7.1.

Table 3.4: Polyamid 6.6 30% GF from Ecoinvent

Materials	Amount	Provider
PA6.6 30% GF	1 kg	market for nylon 6-6, glass-filled | nylon 6-6, glass-filled | APOS, U - RER

Steel - The cast iron and unalloyed steel processes from the Ecoinvent 3.7.1 database were used to account for the steel content in the mounts. In this case, the data was not further modified and the analysis was done for 1 kg of material. Table 3.5 shows the processes used for each material type.

Table 3.5: Steel and iron processes from Ecoinvent database

Material	Amount	Process
Cast Iron	1 kg	Cast iron production | cast iron | APOS, U
Steel, low-alloyed	1 kg	Steel production, converter, unalloyed | steel, unalloyed | APOS, U

Manufacturing Inventory

The manufacturing inventory was created based on the data compiled from the six different suppliers for the powertrain mounts. For confidentiality purposes, the suppliers' names are not shown in thesis. Instead, each supplier is referred to as supplier *"N"*. Table 3.6 illustrates each supplier based on the parts they produce. From now on, suppliers will be identified based on this Table. Suppliers 5 and 6 provide the same part. However, Supplier 5 is located in China while Supplier 6 is based in Germany.

Table 3.6: Classification of PWT mounts suppliers

Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
LLTB	RLTB Link	RLTB Bracket	LHS Bracket	Crossmember (CN)	Crossmember (EU)
RLTB		Small bushing	RHS Bracket		
Mounts			LHM Bracket		
Stopper			RHM Bracket		

Supplier 1 - Supplier 1 is responsible of producing the two engine mounts, the left and right lower torque brackets, and the snubbers. Table shows the inputs and outputs for the manufacturing process, reported by the supplier. The process flows were taken from the Ecoinvent 3.7.1 dataset. Natural rubber is processed on site, while other raw materials such as aluminum alloys, cast iron and steel are outsourced. However, smelting, moulding, HPDC, and extrusion processes are carried out by the supplier.

Table 3.7: Inventory for parts manufactured by Supplier 1

Inputs	**Unit**	**RHM/LHM**	**RLTB**	**LLTB**	**Snubber**
NR	kg/FU	0.241	0.114	0.167	-
Al 46000	kg/FU	0.885	-	-	-
Al 44300	kg/FU	-	0.345	0.343	-
AW6082	kg/FU	-	0.251	0.229	-
Cast iron	kg/FU	0.304	-	-	-
Steel	kg/FU	0.456	-	-	-
PA 6.6 GF 30% (32.5% recyled content)	kg/FU	-	-	-	0.094
Electricity, medium voltage	kWh/FU	0.431	0.447	0.517	0.668
Steam, high pressure	kWh/FU	0.105	0.050	0.073	-
Outputs					
Rubber, waste to soil	g/FU	4.049	1.915	2.806	-
VOC emissions to air	kg/FU	4.425E-5	2.093E-5	3.066E-5	-

Supplier 2 - According to the data reported, Supplier 2 uses high pressure natural gas and medium voltage electricity for the production of the RLTB link. As it was not possible to measure the amount of emissions released by these process flows, the values were estimated using the stoichiometric reaction (3.2) depending on the fuel type. For natural gas, pure methane is assumed. As a result, 1 Nm3 of natural gas, emits 1.86 kg of CO2. The inventory data is shown in Table 3.8.

$$\mathrm{CH_4} + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Table 3.8: Inventory for parts manufactured by Supplier 2

Inputs	**Unit**	**RLTB Link**
Al 6005 T6	kg/FU	0.214
Steel, Unalloyed	kg/FU	0.034
Natural gas, high pressure	Nm3/FU	28.830
Electricity, medium voltage	kWh/FU	7.300
Outputs		
CO_2 emissions to air	kg/FU	44.347

Supplier 3 - Supplier 3 manufactures the two small bushings and one bracket (RLTB Bracket), mainly made by aluminum and RB. Its operations are based in China. Table 3.9 contains the inventory reported by the supplier.

Table 3.9: Inventory for parts manufactured by Supplier 3

Inputs	**Unit**	**Small Bushing**	**Bracket**
Al 6061 T6	kg/FU	0.078	0.201
Al 6005 T6	kg/FU	-	-
NR	kg/FU	0.026	-
Electricity, medium voltage	kWh/FU	0.637	6.94
Outputs			
CO_2 emissions to air	kg/FU	0.815	6.286

Supplier 4 - Supplier 4 produces the left and right mounts (LHM/RHM) and body brackets (LHS/RHS). Like the rest of the Suppliers, the production plant is located in China. According to the delivered data, the aluminum alloys are made of 60% recycled content.

Table 3.10: Inventory for parts manufactured by Supplier 4

Inputs	Unit	RHM Bracket	LHM Bracket	LHS Bracket	RHS Bracket
Al 4600	kg/FU	0.925	1.181	-	-
Al 44300	kg/FU	-	-	1.500	1.566
Electricity, medium voltage	kWh/FU	2.990	3.691	4.886	5.101
Outputs					
Aluminum waste to soil	g/FU	0.007	0.048	-	-

Suppliers 5 and 6 - Suppliers 5 and 6 manufacture the crossmember part,which is made entirely from the aluminum alloy 43500 T7. However, their production sites are different. Supplier's 5 operations are based in China while Supplier 6 is located in Germany. As the inputs for the crossmember production should be similar in both cases, the resulting emissions should be different because of the source of origin of the process flows. However, it was not possible to collect the corresponding information from Supplier 5. For this reason, this thesis assumes that the inputs for both suppliers are exactly the same and that the only difference relies on the location, which is taken into account by the providers selection in OpenLCA. Additionally, Supplier 6 reported that they alloy used contains 20% of secondary aluminum, while this is an unknown fact for Supplier 5. Thus, assumed to be 100% primary aluminum. Table 3.11 shows the inventory data corresponding to the crossmember manufacturing.

Table 3.11: Inventory for parts manufactured by Suppliers 5 and 6

Inputs	Unit	Crossmember
Al 43500	kg/FU	12.212
Compressed air, 800 kPa gauge	kg/FU	6.559
Electricity, medium voltage	kWh/FU	16.189
Natural gas, high pressure	Nm3/FU	3.491
Water	kg/FU	137.000
Outputs		
Aluminum waste to soil	g/FU	0.012
CO2 emissions to air	kg/FU	6.497

Packaging and transportation Inventory

Volvo Cars is responsible for providing packaging and transportation solutions to make sure the powertrain mount pieces arrive to Volvo Cars in Ghent, Belgium. The parts come from different places within Europe but also from China.

Regarding packaging, Volvo Cars has specific guidelines that define the packing type and number of items to be hauled. There are two different formats: single-use and reusable packaging. The reusable category contains wooden pallets and frames, and HDPE boxes that are used multiple times to transport different parts. On the other hand, the single use packaging consists mainly on cardboard boxes, plastic wraps are disregarded because of their weight. This section shows the inventory information for both packaging categories according to the data shared by the packaging department (Ghent).

Reusable packaging - Table 3.12 illustrates the parts and quantities that are transported using the reusable format and the packaging weight. These values are considered for allocation purposes in order to define the impact of a single piece. Similarly, this thesis assumes that each packaging type is used 20 times before is completely discarded.

Table 3.12: Reusable packaging information by part

Powertrain mount	Number of parts	Packaging material	Weight (kg)
Crossmember	10	High Density Polytethylene	58
	10	Polypropylene	8
Bracket	6	High Density Polytethylene	3.71
Left hand bracket engine	6	High Density Polytethylene	3.71
Right hand bracket engine	6	High Density Polytethylene	3.71
Bracket torque	46	High Density Polytethylene	1.88
Left hand bracket engine	48	Wood[1]	51

Single-use packaging - Table 3.13 summarizes the number of parts stored by packing type and the packaging weight. Allocation methods are also used to calculate the impact of the pieces separately. As reported by the packaging department, the cardboard boxes are sent to a recycling facility after each use. This is considered during the calculations through the corresponding waste flows from Ecoinvent 3.7.1.

[1] *Wood content includes a wooden- type L pallete, a plywood lid, and two wooden frames*

Table 3.13: Single-use packaging information by part

Powertrain mount	Number of parts	Packaging material	Weight (kg)
Torque rod link	36	Carboard	0.38
Engine mount	6	Cardboard	0.75
Left lower tie bar	10	Cardboard	0.38
Torque rod	16	Cardboard	0.38

Table 3.14 shows the total amount of packaging material used to transport all the parts that make up one powertrain and the providers used in OpenLCA to reflect the location and operation data from Volvo Cars packaging.

Table 3.14: Total amount of packaging material per powertrain

<table>
<tr><th>Material</th><th>Weight/Volume</th><th>Provider</th></tr>
<tr><td>Polypropylene [kg]</td><td>0.8000</td><td>market for polypropylene, granulate | polypropylene, granulate | APOS, U - GLO</td></tr>
<tr><td>HDPE [kg]</td><td>7.0775</td><td>market for polyethylene, high density, granulate, recycled | polyethylene, high density, granulate, recycled | APOS, U - RoW</td></tr>
<tr><td>Cardboard [kg]</td><td>0.3223</td><td>market for folding boxboard carton | folding boxboard carton | APOS, U - RoW</td></tr>
<tr><td>Wooden pallete + frames [m3]</td><td>0.5300</td><td>market for EUR-flat pallet | EUR-flat pallet | APOS, U (Volvo) - RoW</td></tr>
<tr><td>Plywood [m3]</td><td>0.0004</td><td>market for plywood | plywood | APOS, U - RoW</td></tr>
</table>

Transportation

The data for transportation was obtained from Volvo Cars Road Operation Control department and the suppliers. Due to missing data for the sea shipping transportation, this thesis assumes that all the parts are freighted from the different local ports in China (based on the suppliers location) to the port of Hamburg in Germany. This assumption corresponds to the data provided by Supplier 3. Similarly, the road distances from Hamburg to Volvo Cars in Ghent are based on the information provided by this Supplier. The road distances within China and Europe were calculated using Google Maps. The Shipping Distances and Time calculator tool from [37] was used to estimate the kilometers between the different ports in China and the port of Hamburg. The unit used for the transportation section is 1 Tonne x km. This was calculated by using Eq 3.1., which considers the total weight of the PWT mount part plus the packaging mass carried over the estimated distances. Table 3.15 shows a summary of the weights and distances by part according to the transportation mean and allocation methods used.

$$T_{piece} = (W_{packaging}/N_{parts} + W_{parts}) * D_{km} \tag{3.1}$$

Table 3.15: Transportation data classified by type and part

Part	Type	Tonne*km	Distance [km]
RLTB Link	Diesel truck (road CN)	0.0017	6.1000
	Diesel truck (road EU)	0.1373	500.0000
	Containership	5.6743	20671.4100
LLTB	Diesel truck (road CN)	0.0636	80.7000
	Diesel truck (road EU)	0.3940	500.0000
	Containership	15.5662	19754.1100
RLTB	Diesel truck (road CN)	0.0689	80.7000
	Diesel truck (road EU)	0.4270	500.0000
	Containership	16.8700	19754.1100
Engine mounts	Diesel truck (road EU)	2.1300	500.0000
	Diesel truck (road CN)	0.3438	80.7000
	Containership	84.1525	19754.1100
small bushings	Diesel truck (road EU)	0.0521	500.0000
	Containership	2.0433	19628.2200
	Diesel truck (road CN)	0.0312	300.0000
LHS Bracket	Diesel truck (road CN)	0.2819	110.0000
	Containership	47.0842	18374.3100
	Diesel truck (road EU)	1.2813	500.0000
LHM Bracket	Diesel truck (road CN)	0.2030	110.0000
	Containership	33.9061	18374.3100
	Diesel truck (road EU)	0.9227	500.0000
RHS Bracket	Diesel truck (road CN)	0.2403	110.0000
	Containership	40.1350	18374.3100
	Diesel truck (road EU)	1.0922	500.0000
RHM Bracket	Diesel truck (road CN)	0.1793	110.0000
	Containership	29.9556	18374.3100
	Diesel truck (road EU)	0.8152	500.0000
Snubber	Diesel truck (road CN)	0.2799	1489.0000
	Containership	6.7914	19628.2200
RLTB Bracket	Diesel truck (road EU)	0.1730	500.0000
	Diesel truck (road CN)	0.1038	300.0000

Road transportation within China was assumed to be done on a 22-ton diesel truck

(Euro 4), while more strict sustainable measures were considered for transportation in Europe (Euro 5). For sea shipping, a containership with 43000 tonnes total load capacity was considered according to the information provided by the suppliers. Table 3.16 shows the summary of the transportation types used based on available data from Ecoinvent 3.7.1. As the crossmember has two suppliers with different characteristics, the logistics for this part were analyzed separately. Therefore, the information for the crossmember is not included in this Table.

Table 3.16: Summarized information on transportation

<table>
<tr><th>Type</th><th>Tonne*km</th><th>Distance [km]</th><th>Provider</th></tr>
<tr><td>Diesel truck (road CN)</td><td>1.7974</td><td>2777.2000</td><td>market for transport, freight, lorry 16-32 metric ton, EURO4 | transport, freight, lorry 16-32 metric ton, EURO4 | APOS, U - RoW</td></tr>
<tr><td>Containership</td><td>282.1786</td><td>192687.4200</td><td>market for transport, freight, sea, container ship | transport, freight, sea, container ship | APOS, U - GLO</td></tr>
<tr><td>Diesel truck (road EU)</td><td>7.4245</td><td>5000.0000</td><td>market for transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | APOS, U - RER</td></tr>
</table>

Table 3.17 shows the transportation differences for each supplier of the crossmember part. As supplier 6 is based in EU, only the road transportation from the supplier's warehouse to Volvo Cars in Ghent is considered. For supplier 5, the transportation types match the rest of the parts as it is based in China.

Table 3.17: Transportation data for the crossmember

Supplier	Type	Tonne*km	Distance [km]
Supplier 6	Diesel truck (road EU)	10.3400	550
	Diesel truck (road CN)	2.0116	107
Supplier 5	Containership	345.4370	18374.31
	Diesel truck (road EU)	9.4000	500

Assembly

The data for the assembly of one powertrain weas provided by Volvo Cars manufacturing department in Ghent. Due to the difficulty in obtaining the specific energy consumption required to assemble one powertrain, allocation procedures were carried out. The following information was considered during the calculation for the energy consumption. However, this data represents proprietary information thus, cannot be disclosed.

- Electricity was considered as the main energy source for the assembling process.
- The total amount of XC 40 vehicles produced in Ghent between the 21st week of 2021 and the 13th week of 2022.

- The total amount of electricity consumed in the powertrain assembly line during the same period.

The electricity consumption reported corresponded to diverse activities different to the XC 40 car production itself. Therefore, the energy demand was calculated by disregarding the weeks where the electricity and production ratio was abnormal. The final average energy consumption was found to be around 11 kWh per powertrain. Table 3.18 shows the amount of average electricity consumed for powertrain and it is based on the Belgian energy mix.

Table 3.18: Electricity consumption for the assembly of one powertrain

Input	**kWh**	**Provider**
Electricity, medium voltage	11	market for electricity, medium voltage | electricity, medium voltage | APOS, U - BE

Chapter 4

Life Cycle Impact Assessment

This chapter shows the results obtained by processing the inventory in the OpenLCA software.

4.1 Impact Assessment Method

A Life cycle impact assessment method expresses the emissions and resource extraction in a set of environmental impact categories, based on characterization factors that each method assigns to the environmental parameters [38]. The environmental impact was calculated by implementing the ReCiPe Midpoint (H)[1] V1.13 impact assessment Method. This method has two different ways in which damage can be assessed. These are called the midpoint and endpoint indicators levels.

4.1.1 Midpoint indicators

Midpoint indicators make up a list of 18 categories that address single environmental problems. In this section, only those impact categories that result in a relevant effect will be explained.

[1] *The (H) stands for hierarchist perspective, which portrays a science-based, risk-aware, governance-positive perspective [39]*

4.1.2 Endpoint indicators

Endpoint indicators group several midpoint indicators into global categories, depending on their main impact. The ReCiPe method includes three endpoint categories. However, unifying the single parameters into global impact areas increases the uncertainty of the results [38]. This thesis focuses solely on the interpretation of midpoint indicators as the main interest is to evaluate the environmental effects and not the potential damages of these.

4.2 Impact Categories

Impact categories describe diverse environmental damages that result from the processes being evaluated. The most relevant impact categories derived from the LCA of the powertrain mounts are described in Table 4.1.

Table 4.1: Impact categories with highest effects

Impact Category	Unit	Description
Agricultural land occupation - ALOP	m2	Refers to the amount of agricultural land occupied for a certain purpose.
Climate Change - GWP100	kg CO2-Eq	Describes the effect of one mass based unit of any greenhouse gas relative to that of carbon dioxide.
Fossil depletion - FDP	kg oil-Eq	Represents the amount of fossil fuels extracted, based on the LHV.
Freshwater ecotoxicity - FETPinf	kg 1.4-DCB-Eq	Accounts for the environmental accumulation in a human food chain and the toxicity effect of chemical elements.
Human toxicity - HTPinf	kg 1.4-DCB-Eq	Accounts for the environmental accumulation in a human food chain and the toxicity effect of chemical elements.
Ionizing radiaton-IRP_HE	kg U235-Eq	Describes the damage to human health and ecosystems related to the exposure to particulate emissions of radioactive elements.
Marine ecotoxicity - METPinf	kg 1.4-DCB-Eq	Accounts for the environmental accumulation in a human food chain and the toxicity effect of chemical elements.
Metal depletion - MDP	kg Fe-Eq	Represents the grade of decrease of minerals in terms of iron equivalence.
Natural land transformation - NLTP	m2	Accounts for the amount natural land transformed and occupied for a certain purpose.
Urban land occupation - ULOP	m2	Refers to the amount of urban land occupied for a certain purpose.

4.3 Raw materials extraction, refining, and transportation

Figure 4.1 shows the main impact categories that have a relevant impact by the extraction and refinement of raw materials. As aluminum represents more than 90% of the components' materials, it is evident that it has the highest environmental impact in climate change, human toxicity, metal, and fossil depletion. Although aluminum extraction causes soil erosion due to the amount of land and vegetation that must be removed, refinement accounts for the most impactful activity in the aluminum creation process. Aluminum refinement is a heat intensive method that requires large amounts of electricity and water. Heat production generates a large amount of carbon emissions (29.42 kg CO2eq) and creates water pollution. The effect of aluminum on the climate change category can be explained from the amount of power that is needed during the smelting process. The high impact is due to the fact that the energy to produce electricity and heat comes from fossil fuel sources in China, mainly coal-fired power plants. This represents 26.86 kg CO2eq for coal extraction and processing, and 121.57 kg CO2eq for electricity (high voltage) generation. Besides power consumption, CO and CO2 gases along with tetrafluoromethane are released (31.07 CO2 eq), which are direct contributors to the global warming effect. This is mainly due to the use of a carbon anode in the electrolysis process. The production of this material also accounts for an important part of the GHG emissions attributed to the aluminum production.

Although the use of polyamid in the powertrain mounts is not representative when compared to the total amount of materials, its climate change impact is the second highest one. This is due to the CO2, methane, and dinitrogen monoxide emitted to the air during production, which are equivalent to 5.86 CO2 eq.

The effect of raw materials on human toxicity, specially for aluminum is the result of the impact of the sediments and residual elements from hard coal and lignite mining and bauxite processing, which account for 57.98 kg 1,4-DCB-Eq. The aforementioned results describe the impact of the total weight of raw materials used in the powertrain mounts production. A further analysis of the impact per kilogram of material was conducted. The results are shown in Figure 4.1 and coincide with the environmental impact description of the total weight. It is observed that the GWP per kilogram of aluminum is between the carbon footprint range found in the literature review.

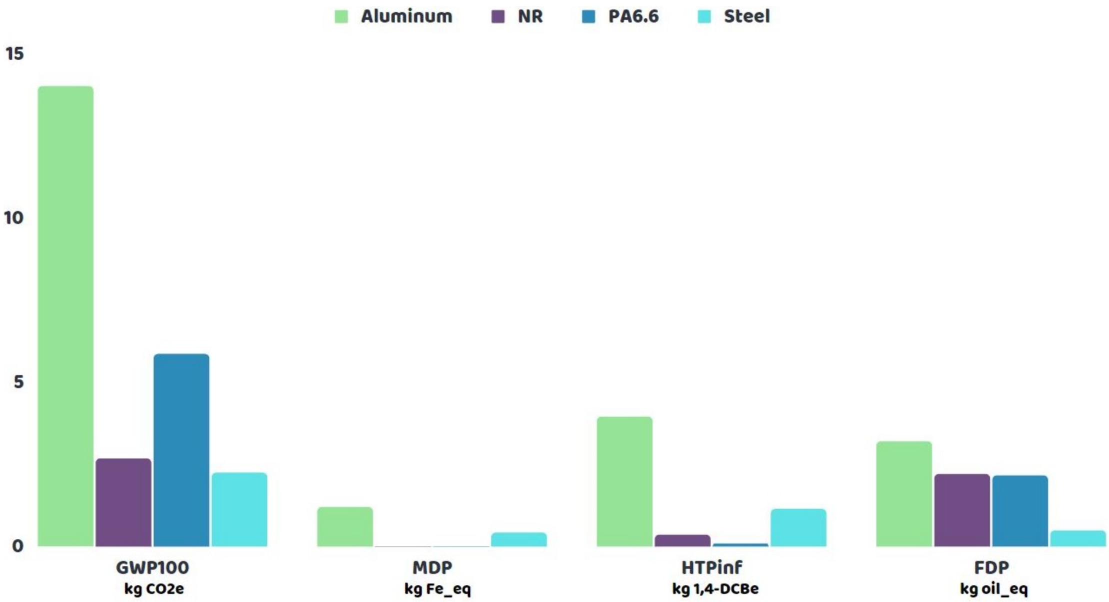


Figure 4.1: Raw materials impact per kg of material

Name	Aluminium	NR	PA6.6	Steel	Unit
climate change - GWP100	13.9812	2.6769	5.8630	2.2520	kg CO2-Eq
metal depletion - MDP	1.1744	0.0082	0.0043	0.4123	kg Fe-Eq
human toxicity - HTPinf	3.9328	0.3579	0.0945	1.1547	kg 1,4-DCB-Eq
fossil depletion - FDP	3.1854	2.2006	2.1559	0.4898	kg oil-Eq

4.4 Manufacturing

4.4.1 Manufacturing impact by supplier

The results obtained for the manufacturing process correspond to the information provided by each individual supplier and the assumptions considered. There are three main major categories where manufacturing has the biggest impacts. This section analyzes the effects of manufacturing by supplier. Figure 4.2 refers to the equivalent C02 emissions, human toxicity and fossil depletion incurred by different suppliers in the manufacturing of the power train mounts. It can be observed that Supplier 2 is responsible for 57.989 kg CO2 eq, which represents almost 50% of the total GHG emissions from all suppliers. Supplier 2 is responsible for the production of the RLTB link, which weights 0.231 kg. Nevertheless, the energy use reported by the supplier integrates a significant quantity of natural gas. Moreover, since the production plant is located in China, the electricity mix is primarily based on coal. As fossil depletion comes along with climate change impact, Supplier 2 is also responsible for the highest impact in this category (29.99 kg oil-Eq) mainly due to the extraction of natural gas and hard coal. On the other hand, Supplier 5 accounts for the highest value of human toxicity impact (11.156 kg 1,4 DCB-Eq) due to the high concentration of contaminants (manganese, arsenic, and selenium) that end up in the water streams as a result from the lignite waste treatment.

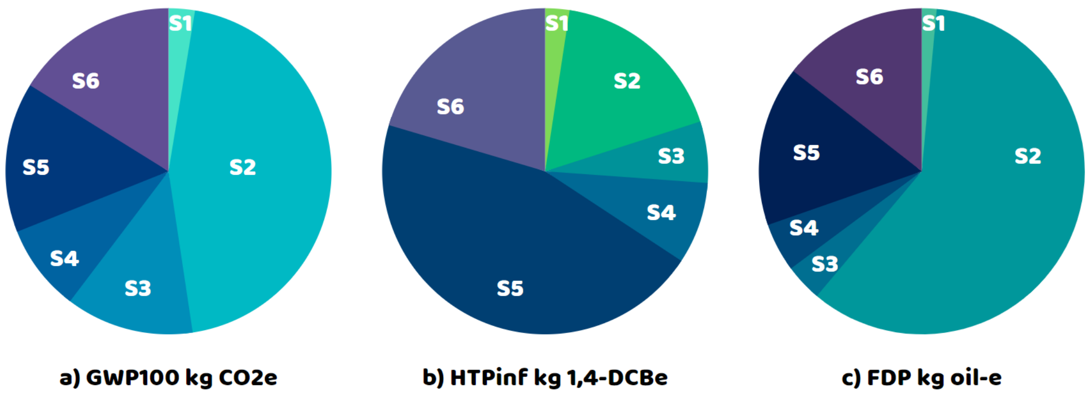


Figure 4.2: Environmental impact by supplier

Impact Categories	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6	Units
GWP100	3.359	57.989	16.303	1.462	19.180	20.812	kg CO2-Eq
HTPinf	0.592	4.346	1.474	0.171	11.156	5.029	kg 1,4-DCB-Eq
FDP	0.735	29.997	1.849	0.403	7.984	7.267	kg oil-Eq

Apart from the most obvious impact categories, the are other environmental levels that are affected by the production of the parts. Each supplier has a different contribution that depends on the geological resources and infrastructure used in the process. Figure 4.3 presents six impact types, which constitute the second most relevant group of effects. According to the Figure, Supplier 5 has a significant incidence in urban land occupation, metal depletion, and ionizing radiation. The main reason behind the values can be described by the weight of the component (crossmember; 12.2 kg). However, the values are still above those from Supplier 6. This is because of the different considerations that the Ecoinvent 3.7.1 makes based on the selected provider.

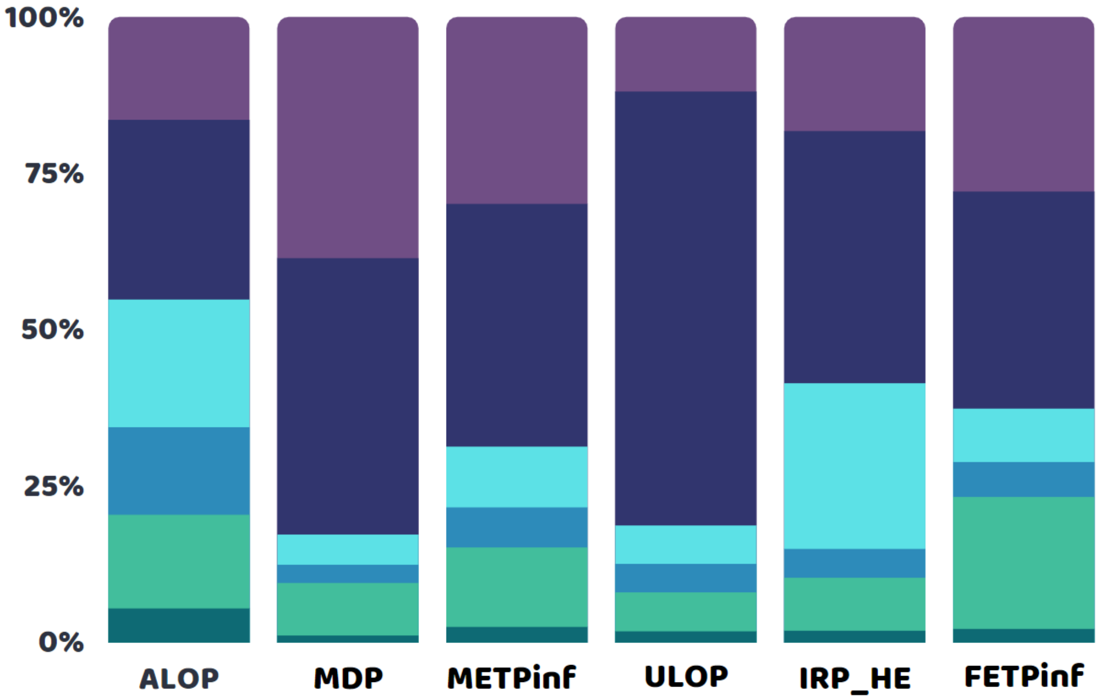


Figure 4.3: Indirect manufacturing impacts

Impact Categories	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6	Units
agricultural land occupation - ALOP	0.071	0.195	0.180	0.020	0.746	0.427	m2a
metal depletion - MDP	0.016	0.120	0.031	0.005	1.263	1.103	kg Fe-Eq
urban land occupation - ULOP	0.032	0.111	0.077	0.009	2.462	0.424	m2a
ionising radiation - IRP_HE	0.053	0.235	0.127	0.026	2.235	1.012	kg U235-Eq
freshwater ecotoxicity - FETPinf	0.030	0.284	0.053	0.009	0.934	0.751	kg 1,4-DCB-Eq

4.4.2 Manufacturing impact by component

Reckoning some suppliers provide more than one component and that each of them has different weights, the impact analysis is then extended to each part. According to Figure 4.2, Supplier 2 is responsible for the highest share of CO2-e and iol-e. Figure 4.4 confirms that the RLTB bracket accounts for 55% of the CO2-e emissions to the atmosphere, regardless of representing 1% of the powertrain's weight. As a result, it can be observed that the parts that have a stronger impact on climate change are the RLTB link, RLTB bracket, and the crossmember, which in total represent 87% of the powertrain manufacturing emissions. This is an effect of the natural gas, and hard coal extraction and use.

Accordingly, Figure 4.4 shows that the same components are accountable for 77% of the 1.4 DCB Eq for human toxicity potential, as a consequence of the heavy metals released during the production processes.

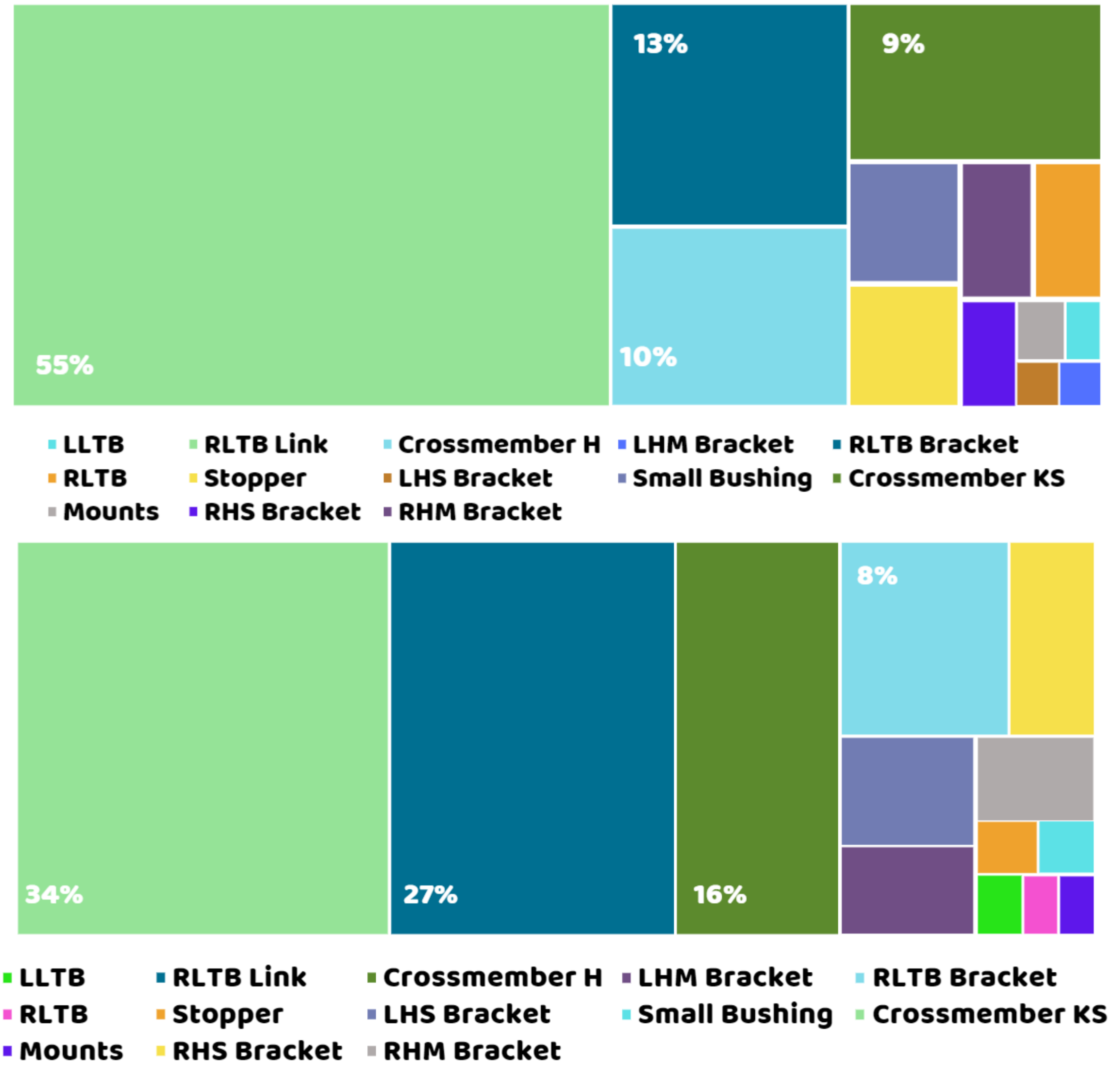


Figure 4.4: Global Warming and Human Toxicity Potential impacts by part

4.5 Logistics

Logistics summarizes the results obtained for the packaging and transportation stages of each powertrain mount. However, as there are two different suppliers for the crossmember part, a separate analysis was conducted to account for the main differences. Figure 4.5 shows the most relevant impact categories that are affected by the packaging and transportation of all the PWT mounts.Although the packaging composition is the same for Suppliers 5 and 6, there is a considerable difference in the transportation stage. It is observed that the GWP from Supplier 5 is 1.4 times bigger than that of Supplier 6. In accordance, fossil depletion is 1.2 times higher for Supplier 5. These results reflect the fossil fuel extraction and use during the transportation stage, which accounts for a bigger amount in the case of Supplier 5 due to its location.- The impact for the rest of the categories remain similar for both suppliers.

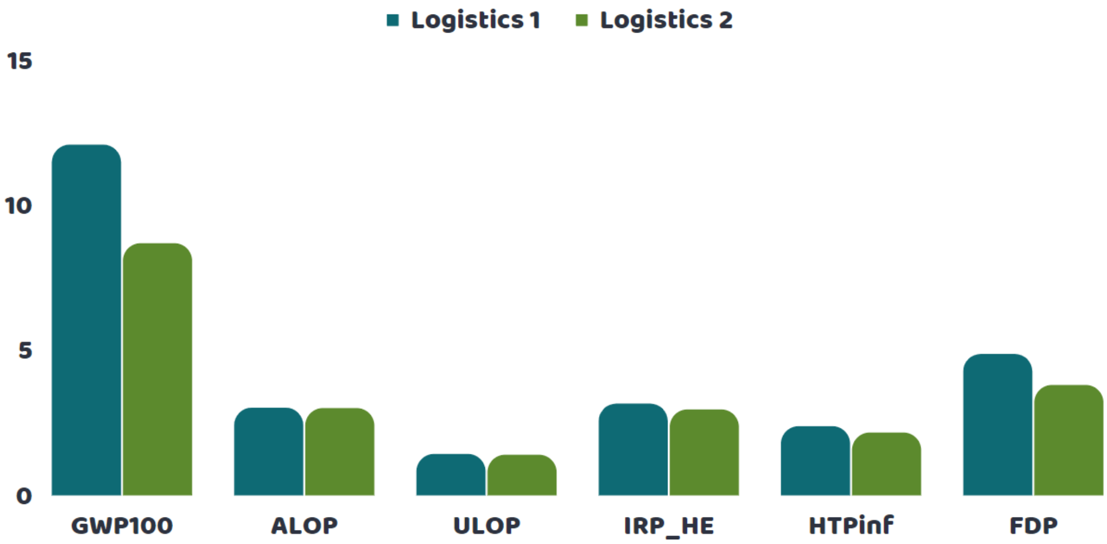


Figure 4.5: Logistics impact

Impact Categories	Supplier 5	Supplier 6
climate change - GWP100	12.0732	8.6795
fossil depletion - FDP	6.0091	4.9422
human toxicity - HTPinf	1.2654	1.0483
water depletion - WDP	1.1632	1.1602
terrestrial acidification - TAP100	2.6939	2.6130
freshwater eutrophication - FEP	1.2001	1.2000
natural land transformation - NLTP	1.7962	1.7963

4.5.1 Packaging

Figure 4.6 reflects the most relevant categories resulting from the impact of packaging. Single-use and reusable elements are shown separately to have a more detailed analysis of their effects. As expected, single-use materials are responsible for a higher impact. However, reusable materials (specifically wooden pallets) have a special effect on agricultural land occupation (1.914 m2) due to the amount of land required for cultivation and growing of wood (pine, spruce, birch) from sustainable forest management practices in Sweden (according to the Ecoinvent 3.7.1 database). Although the use of polypropylene materials is negligible compared to the other components, it is responsible for the high climate change impact category (2.515 kg CO2e) for single use packaging due to the energy sources and materials considered in the manufacturing processes of plastic. More specifically, the CO2 and methane emissions to air. In the case of fossil depletion, single use packaging accounts for 1.708 kg oil-eq. It corresponds mainly to the extraction of oil, gas, and coal to produce polypropylene. The impact for urban land occupation (1.067 m2a) is the result of the green area, used as landfill for generated waste streams and occupied by infrastructure for electricity generation for packaging production. Human toxicity (1.098 kg 1.4-DCB-eq) is explained due to the emissions to air and ground water caused by polypropylene waste in landfills. Cardboard production is also responsible for several toxic emissions (Lead, arsenic, cadmium, zinc, mercury) resulting from the manufacturing and transportation, as well as the derived waste treatment processes.

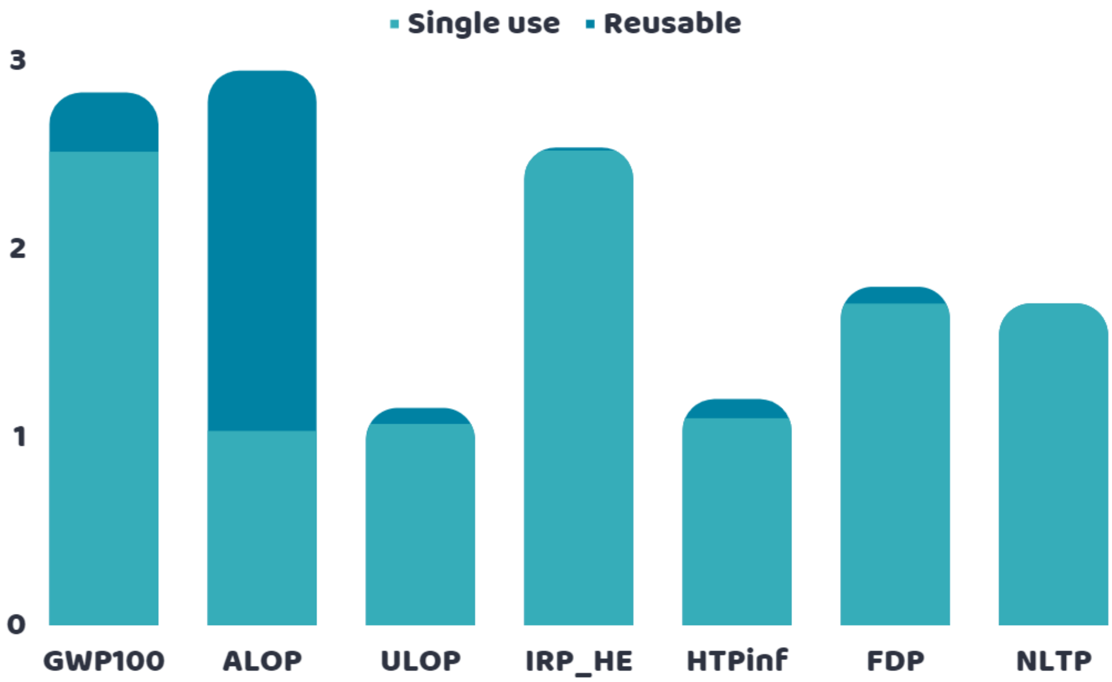


Figure 4.6: Packaging impact

Impact Categories	**Single use**	**Resuable**	**Units**
climate change - GWP100	2.5149	0.3139	kg CO2-Eq
agricultural land occupation - ALOP	1.0318	1.9139	m2
urban land occupation - ULOP	1.0674	0.0854	m2a
ionizing radiation - $\mathrm{IRP}_H E$	2.5208	0.0165	kg U235-Eq
human toxicity - HTPinf	1.0983	0.1014	kg 1.4 DCB-Eq
fossil depletion - FDP	1.7080	0.0886	kg oil-Eq

4.5.2 Transportation

Due to the existence of two different suppliers for the crossmember part, the transportation results are analyzed considering the location and transportation types used by each. Figure 4.7 shows the most relevant impact categories tackled by the transportation process. The climate change impact is the highest one for both cases as the transportation sector heavily relies on fossil fuels. However, in the case of supplier 5, the highest impact is mainly due to the tailpipe emissions caused by the CO2 and dinitrogen monoxide released by the containership. Accordingly, the same emissions are released in a more relevant amount by the trucks in Europe than in China, regardless of the consideration of more sustainable diesel trucks in Europe. This is because the distances covered in Europe are larger due to the assumption that all parts are carried from the port of Hamburg to Volvo Cars in Ghent. In the same way, the fossil depletion impact results from the oil and gas extraction to produce the fossil fuels. Non-exhaust emissions are generated by ancillary automotive systems such as the break and tyres. Break wear is responsible for 55% of non tailpipe particles coming from road transport, which have a meaningful effect on human health diseases related to air pollution [40]. For this reason, human toxicity is considered as one of the most relevant categories within transportation. The main impact is derived from the treatment required to remove toxic substances from the atmosphere such as antimony, lead, and zinc. Other contributors to this category are directly related to fossil fuels obtainment. In this case, the GWP from Supplier 5 is around 1.6 times higher than that of Supplier 6. Accordingly, the fossil depletion and human toxicity impacts are 1.5 and 1.2 times higher for Supplier 5. These results are similar to those show in Figure 4.5.

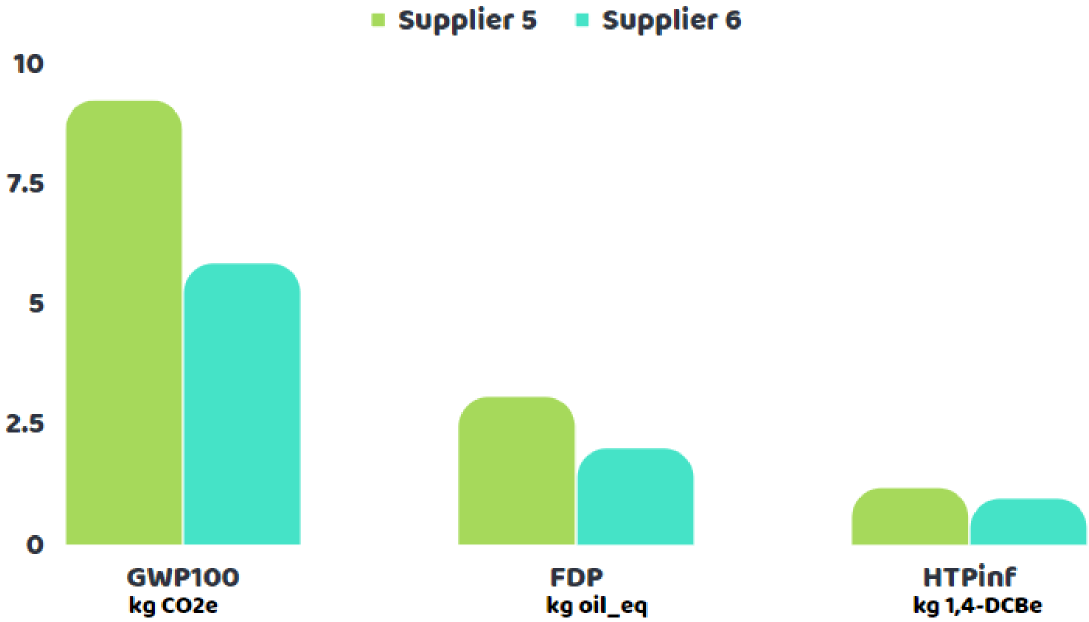


Figure 4.7: Transportation impact

Impact Categories	Supplier 5	Supplier 6
climate change - GWP100	9.2444	5.8508
fossil depletion - FDP	3.0633	1.9964
human toxicity - HTPinf	1.1686	0.9515

A more in-depth analysis of the impact of each specific transport type was conducted and shown in figure 4.8, according to the differences of the crossmember's suppliers. In this case it is evident that road freight transport is the main contributor to the three impact categories previously discussed. More specifically, it accounts for 50% of the total GHG emissions. Although the European exhaust emissions standards, Euro 5, are stricter on particulate emissions for diesel vehicles, the climate impact of the road transport in Europe is four times greater than that of China. This is because the total travel distance in Europe is around two times larger than the total distance in China. However, if the crossmember is provided by Supplier 6, around 18.300 km of sea freight are saved. This is equivalent to 3.206 kg CO2-Eq. coming from heavy oil production and combustion. Thus, it is evident that the crossmember part has greater climate impact and human toxicity values when

Supplier 5 is the desired option.

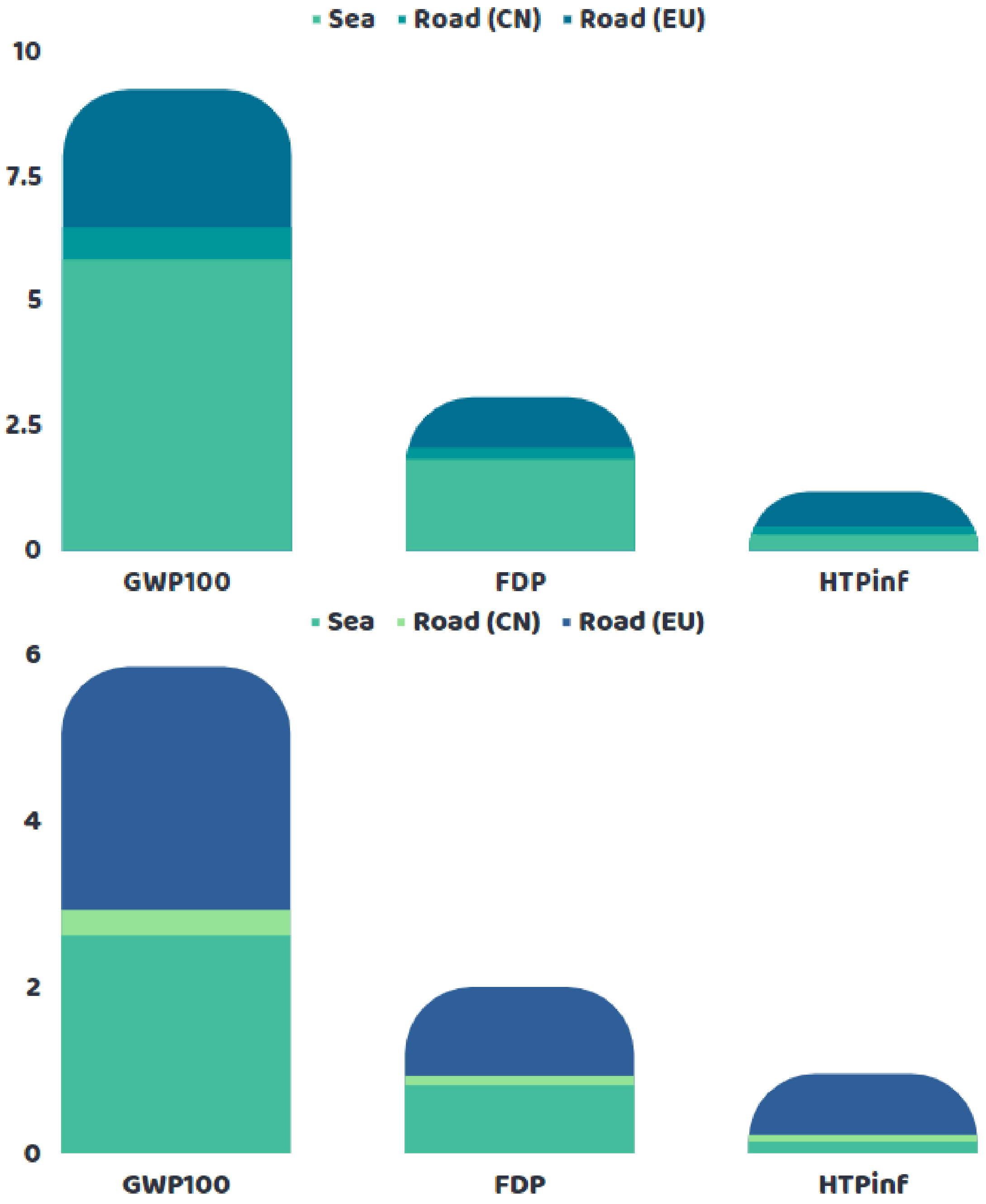


Figure 4.8: Environmental impact by transportation mean. Supplier 5 (up), Supplier 6 (down)

Impact categories	Sea	Road (CN)	Road (EU)
climate change - GWP100	2.6191	0.3057	2.9259
fossil depletion - FDP	0.8164	0.1108	1.0692
human toxicity - HTPinf	0.1382	0.0776	0.7357

4.6 Assembly

As described in the inventory section, the principal energy form used in the assembly process is electricity, medium voltage. Figure 4.9 shows the three most relevant impact categories according to the energy mix composition in Belgium, where 61% of the electricity is produced from nuclear power plants [41]. The climate impact results principally from the CO2 pollutants during the electricity production from gas. The urban land impact is caused by the amount of green area required for the waste treatment of by-products derived from the electricity generation process. Finally the ionizing radiation impact can be explained due to the potential damage induced by the exposure to radioactive elements from nuclear plants.

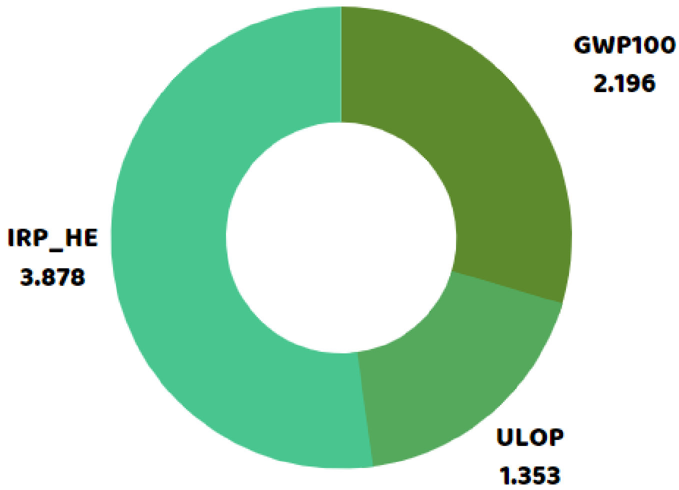


Figure 4.9: Assembly impact

Impact Categories	Electricity consumption	Units
climate change - GWP100	2.1961	kg CO2-Eq
urban land occupation - ULOP	1.3530	m2a
ionising radiation - IRP_HE	3.8785	kg U235-Eq

4.7 Environmental impact of the power train

This section presents the total environmental impact of one powertrain from cradle-to-gate. It is not possible to obtain the results per 1 kg of produced piece since the behavior of the production systems for each supplier are unknown and cannot be assumed to be linear. According to the results obtained, there are three major impact categories that are affected during the creation process of the different parts. Figure 4.10 a) shows the climate impact potential of each of the stages previously analyzed. The total cradle-to-gate emissions correspond to 420.03 kg CO2eq. When compared to the carbon footprint from Volvo Cars report mentioned in Chapter 2, it represents 2% of the materials production and vehicle manufacturing. This can be explained because the powertrain weight is 100 times lower than the XC40 vehicle (2170 kg). As discussed earlier, it can be observed that the raw materials extraction is responsible for the higher GHG emissions, representing around 76% of the total GWP. The second highest impact belongs to the manufacturing process, which emits 108.82 kg CO2eq. These results correspond to direct emissions from aluminum production, and indirect emissions coming from hard coal and lignite production for electricity generation. On the other hand, logistics and assembly have the least climate change impact, accounting for around 3% of the total emissions. b) depicts the fossil depletion potential, which in total corresponds to 117.32 kg oileq, while c) illustrates the human toxicity potential equal to 103.50 kg 1.4-DCBeq.

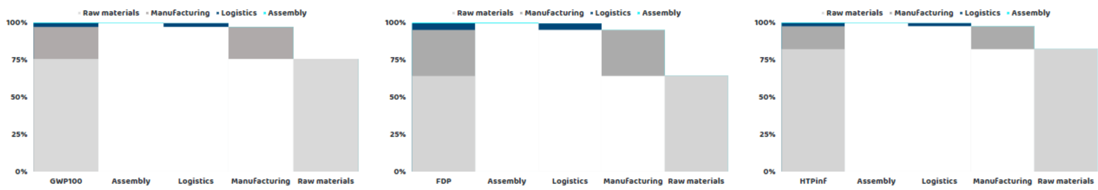


Figure 4.10: Cradle to Gate environmental impact

Chapter 5

Analysis

This section evaluates the effect of different key parameters in order to reduce the environmental impact of the power train across its value chain.

5.1 Sensitivity Analysis

Aluminum production

As Volvo Cars has the target of achieving 40% recycled aluminum content in their parts by 2025, a sensitivity analysis was performed to compare the impact of producing aluminum in Europe, and having 40% recycled-content aluminum vs the baseline scenario (all parts produced in China). The climate impact potential is reduced by 60% in the case of the aluminum produced in Europe. This can be attributed to the low share of hard coal mine production and electricity generation from hard coal, which is responsible for 122 kg of CO2 equivalent emissions. Consequently, fossil depletion is reduced in 49% and the human toxicity potential is reduced in 34%. This is explained by the reduction of the chemical components released to water in the treatment from hard coal and lignite mining. On the other hand, if the power train had 40% recycled aluminum content, the climate impact would be reduced in 31% due to the reduction in electricity demand and coal to produce primary aluminum. Nevertheless, additional energy is required during the recycling process (cleaning and separation). Although all the categories seem to decrease, the ionising radiation potential increases in more than 50% when the aluminum is produced in Europe. This is due to the high share of nuclear energy in the European electricity mix. Figure 5.1 shows the principal environmental impact results for the three scenarios described above. It is then demonstrated that the current aluminum production has the highest carbon footprint compared to the other two alternatives. These results confirm that the source of origin of electricity is the main cause of emissions for aluminum production. Consequently, by increasing the share of renewables, the GWP of aluminum production can be significantly decreased. Electricity frOm hydro is considered as the best option because of its ability to generate large amounts of power and its reliability, compared to solar or wind [42].

According to the discussion with Suppliers and the Metallic Materials Technical Expert from Volvo Cars, the aluminum recycled content can be further increase. In consequence, having an important reduction on the environmental impact. However, the recycling process of the alloys must be carefully performed to ensure the right concentration of additives and aluminum to preserve the mechanical properties of the parts. As a consequence, this might represent one of the main constraints in the integration of higher amounts of secondary aluminum.

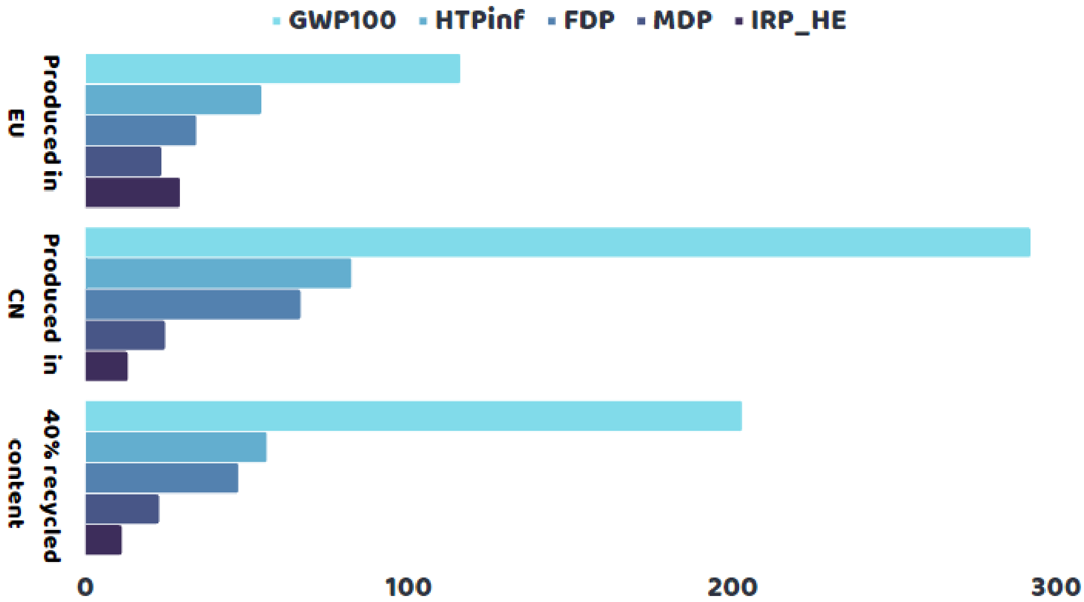


Figure 5.1: Environmental impact reduction Potential of Aluminum

Manufacturing

Currently, most of the power train mounts are manufactured in China, which implies a high climate impact derived from the use of hard coal (78%) [43] in the electricity production. Based on the European Aluminum (EA) information for aluminum suppliers in the automotive sector [44], a comparison between two production scenarios in Europe and China was performed. Figure 5.2 shows the five most relevant impact categories affected by the manufacturing location. Norway and Germany were chosen due to the economic importance that the aluminum industry represents in each country and the number of aluminum production and manufacturing options available. Germany has four of the 15 smelters present in Europe and numerous extrusion facilities. On the other hand, Norway, is one of the largest exporters of aluminum to the European Union, with seven smelter plants. Besides, 88% of its electricity production is based on hydropower sources [45]. As a result, the climate impact is reduced nearly by 40%. During the operation phase, hydro is one of the cleanest sources of energy. For this reason, the human toxicity impact is drastically reduced when compared to China and Germany. Germany represents a better option than China, when it comes to climate impact. Showing a CO2 equivalent emissions reduction of 6%. However, the effect on the other impact categories increase due to the share of coal, natural gas, and nuclear energy in the national energy mix.

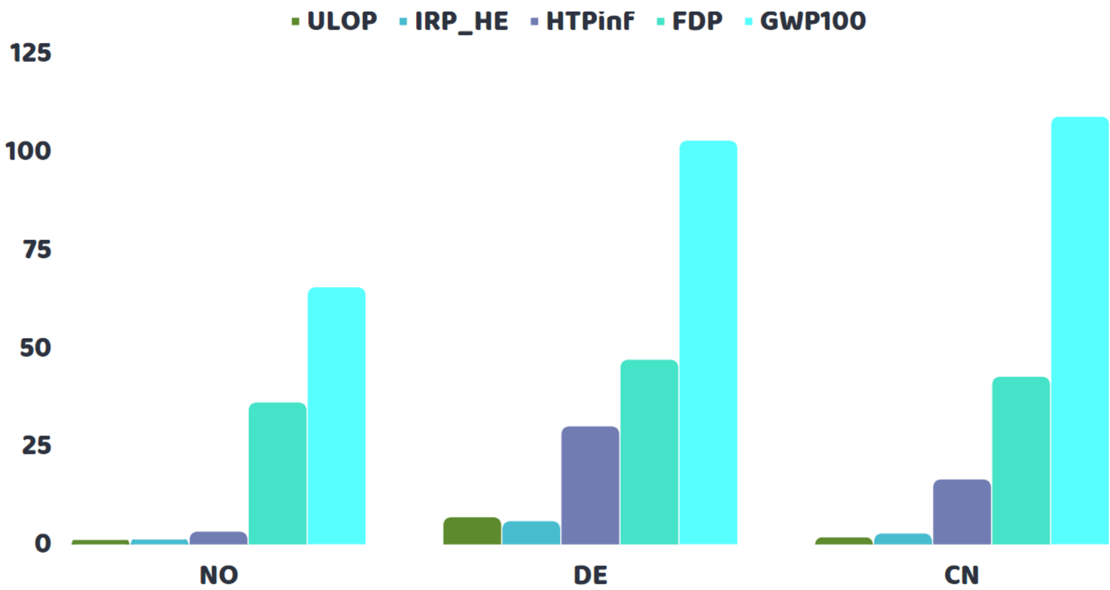


Figure 5.2: Environmental impact reduction Potential of Manufacturing location

Transportation

As defined in Chapter 3, all parts are exported from China through the port of Hamburg. In this section, other ports in Europe are considered based on its relevance and the proximity to the final destination at Volvo Cars' manufacturing plant in Ghent. Accordingly, three different ports were selected:

- Le Havre port, France
- Rotterdam port, The Netherlands
- Antwerp port, Belgium.

Distances were calculated using the Shipping Distances and Time calculator tool [37], considering departure locations as the suppliers' warehouses in China. Thus, as observed in Chapter 4, transportation has three major components. The road routes in China and Europe and the sea shipping. It is important to highlight that the sensitivity analysis was performed assuming that the parts are shipped from the local ports in China that are closest to the suppliers' sites. As the road transportation in Europe is one of the largest contributors to the environmental impact, the main aim was to reduce the distance within European borders while keeping the sea route as short as possible. As a result, shipping the parts to the port of Antwerp in Belgium has the lowest environmental impact of all the scenarios proposed. When compared to the base line, it reduces the climate impact by nearly 29% and the human toxicity is decreased by 54%. Figure 5.3 shows the environmental implications of shipping the power train mounts to different ports in Europe to finally arrive in Volvo Cars in Ghent. Table 5.1 shows the environmental impact reduction potential for all the scenarios compared to the baseline.

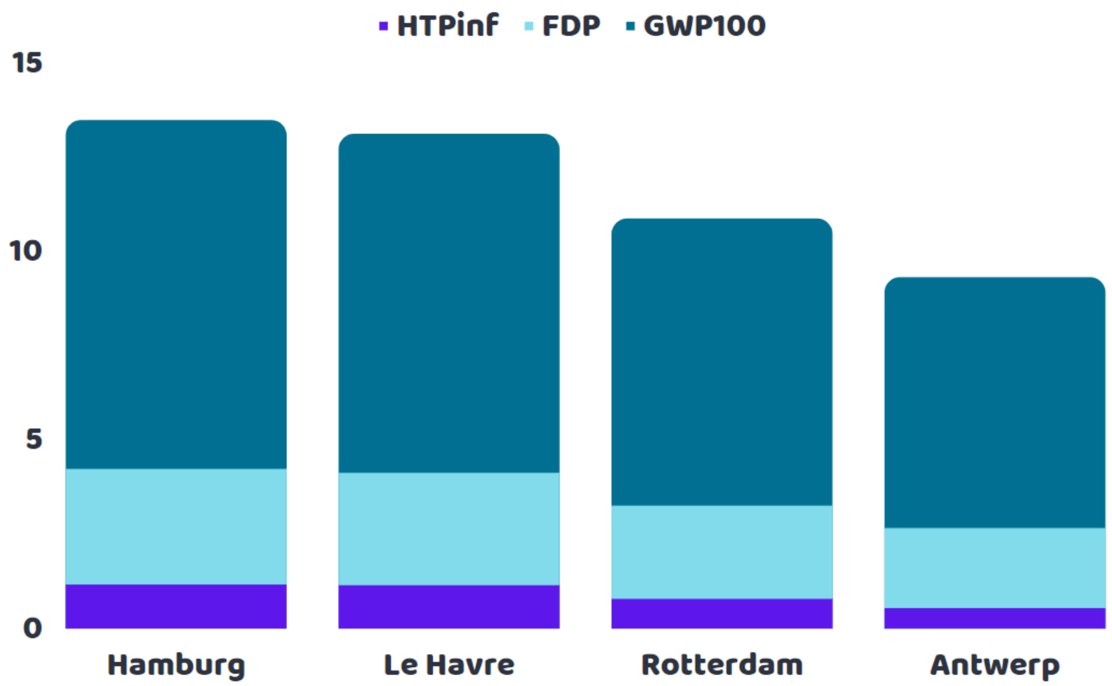


Figure 5.3: Environmental impact reduction Potential of transportation

Table 5.1: Environmental impact reduction of transportation

Impact category	Le Havre	Rotterdam	Antwerp
HTPinf	1.61%	32.52%	53.46%
FDP	2.77%	19.33%	30.77%
GWP100	2.83%	17.73%	28.14%

Electricity in the assembly process

As demonstrated in section 4.6, the environmental impact of the assembly process is attributed to the electricity generation from the Belgian energy mix. This section analyses the effect of implementing solar PV energy to generate the electricity needed during the assembly process. Figure 5.4 demonstrates that the ionizing radiation and climate change potentials can be reduced by 98% and 65%, respectively. These results are based on the low voltage electricity production from a 570 kWp ground installation in Belgium, available in the Ecoinvent 3.7.1 database. It does not consider the impact of low voltage to medium voltage transformation.

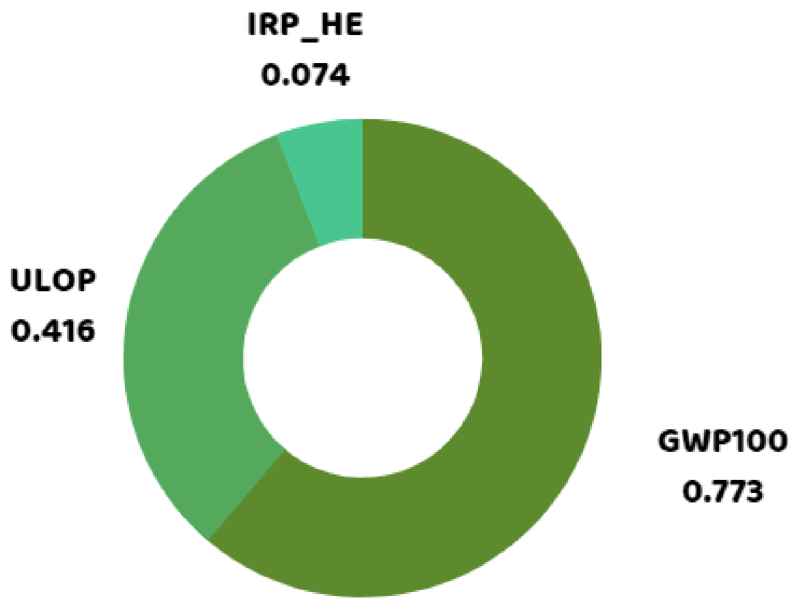


Figure 5.4: Environmental impact of solar PV electricity

ICE vs BEV platform

The transition from internal combustion to electric vehicles was done slowly given the significant adjustments to the current infrastructure that were required. Hence, the already existing structure for the ICE vehicles had to be modified to adapt an electric motor. As the XC 40 was born from an ICE platform, it has substantial differences with a platform made specifically for BEV. Another significant difference relies on the suspension type of the power train. Since the XC 40 has a pendulum-type suspension it requires additional mounts to hold the engine from the top of the structure. The XC 40 power train was compared against a BEV platform with a standing-type suspension. The BEV platform has the following components:

- Left rear engine mount
- Right rear engine mount
- Rear bracket
- Front left engine mount
- Front right engine mount

and weighs 5.92 kg in total, which is 72% less than the XC 40 platform. But the most relevant characteristic, is that it does not contain a crossmember. This subtracts 12.2 kg of aluminum from the power train's body. As a result, less raw materials are needed, which has a drastic reduction impact in the CO2 equivalent emissions, 66% less CO2eq. Figure 5.5 shows the comparison among three impact categories for the raw materials extraction, manufacturing, and logistics of the two platforms. As a consequence of the carbon dioxide emissions reduction, the fossil depletion impact decreases in 73%, while the human toxicity resulting from the release of hazardous chemicals (from the hard coal mining treatment), is reduced by 67%.

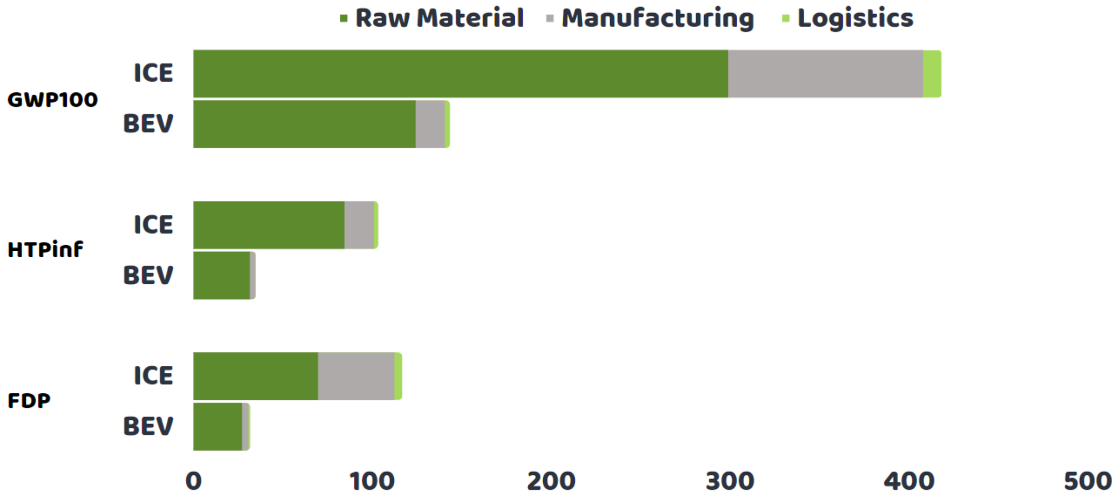


Figure 5.5: Environmental impact of ICE vs BEV platforms

5.2 Techno economic Analysis

The techno economic analysis focuses on two premises.

1. Transportation from China to the closest port to Volvo Cars in Ghent

2. The effects of the EU ETS and the carbon tax mechanisms on the production of the parts to assess the cost in the long run.

Optimization of the sea shipping transportation

As described during the sensitivity analysis, the environmental impact of shipping the parts to different ports in Europe was calculated. This section focuses on the cost analysis of the sea distances and disregards the costs implied by the road transportation. The cost values were obtained via the sea rates tool for 40 ft containers, considering September as the shipping month and being consulted three months in advance. It is relevant to mention that the sensitivity analysis was based on the distances from the respective City's local ports in China to the final destinations in Europe. Nevertheless, these routes do not correspond to the real existent itineraries as there are no direct shipping possibilities. Consequently, alternative routes were considered, choosing the closest available ports in China to evaluate the cost implications. Table 5.2 shows the origin ports based on the Suppliers location, the average costs for the evaluated routes and the price difference between the baseline (Hamburg port) and the proposed options.

Table 5.2: Sea shipping rates according to destination ports in EU

Base location	Origin	Destination	Average	Price difference
Shangai	Shangai	Hamburg	10 060.80 €	
Shangai	Shangai	Le Havre	9 981.60 €	79.20 €
Shangai	Shangai	Rotterdam	10 068.00 €	- 7.20 €
Shangai	Shangai	Antwerp	9 623.04 €	437.76 €
Qinhuangdao	Tianjin	Hamburg	8 969.28 €	
Qinhuangdao	Tianjin	Le Havre	8 953.92 €	15.36 €
Qinhuangdao	Tianjin	Rotterdam	9 084.48 €	- 115.20 €
Qinhuangdao	Tianjin	Antwerp	8 924.16 €	45.12 €
Wuxi	Shangai	Hamburg	10 059.84 €	
Wuxi	Shangai	Le Havre	10 060.80 €	- 0.96 €
Wuxi	Shangai	Rotterdam	10 262.88 €	- 203.04 €
Wuxi	Shangai	Antwerp	9 623.04 €	436.80 €
Zhaoqing	Guangzhou	Hamburg	14 052.48 €	
Zhaoqing	Guangzhou	Le Havre	14 038.08 €	14.40 €
Zhaoqing	Huangpu	Rotterdam	12 703.20 €	1 349.28 €
Zhaoqing	Huangpu	Antwerp	14 296.80 €	- 244.32 €

It is observed that in the case of Shangai, Qinhuangdao, and Wuxi, shipping to the port of Antwerp represents the best choice as it accounts for savings of 4%, 1%, and 4% respectively. Conversely, Rotterdam is the best option when Zhaoqing is the base location, accounting for 10% savings.

Including the maritime sector in the EU ETS

Moreover, as part of the "fit for 55" package, the EU Commission is actively looking for measures that aim to reaching the decarbonization goals set in the Paris Agreement. For this reason, a proposal of including the maritime emissions in the European ETS is being analyzed. This implies that large vessels (over 5000 gross tons) would need to purchase carbon allowances for 20% of their verified emissions starting from 2023. The extension would include all ships that call at EU ports. The percentage is proposed to increase each year, until reaching 100% in 2026 [46] [47]. Table 5.3 shows the behavior of the maritime carbon emissions mechanism and the corresponding additional cost.

Table 5.3: Extension of European ETS to the maritime sector

Percentage of emissions	Emissions subject to carbon allowance (Tonns)	Carbon emissions cost	Year
20%	0.7002	58.12 €	2023
45%	1.5755	130.76 €	2024
70%	2.4507	203.41 €	2025
100%	3.5011	290.59 €	2026

Based on the climate impact results from Ecoinvent 3.7 in OpenLCA, a 43000 Max tonns container ship is calculated to emit 0.00928 kg CO2e Tonn/km. According to [48] The price of the carbon allowances as for June 2022 is 83 Euros. If the average distance from the different ports in China to the proposed ports in Europe is taken, it would be equal to 188,634.53 km. Considering the carbon allowance applies for a round trip at the aforementioned price, shipping companies would have to pay additional 50,101.33 Euros starting from next year.

As a result, the transportation allowance cost was calculated taking one crossmember as a reference and scalated to the total XC 40 car production in 2021. Taking into consideration that a crossmember represents 0.04% of a full 40 ft container and that 1409 full containers can be fitted in a 43000 tonns containership.The additional cost of importing the total 2021 production parts is calculated to be 0.396 Euros. Table 5.4 shows the increment of the evaluated cost for the total number of crossmembers evaluated, throughout the following 10 years.

Table 5.4: Additional cost resulting from maritime carbon allowance

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031
Additional cost	0.396 €	0.890 €	1.385 €	1.979 €	1.979 €	1.979 €	1.979 €	1.979 €	1.979 €

Consequently, the extension of the European ETS would cost Volvo Cars an additional 0.002% over the calculated shipping price per container of 4.91 Euros, by 2031.

In order to simplify the calculations, the shipping cost of one 40 ft container from Shangai to Hamburg was taken as reference for base calculations. This cost was obtained using the Logistics Explorer tool from sea rates [49].

Carbon tax on imported aluminum products

Additionally, as part of the climate change policies, the European commission is proposing to introduce the Carbon Border Adjustment Mechanism (CBAM), a carbon tariff to imports. Therefore, aluminum will be subject to carbon taxes starting from 2026 [50]. The tax is estimated to cost 75 Euros per metric ton of

CO2e emissions [51]. Although the plan mentions that initially it will address direct emissions only, it does not preclude the inclusion of indirect emissions in the future [52].

Based on the climate impact results from the Ecoinvent 3.7 database, the aluminum extraction required for the production of one crossmember in China is responsible for 0.0286 CO2e Tonns (direct emissions). Table 5.4 shows the behavior of the border carbon tax for the total number of crossmembers analyzed over a 10 year scenario, assuming the carbon price would have a yearly increase of 5%.

Table 5.5: Additional costs resulting from border carbon tax on aluminum imports

Carbon tax imports EUR/CO2 Ton	Additional cost	Year
75.00 €	51 436.25 €	2023
78.75 €	54 008.06 €	2024
82.69 €	56 708.47 €	2025
86.82 €	59 543.89 €	2026
91.16 €	62 521.08 €	2027
95.72 €	65 647.14 €	2028
100.51 €	68 929.49 €	2029
105.53 €	72 375.97 €	2030
110.81 €	75 994.77 €	2031

This thesis assumes that both the ETS extension and the CBAM become effective from 2023. The calculations does not consider the yearly inflation.

If the crossmember was to be produced in Europe instead, more precisely in Norway (according to the results from the sensitivity analysis), it would be subject to the national carbon tax. As of 2021, the Norwegian carbon tax was 58.59 Euros [53], being the fifth highest in Europe. The direct CO2e emissions corresponding to the total crossmember production in Norway are equivalent to 503.49 Tons CO2, based on the OpenLCA results.

In addition to the carbon tax, Volvo Cars is responsible for purchasing the corresponding tooling for the part's manufacturing. In the case of the crossmember, the tooling cost represents around 14 times the cost of a fully electric XC40 vehicle.

The cost difference between the extraction and production of the crossmember part in China vs Europe was calculated over a 10 year scenario. Figure 5.6 shows the costs of producing in China vs Europe considering the carbon pricing mechanisms in both cases. It can be observed that if only direct emissions are considered as part of the CBAM, the tooling cost to produce the crossmember in Europe would be recovered in approximately 5 years.

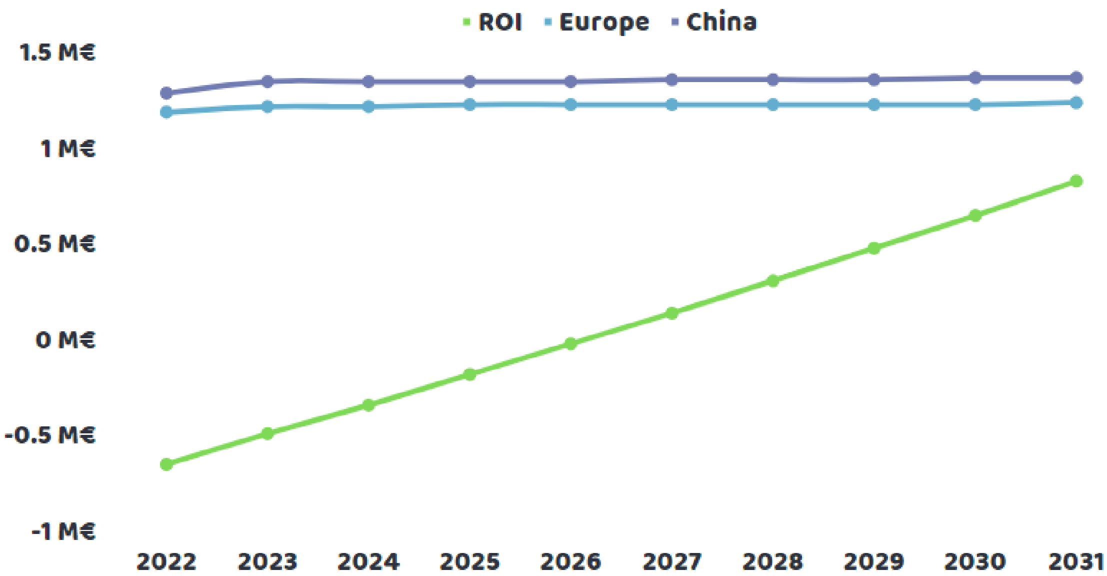


Figure 5.6: Economic impact of carbon price mechanisms on direct emissions

In addition, this thesis analyzes the economic impact considering indirect emissions were included in the CBAM starting from next year. It must be highlighted that the calculations presented does not take into consideration the efficiency improvement of the technology used. It is assumed that the technology remains the same over the 10 year period.

The total (direct + indirect) CO2e emissions resulting from the aluminum extraction to produce one crossmember in China were calculated to be 0.286 Ton CO2e. This is 10 times more than the direct emissions. Considering the same carbon pricing premises as in the direct emissions scenario, Figure 5.7 depicts the carbon pricing impact for both production instances, Norway and China. In this case, the return of investment of the tooling price in Europe results in Approximately 2 years.

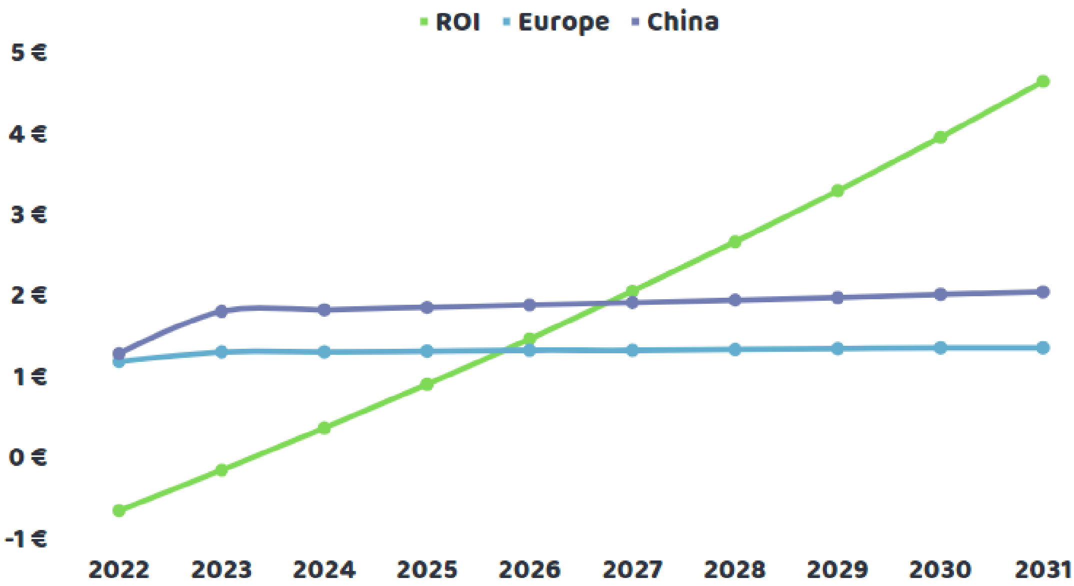


Figure 5.7: Economic impact of carbon price mechanisms on indirect emissions

Electricity represents one of the biggest differences in the CO2e pollutants between China and Norway due to the energy intensive aluminum production process. While electricity production in China comes mainly from coal, electricity in Norway is generated from hydro. In other words, to generate 1 kWh of electricity in each country, 1.0034 kg CO2e and 0.0059 kg CO2e are released, respectively.

Chapter 6

Discussion and Conclusions

In this chapter a detailed analysis of the results is provided along with some action points to explore in the future. The conclusions reached after analyzing the results are presented.

6.1 Conclusion

A complete analysis of the Cradle-to-Gate life cycle of the power train mounts was developed. The results show that aluminum extraction and manufacturing accounts for the highest proportion of the CO2 emissions since aluminum represents 93% of the total weight. As the aluminum production requires a considerable amount of energy, the electricity and heat generation sources constitute a major impact in this analysis as all the Suppliers of the power train mounts are located in China, which has a 78% percent penetration of hard coal in its energy mix. Another key element in the GHG release is the use of a carbon anode in the electrolysis method used for the smelting process. As a result, raw material extraction and mounts production represent 71% and 26% of the total CO2 emissions, respectively.

Nevertheless, there are other impact categories that are affected by the aluminum extraction such as human toxicity. This is due to the residual material that is discharged from the mining of hard coal and lignite, and bauxite processing. Consequently, the environmental impact of the raw material extraction can be addressed by implementing different alternatives. Switching from fossil fuels to renewable electricity sources for the aluminum smelting process seems to be the most straightforward option. Due to the high levels of power demanded by the production method, hydropower can represent the cheapest and cleanest possibility. According to the results shown in the techno-economic analysis, producing 1kWh from hydro against coal, derives in a 99% carbon footprint reduction. Similarly, in the electrolysis process, the adoption of an inert annode material and the integration of green hydrogen have been discussed to have a climate reduction impact. In addition, the climate impact and human toxicity potential could be further reduced by increasing the percentage of recycled aluminum, from both open- and closed-loop options.

In the case of manufacturing, the highest climate impact is hold by Supplier 2 due to the high reported quantities of natural gas usage during their process. However, the part produced by supplier two represents 1% of the total weight. Thus, It is important to mention that this results portray the data that was provided by each Supplier, which might not be 100% accurate since suppliers are starting to become familiar with the LCA methodology and the way in which data should be reported.

On the other hand, Supplier 5 is responsible for the highest impact on human toxicity potential due to the heavy metals that are released into water as a result of the lignite waste treatment in Europe. Extending the analysis to each component, it was found that the crossmember piece (China), the RLTB link and, the RLTB bracket account for 87% of the total powertrain manufacturing emissions. This is a consequence of the extraction and usage of coal and natural gas in China, which can be abated by the implementation of renewable energy sources.

Since most of the parts are imported, an estimated 211000 km are covered by containerships from China to the port of Hamburg. As a result, the maritime transportation was found to have the highest climate impact and human toxicity potential, among the transportation means used, due to its heavy dependency on fossil fuels. However, as two different suppliers were analyzed for the crossmember, it was calculated that if the Supplier 6 was selected, a total amount of 3.206 kg of CO2e emissions could be saved. Moreover, the results of the sensitivity analysis show that by changing the destination port from Hamburg to Antwerp, would translate into 28.14% of CO2e savings and a reduction of 53.46% in the human toxicity indicator.

The irradiation potential impact category appears to have the highest effect in the assembly analysis. Since the production process of the powertrain is conducted in Belgium, the country's energy mix has a significant impact on this result. 61% of the national electricity production is covered by nuclear energy, which represents a high potential risk to human health and ecosystems. Based on the Ecoinvent 3.7.1 dataset, by implementing solar PV technology in the assembly stage, both the climate impact and radiation potential could be reduced in approximately 65% and 98%, respectively.

As it has been demonstrated, the highest impact of the powertrain mounts design rely on the raw material extraction and manufacturing. Therefore, different alternatives were analyzed to abate the CO2eq emissions, from shifting the production to Europe to integrating more environmentally friendly energy sources into the value chain. As shown in the sensitivity analysis, aluminum production and extrusion in Norway can help reduce the climate potential impact in 40%. Besides contributing to the avoidance of the carbon border tax on imports and the tax allowance on maritime transportation, as evidenced during the techno-economic analysis. Similarly, increasing the aluminum recycling percentage has proven to be a very effective method to reduce the environmental impact of the powertrain mounts design without compromising the mechanical properties of the parts, as long as the concentration of additives and aluminum are well preserved.

The techno-economic analysis proved that it is economically viable to produce the parts in Europe due to the upcoming regulations on carbon emissions. However, this study was based on the costs of one crossmember and might not be representative for the rest of the parts, as this can vary according to each supplier. Similarly, conservative cost assumptions were taken to predict the carbon tax and allowance behavior over the next 10 years. These assumptions might not reflect the reality. Nevertheless, it was found that a higher carbon tax price and the inclusion of indirect emissions in the CBAM present a more suitable scenario for the reduction of CO2eq emissions. Moreover, if the cost-effective outcome of producing in China is demonstrated to be higher, even after the carbon price mechanisms, it is advised that suppliers who integrate the highest percentage of recycled aluminum are chosen. A more preferable alternative, however more complex to achieve, is that the current suppliers change to renewable energy electricity generation sources or select suppliers that are already implementing this option. In case the aluminum production is shifted entirely to Europe, increasing the recycled content upon this would yield the most sustainable alternative impact, having a drastic reduction in the environmental indicators that are affected by this activity.

6.2 Discussion and future work

As raw materials and manufacturing have been found as the most impactful stages in the design process, other alternatives have been analyzed. Aluminum 3D printing presents an alternative to agile design and long waiting times due to transportation. However, this technology is not yet in its mature phase to be implemented in the automotive industry. Although 3D printing delivers high precision pieces, the extra cost and time that is required does not compensate for the other benefits. Furthermore, the aluminum alloys options that are available as feedstock for a 3D printer are limited at the time of writing this thesis. In addition, it is yet to be analyzed if the printed aluminum parts comply with the physical and mechanical properties required for safety purposes by the automotive industry. Moreover, as 3D printing demands a large amount of electricity, renewable sources would be the preferable option to maintain the environmental impact as low as possible. Additionally, as green alternative fuels and energy sources are becoming more popular in the decarbonization pathway, there are some companies such as SSAB in Sweden that are starting integrate green hydrogen in the production of metals.

During the literature review, it was observed that the Software Catia (used by Volvo Cars in the design process) has an ancillary LCA tool, which embeds the Ecoinvent database. The implementation of this tool would help Volvo Cars to evaluate the environmental impact of the parts from an early design phase.

Whereas some of the information for the elaboration of this thesis was obtained from the Ecoinvent 3.7.1 database and literature review, the relevance of the results is on the accuracy of the information gathered from the Suppliers. However, there were some limitations during the data collection due to various reasons like the lack of familiarity of the suppliers with the methodology, availability of the data, and communication. Consequently, this work can be improved by obtaining more accurate data for the inventory creation such as precise amounts of elementary and process flows. The transportation data could be further upgrade by analyzing the exact available routes that are used to haul the different parts. In addition, including an inventory for the prototyping stage can help to identify environmental impact reduction potential. To finalize, Volvo Cars can extend the impact on the climate change reduction potential by increasing its efforts to properly sort and recycle the different parts of the powertrain. These processes could be integrated in the the life cycle analysis in the future.

Bibliography

[1] European Commission. *The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050, boosting the economy, improving people's health and quality of life, caring for nature, and leaving no one behind*. European Commission. Dec. 2019. URL: `https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691` (cit. on p. 1).

[2] European Commission. *climate Impact*. European Commission. June 2021. URL: `https://ec.europa.eu/clima/eu-action/european-green-deal/european-climate-law_en` (cit. on p. 1).

[3] T. Deloison, M.Ballweg, J. Potocnik, M. Stuchtey, T. Vahle, and M. Wehinger. *Paving the Way: EU Policy Action for Automotive Circularity*. Tech. rep. World Economic Forum, June 2021 (cit. on p. 1).

[4] R. Jain, K. K. Ramakrishnan, and D. M. Chiu. *The Circular Cars Initiative*. Tech. rep. World Economic Forum. URL: `https://www.weforum.org/projects/the-circular-cars-initiative` (cit. on pp. 1, 2).

[5] T. Deloison, C.Wolff, L. Tillemann, B. Heid, and E. Hannon. *Forging Ahead. A materials roadmap for the zero-carbon car*. Tech. rep. World Economic Forum, Dec. 2020 (cit. on p. 1).

[6] KIA. *What is a Powertrain?* KIA. URL: `https://www.kia.com/id/discover-kia/ask/what-is-a-powertrain.html` (cit. on p. 4).

[7] Jesper Schwartz. «Electric motor installation for improved vehicle noise characteristics». MA thesis. Lund: Lund University, 2014 (cit. on p. 4).

[8] Katrin Engel. «Predicting the design relevant loads in the engine mount system at an early stage of the develpment process». MA thesis. Stockhokm: Royal Institute of Technology, 2013 (cit. on pp. 4, 8).

[9] Y. Yu, N. Nagahathan, and R. V. Dukkipati. «A literature review of automotive vehicle engine mounting systems». In: *Mechanism and machine theory* 36 (Dec. 1999), pp. 123–142 (cit. on p. 4).

[10] KIA. *Do electric cars have transmissions?* KIA. URL: `https://www.kia.com/dm/discover-kia/ask/do-electric-cars-have-transmissions.html` (cit. on p. 7).

[11] Volvo Cars. *XC40 Recharge Specifications*. Volvo Cars. URL: `https://www.volvocars.com/se/v/cars/xc40-electric/specification/` (cit. on p. 8).

[12] G. A. Blengini. «Life Cycle Assessment (LCA)». Unpublished (cit. on pp. 8, 15).

[13] A. Nordelöf, E.Grunditz, and A. Tillman et al. *A Scalable Life Cycle Inventory of an Electrical Automotive Traction Machine - Part I: design and composition*. Tech. rep. Apr. 2017, pp. 55–69 (cit. on pp. 8, 10).

[14] A. Nordelöf and AM. Tillman. *A Scalable Life Cycle Inventory of an Electrical Automotive Traction Machine - Part II: manufacturing processes*. Tech. rep. Apr. 2017, pp. 295–313 (cit. on p. 9).

[15] E. Helmers, J. Dietz, and M. Weiss. «Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions». In: *MDPI - Sustainability* (Feb. 2020) (cit. on p. 10).

[16] E. Evrard, J.Davis, KH. Hagdahl, R. Palm, J. Lindholm, and L Dahllöf. *Carbon footprint report. Volvo C40 Recharge*. Tech. rep. Gothenburg, Sweden: Volvo Cars, 2021 (cit. on p. 10).

[17] W. Butler, G. Timelli, E. Battaglia, and F. Bonollo. «Die Casting (Permanent Mold)». In: *Encyclopedia of Materials: Science and Technology* 2 (Jan. 2003), pp. 2147–2152 (cit. on p. 11).

[18] G.T. Kridli, P.A Friedman, and J.M Boileau. «Manufacturing processes for light alloys». In: *Materials, Design and Manufacturing for Lightweight Vehicles* 2 (Oct. 2020), pp. 267–320 (cit. on p. 11).

[19] N.B. Manjong, L. USai, O.s. Burheim, and A.H. Stromman. «Life Cycle Modelling of Extraction and Processing of Battery Minerals - A Parametric Approach». In: *Batteries - MDPI* 7 (Aug. 2021) (cit. on pp. 11, 12).

[20] World Aluminum. *Life Cycle Inventory Data and Environmental Metrics for the Primary Aluminum Industry*. Tech. rep. International Aluminum Institute, June 2017 (cit. on p. 11).

[21] G. Liu and D.B Müller. «Addressing sustainability in the aluminum industry: a critical review of life cycle assessments». In: *Journal of Cleaner Production* 35 (Nov. 2012), pp. 108–117 (cit. on p. 11).

[22] D. Krewski, R.A. Yokel, E. Nieboer, and D. Borchelt et al. «Human Health Risk Assessment for Aluminum, Aluminum Oxide, and Aluminum Hydroxide». In: *Journal of Toxicology and Environmental Health, Part B* 10 (Nov. 2009) (cit. on p. 11).

[23] M. Birnbach, A. Lehmann, E. Naranjo, and M. Finkbeiner. «A condom's footprint - life cycle assessment of natural rubber condom». In: *The International Journal of Life Cyle Assessment* 25 (May 2020), pp. 964–979 (cit. on p. 12).

[24] S. Petsri, A. Chidthaisong, N. Pumijumnong, and C. Wachrinrat. «Greenhouse gas emissions and carbon stock changes in rubber tree plantations in Thailand from 1990 to 2004». In: *Journal of Cleaner Production* 52 (Aug. 2013), pp. 61–70 (cit. on p. 12).

[25] P. Usubharatana and H. Phungrassami. «Carbon Footprints of Rubber Products Supply Chains (Fresh Latex to Rubber glove)». In: *Applied Ecology and Environmental Research* 16 (Feb. 2018), pp. 1639–1657 (cit. on p. 13).

[26] Ensinger. *TECAMID 66 GF30 black*. Ensinger. URL: `https://www.ensingerplastics.com/en/shapes/products/pa66-tecamid-66-gf30-black` (cit. on p. 13).

[27] Omnexus. *Polyamide (PA) or Nylon: Complete Guide*. Omnexus, the material selection platform. URL: `https://omnexus.specialchem.com/selection-guide/polyamide-pa-nylon` (cit. on p. 13).

[28] OEC. *Polyamide-6,-11,-12,-6.6,-6.9-6.10 or-6.12*. OEC. Observatory of Economic Complexity. URL: `https://omnexus.specialchem.com/selection-guide/polyamide-pa-nylon` (cit. on p. 13).

[29] BASF. We create cheimstry. *Ultramid Mass Balance. High performance polyamid derived from renewable raw materials*. BASF Group. URL: `https://www.basf.com/vn/en/products/textile-leather-and-footwear/ultramid-biomass-balance-renewable-polyamide.html` (cit. on p. 13).

[30] V. Strezov, X. Zhou, and T. J. Evans. «Life cycle impact assessment of metal production industries in Australia». In: *Scientific Reports* 11 (May 2021), pp. 2045–2322 (cit. on p. 13).

[31] P. Nuss and MJ. Eckelman. «Life Cycle Assessment of Metals: A Scientific Synthesis». In: *PLoS ONE* 9 (July 2014) (cit. on p. 14).

[32] L. Huimin, L. Qiqiang, L. Guanguan, and D. Ran. «Life Cycle Assessment of Environmental Impact of Steelmaking Process». In: *Complexity* (Dec. 2020) (cit. on p. 14).

[33] P. Renzulli, B. Notarnicola, G. Tassielli, G. Arcese, and R. Di Capua. «Life Cycle Assessment of Steel Produced in an Italian Integrated Steel Mill». In: *MDPI - Sustainability* 8 (July 2016) (cit. on p. 14).

[34] European Commission. *Circular Economy Action Plan. For a cleaner and more competitive Europe*. Tech. rep. European Commission, 2020 (cit. on p. 14).

[35] World Economic Forum. *The future of industry is circular*. Circular Economy for Net-Zero Industry Transition. URL: `https://www.weforum.org/circular-economy-for-net-zero` (cit. on p. 14).

[36] World Economic Forum. *The Road Ahead: A policy research agenda for automotive circularity*. Tech. rep. World Economic Forum, Dec. 2020 (cit. on p. 14).

[37] Sea Rates. *Shipping Distances Time Calculator*. Sea Rates by DP World. URL: `https://www.searates.com/es/services/distances-time/` (cit. on pp. 25, 46).

[38] National Institute for Public Health and the Environment. *LCIA: the ReCiPe model*. Sea Rates by DP World. URL: `https://www.searates.com/es/services/distances-time/` (cit. on pp. 29, 30).

[39] B.P Weidema, M. Wesnaes, Hermansen J, T. Kristensen, and N. Halberg. «Comparing Three Life Cycle Impact Assessment Methods from an Endpoint Perspective». In: *Journal of Industrial Ecology* 19 (June 2013) (cit. on p. 29).

[40] M. Rahimi, D. Bortoluzzi, and J. Wahlström. «Input Parameters for Airborne Brake Wear Emission Simulations: A Comprehensive Review». In: *Atmosphere - MDPI* 12 (July 2021) (cit. on p. 38).

[41] International Energy Agency. *IEA Sankey Diagram - Belgium*. IEA. URL: `https://www.iea.org/sankey/#?c=Belgium&s=Balance` (cit. on p. 41).

[42] W.A Reinsch and E. Benson. *Decarbonizing aluminum: Rolling Out a More Sustainable Sector*. Center for Strategic International Studies (CSIS). URL: `https://www.csis.org/analysis/decarbonizing-aluminum-rolling-out-more-sustainable-sector` (cit. on p. 44).

[43] International Energy Agency. *IEA Sankey Diagram - China and Hong Kong*. IEA. URL: `https://www.iea.org/sankey/#?c=China%5C%20(P.R.%5C%20of%5C%20China%5C%20and%5C%20Hong%5C%20Kong,%5C%20China)&s=Balance` (cit. on p. 44).

[44] European Aluminum. *Our Members - Automotive and Transport Market Group*. European Aluminum. URL: `https://www.european-aluminium.eu/about-us/our-members/` (cit. on p. 44).

[45] International Energy Agency. *IEA Sankey Diagram - Norway*. IEA. URL: `https://www.iea.org/sankey/#?c=Norway&s=Balance` (cit. on p. 45).

[46] Climate Action. *Reducing emissions from the shipping sector*. European Commission. URL: `https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en` (cit. on p. 50).

[47] K. Hansen, P. Roche, and E. Martin. *EU ETS and Shipping*. Norton Rose Fulbright. URL: https://www.nortonrosefulbright.com/en/knowledge/publications/f5c8d3fa/eu-ets-and-shipping (cit. on p. 50).

[48] Carbon Credits. *European Carbon Credit Market*. Carbon credits. URL: https://carboncredits.com/carbon-prices-today/ (cit. on p. 51).

[49] Sea Rates. *Logistics Explorer*. Sea Rates by DP World. URL: https://www.searates.com/freight/?cont%5C%5B40st%5C%5D=1 (cit. on p. 51).

[50] D. Kinch and W. Healy. *EU proposes carbon tax for steel, aluminum imports, to be full effective 2026*. SP Global Commodity Insights. URL: https://www.spglobal.com/commodityinsights/es/market-insights/latest-news/metals/071421-eu-proposes-carbon-tax-for-steel-aluminum-imports-to-be-fully-effective-2026/ (cit. on p. 51).

[51] T. Figures, M. Gilbert, M. McAdoo, and N. Voigt. *The EU's Carbon Border Tax Will Redefine Global Value Chains*. BCG. URL: https://www.bcg.com/publications/2021/eu-carbon-border-tax (cit. on p. 52).

[52] R. Pehlivan, J. Hollebeek, and R. Ramautarsing. *EU Carbon Border Adjustment Mechanism (CBAM). The state of play and ways forward*. Deloitte. URL: https://www2.deloitte.com/nl/nl/pages/tax/articles/eu-carbon-border-adjustment-mechanism-cbam.html (cit. on p. 52).

[53] E. Asen. *Carbon Taxes in Europe*. Tax Foundation. URL: https://taxfoundation.org/carbon-taxes-in-europe-2021/ (cit. on p. 52).

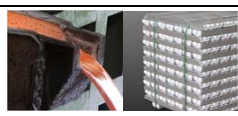
Appendix A

Raw Materials Data Sheets

AC 46000

RAFFMETAL

THE ALUMINIUM EVOLUTION



Leghe di alluminio in colata continua. Continuous casting aluminium alloys

Standard: **UNI EN 1676 and 1706**

Alloy group: **Al Si 9 Cu**

Alloy designation: **EN AB and AC 46000 - Al Si 9 Cu 3 (Fe)**

Replaces: **DIN 226 D - GD Al Si 9 Cu 3**

CHEMICAL COMPOSITION %

ALLOY		ELEMENTS												
		Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Individual impurities	Global impurities
EN AB 46000	min	8,0	0,6	2,0		0,15								
	max	11,0	1,1	4,0	0,55	0,55	0,15	0,55	1,2	0,35	0,15	0,20	0,05	0,25
DIN 226 D	min	8,0		2,00	0,10	0,10								
	max	11,0	1,0	3,50	0,5	0,50	0,10	0,30	1,20	0,20	0,10	0,15	0,05	0,25

MECHANICAL FEATURES DETECTED FROM SEPARATE CASTING TEST SPECIMENS

Casting process	Temper designations	Rm Tensile strenght		Sp 0,2 Yield strenght		A Elongation		HB Brinell hardness	
		EN 1706	DIN 1725	EN 1706	DIN 1725	EN 1706	DIN 1725	EN 1706	DIN 1725
		Mpa	N/mm2	Mpa	N/mm2	%	%	HBW	HB
SAND (as cast)									
Annealed									
SHELL (as cast)									
Annealed									
PRESSURE DIE (as cast)	F	240	240 - 310	140	140 - 240	1	0,5 - 3	80	80 - 120

PHYSICAL PROPERTIES (indicative values subject to the UNI EN and ex DIN Standards)

DENSITY	2.76 Kg/dm³
MELTING RANGE or MELTING POINT	500 ℃ 600 ℃
SPECIFIC HEAT (at 100)°	0.88 J/Gk
LINEAR SHRINKAGE IN SAND PROCESS	
LINEAR SHRINKAGE IN SHELL PROCES	
LINEAR SHRINKAGE IN HIGH PRESSUR	0.4 - 0.6 %
ELECTRIC CONDUCTIVITY	13 - 17 MS/m
MODULUS OF ELASTICITY	7500 Kg/mm²

THERMAL CONDUCTIVITY at 20°C	110 - 120 W/(m K)
LINEAR THERMAL EXPANSION from 20 t 100℃	21 10-6/°K
LINEAR THERMAL EXPANSION from 20 t 200℃	
LINEAR THERMAL EXPANSION from 20 t 300℃	
SUGGESTED MAXIMUM TEMPERATURE	750 ℃
SUGGESTED CASTING TEMPERATURE	
°in sand	
°in shell	
°in pressure die	630-710 ℃

TECHNOLOGICAL FEATURES, QUALITATIVE INDICATIONS

STRENGTH AT ELEVATED TEMPERATURE(to 200°C)	GOOD
GENERAL RESISTANCE TO CORROSION	LOW
MACHINABILITY	EXCELLENT
CASTABILITY	GOOD
POLISHING	MEDIUM

RESISTANCE TO HOT TEARING	MEDIUM
PRESSURE TIGHTNESS	MEDIUM
WELDABILITY	GOOD
DECORATIVE ANODISING	INSUFFICIENT
PROTECTIVE ANODISING	MEDIUM

AC 43500

RAFFMETAL

THE ALUMINIUM EVOLUTION

Leghe di alluminio in colata continua. Continuous casting aluminium alloys

Standard: **UNI EN 1676 and 1706**

Alloy group: **Al Si 10 Mg**

Alloy designation: **EN AB and AC 43500 Al Si 10 Mn Mg**

Replaces: **AlSi10MgMn**

CHEMICAL COMPOSITION %

ALLOY		ELEMENTS												
		Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Individual impurities	Global impurities
EN AB 43500	min	9,0			0,40	0,15								
	max	11,5	0,20	0,03	0,80	0,60	-	-	0,07	-	-	0,15	0,05	0,15
AlSi10MgMn	min	9,5			0,50	0,10								
	max	11,5	0,15	0,03	0,8	0,50	-	-	0,10	-	-	0,15	SR	0,03

MECHANICAL FEATURES DETECTED FROM SEPARATE CASTING TEST SPECIMENS

Casting process	Temper designations	Rm Tensile strenght		Sp 0,2 Yield strenght		A Elongation		HB Brinell hardness	
		EN 1706	AlSi10MgMn	EN 1706	AlSi10MgMn	EN 1706	AlSi10MgMn	EN 1706	AlSi10MgMn
		Mpa	N/mm2	Mpa	N/mm2	%	%	HBW	HB
	F	250	250 - 290	120	120 - 150	5	5 - 10	65	75 - 100
PRESSURE DIE (as cast)	T5	270	260 - 330	150	150 - 240	4	3 - 10	80	90 - 115
The values indicated are obtained by modifying the Magnesium content in the alloy	T6		290 - 350		200 - 280		6 - 12		100 - 115
	T4		210 - 260		95 - 140		15 - 22		60 - 75
	T7	200	200 - 240	120	120 - 170	12	15 - 20	60	60 - 75

PHYSICAL PROPERTIES (indicative values subject to the UNI EN Standards)

DENSITY	2.64 Kg/dm³
MELTING RANGE or MELTING POINT	550 ℃ 590 ℃
SPECIFIC HEAT (at 100)°	
LINEAR SHRINKAGE IN SAND PROCESS	
LINEAR SHRINKAGE IN HIGH PRESSUR	0.4 - 0.6 %
ELECTRIC CONDUCTIVITY	19 - 25 MS/m
MODULUS OF ELASTICITY	70 - 80 Gpa

THERMAL CONDUCTIVITY at 20°C	140 - 170 W/(m K)
LINEAR THERMAL EXPANSION from 20 t 100℃	-
LINEAR THERMAL EXPANSION from 20 t 200℃	21.0-10-6/°C
LINEAR THERMAL EXPANSION from 20 t 300℃	-
SUGGESTED MAXIMUM TEMPERATURE	780 ℃
SUGGESTED CASTING TEMPERATURE	
°in sand	
°in shell	
°in pressure die	650 - 730 ℃

TECHNOLOGICAL FEATURES, QUALITATIVE INDICATIONS

STRENGTH AT ELEVATED TEMPERATURE(to 200°C)	CORRECT
GENERAL RESISTANCE TO CORROSION	GOOD
MACHINABILITY	GOOD
CASTABILITY	EXCELLENT
POLISHING	MEDIOCRE

RESISTANCE TO HOT TEARING	EXCELLENT
PRESSURE TIGHTNESS	CORRECT
WELDABILITY	EXCELLENT
DECORATIVE ANODISING	OT RECOMMENDE
PROTECTIVE ANODISING	OT RECOMMENDE

AZIENDA CON SISTEMA DI GESTIONE PER LA QUALITÀ CERTIFICATO DA DNV = UNI EN ISO 9001:2008 =	Raffmetal S.p.a. via malpaga, 82 25070 Casto (BS) tel:0365.890.100 fax 0365.899.327 qualita@raffmetal.it vendite@raffmetal.it	AZIENDA CON SISTEMA DI GESTIONE AMBIENTALE CERTIFICATO DA DNV = UNI EN ISO 14001:2004 =

AC 44300

RAFFMETAL

THE ALUMINIUM EVOLUTION

Leghe di alluminio in colata continua. Continuous casting aluminium alloys

Standard: **UNI EN 1676 and 1706**

Alloy group: **Al Si**

Alloy designation: **EN AB and AC 44300 Al Si 12 (Fe)(a)**

Replaces: **DIN 230 D - GD Al Si 12**

CHEMICAL COMPOSITION %

ALLOY		ELEMENTS												
		Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Individual impurities	Global impurities
EN AB 44300	min	10,5	0,45											
	max	13,5	0,90	0,08	0,55	-	-	-	0,15	-	-	0,15	0,05	0,25
DIN 230 D - GD Al Si 12	min	10,5												
	max	13,5	1,00	0,10	0,4	-	-	-	0,15	-	-	0,15	0,05	0,25

MECHANICAL FEATURES DETECTED FROM SEPARATE CASTING TEST SPECIMENS

Casting process	Temper designations	Rm Tensile strenght		Sp 0,2 Yield strenght		A Elongation		HB Brinell hardness	
		EN 1706	DIN 1725	EN 1706	DIN 1725	EN 1706	DIN 1725	EN 1706	DIN 1725
		Mpa	N/mm2	Mpa	N/mm2	%	%	HBW	HB
SAND (as cast)			-		-	-		-	
			-		-	-		-	
SHELL (as cast)			-		-	-		-	
			-		-	-		-	
PRESSURE DIE (as cast)	F	240	220 - 280	130	140 - 180	1	1 - 3	60	60 - 100

PHYSICAL PROPERTIES (indicative values subject to the UNI EN and ex DIN Standards)

DENSITY	2.68 Kg/dm³
MELTING RANGE or MELTING POINT	570 °C 580 °C
SPECIFIC HEAT (at 100)°	0.90 J/Gk
LATENT HEAT OF MELTING	
LINEAR SHRINKAGE IN HIGH PRESSUR	0.4 - 0.6 %
ELECTRIC CONDUCTIVITY	16 - 22 MS/m
MODULUS OF ELASTICITY	7500 Kg/mm²

THERMAL CONDUCTIVITY at 20°C	130 - 160 W/(m K)
LINEAR THERMAL EXPANSION from 20 t 100°C	20 10-6/°K
LINEAR THERMAL EXPANSION from 20 t 200°C	21-10-6/K
LINEAR THERMAL EXPANSION from 20 t 300°C	-
SUGGESTED MAXIMUM TEMPERATURE	740 °C
SUGGESTED CASTING TEMPERATURE	
°in sand	-
°in shell	-
°in pressure die	640 - 680

TECHNOLOGICAL FEATURES, QUALITATIVE INDICATIONS

STRENGTH AT ELEVATED TEMPERATURE(to 200°C)	MEDIUM
GENERAL RESISTANCE TO CORROSION	GOOD
MACHINABILITY	MEDIUM
CASTABILITY	EXCELLENT
POLISHING	MEDIUM

RESISTANCE TO HOT TEARING	SMALL
PRESSURE TIGHTNESS	MEDIUM
WELDABILITY	MEDIUM
DECORATIVE ANODISING	LOW
PROTECTIVE ANODISING	

AZIENDA CON SISTEMA DI GESTIONE PER LA QUALITÀ CERTIFICATO DA DNV
= UNI EN ISO 9001:2008 =

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AZIENDA CON SISTEMA DI GESTIONE AMBIENTALE CERTIFICATO DA DNV
= UNI EN ISO 14001:2004 =

AW 6082

ALLOY DATA SHEET
EN AW-6082 [AlSi1MgMn]

Type:
High strength structural alloy

The alloy EN AW-6082 is a high strength alloy for highly loaded structural applications. Typical applications are scaffolding elements, rail coach parts, offshore constructions, containers, machine building and mobile cranes. Due to the fine grained structure this alloy exhibits a good resistance to dynamic loading conditions. EN AW-6082 is certified for use in marine applications.

Chemical composition according to EN573-3 (weight%, remainder Al)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	remarks	others	
									each	total
0.7 – 1.3	max. 0.50	max. 0.10	0.40 – 1.0	0.6 – 1.2	max 0.25	max 0.20	max 0.10		max 0.05	max 0.15

Mechanical properties according to EN755-2

Temper*	Wallthickness e***	Yield stress $Rp_{0.2}$ [MPa]	Tensile strength Rm [MPa]	Elongation A [%]	Elongation A_{50mm} [%]	Hardness** HB
T4	e ≤ 25	110	205	14	12	65
T5	e ≤ 5	230	270	8	6	80
T6	e ≤ 5	250	290	8	6	95
	5 < e ≤ 25	260	310	10	8	95

*Temper designation according to EN515: T4-Naturally aged to a stable condition, T5-cooled from an elevated temperature forming operation and artificially aged, T6-Solution heat treated, quenched and artificially aged (T6 properties can be achieved by press quenching)
** Hardness values are for indication only
***For different wall thicknesses within one profile, the lowest specified properties shall be considered as valid for the whole profile cross section

Physical properties (approximate values, 20℃)

Density [kg/m^3]	Melting range [℃]	Electrical conductivity [MS/m]	Thermal conductivity [W/m.K]	Co-efficient of thermal expansion 10^{-6}/K	Modulus of elasticity [GPa]
2700	585-650	24-32	170-220	23.4	~70

Weldability[1]
Gas: 3 TIG: 2 MIG: 1 Resistance welding: 3 Spot welding: 2
Typical filler materials (EN ISO18273): AlMg5Cr(A), AlMg4.5Mn0.7(A) or AlSi5. Due to the heat input during welding the mechanical properties will be reduced by approximately 50% (ref. EN1999-1).

Machining characteristics[1]**:**
T4 temper: 4 T5 and T6 temper: 2

Corrosion resistance[1]
General: 2 Marine: 2

Coating properties[1]
Hard/protective anodising: 2 Bright/colour anodising: 3

[1] Relative qualification ranging from 1-very good to 6 – unsuitable

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Alloy data sheet
EN AW-6082

jun-2005
rev.00

AW 6061

ALLOY DATA SHEET EN AW-6061 [AlMg1SiCu]

Type: High strength structural alloy

The alloy EN AW-6061 is a high strength alloy for highly loaded structural applications. Typical applications are scaffolding elements, rail coach parts, containers, machine building and aerospace parts. This alloy is equivalent to EN AW-6082, however due to its higher Cu-content, the corrosion resistance is somewhat lower.

Chemical composition according to EN573-3 (weight%, remainder Al)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	remarks	others each	others total
0.40 – 0.8	max. 0.7	0.15 - 0.40	max. 0.15	0.8 – 1.2	0.04 - 0.35	max 0.25	max 0.15		max 0.05	max 0.15

Mechanical properties according to EN755-2

Temper*	Wallthickness e***	Yield stress $Rp_{0.2}$ [MPa]	Tensile strength Rm [MPa]	Elongation A [%]	Elongation A_{50mm} [%]	Hardness** HB
T4	e ≤ 25	110	180	15	13	65
T6	e ≤ 5	240	260	9	7	85
	5 < e ≤ 25	240	260	10	8	85

*Temper designation according to EN515: T4-Naturally aged to a stable condition, T6-Solution heat treated, quenched and artificially aged (T6 properties can be achieved by press quenching).
** Hardness values are for indication only
***For different wall thicknesses within one profile, the lowest specified properties shall be considered as valid for the whole profile cross section

Physical properties (approximate values, 20℃)

Density [kg/m³]	Melting range [℃]	Electrical conductivity [MS/m]	Thermal conductivity [W/m.K]	Co-efficient of thermal expansion 10^{-6}/K	Modulus of elasticity [GPa]
2700	585-640	22-30	170-200	23	~70

Weldability[1]
Gas: 3 TIG: 2 MIG: 1 Resistance welding: 3
Typical filler materials (EN ISO18273): SG-AlMg5Cr(A), SG-AlMg4.5Mn0.7(A) or AlSi5. Due to the heat input during welding the mechanical properties will be reduced by approximately 50% (ref. EN1999-1).

Machining characteristics[1]:
T4 temper: 4 T6 temper: 2

Corrosion resistance[1]
General: 2 Marine: 2-3

Coating properties[1]
Hard/protective anodising: 1 Bright/colour anodising: 3 Other: 2

[1] Relative qualification ranging from 1-very good to 6 – unsuitable

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Alloy data sheet EN AW-6061

jun-2005
rev.00

AW 6005

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ALLOY DATA SHEET
EN-AW 6005A[AlSiMg(A)]
(Type: Medium strength extrusion alloy)

The alloy EN AW-6005A is a general purpose extrusion alloy, suitable for structural products where medium strength properties are required. Typical application fields are ladders, train- and truckbuilding, marine constructions, off shore applications, etc. Through special control of the chemical composition and the processing parameters, Nedal can achieve specially defined grain structures which are optimised for static and dynamic loading conditions.

Chemical composition according to EN573-3 (weight%, remainder Al)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	remarks	others	
									each	total
0.50-0.9	max. 0.35	max. 0.30	max. 0.50	0.40-0.7	max. 0.30	max. 0.20	max. 0.10	Mn+Cr 0.12-0.50	max. 0.05	max. 0.15

Mechanical properties according to EN755-2

Temper*	Wallthickness e*** [mm]		Yield stress $Rp_{0.2}$ [MPa]	Tensile strength Rm [MPa]	Elongation A [%]	Elongation A_{50} [%]	Hardness** HB
T4	Open profile: ≤ 25 Hollow profile: ≤ 10		90	180	15	13	60
T6	Open profile	≤ 5	225	270	8	6	90
		5 < e ≤ 10	215	260	8	6	85
		10 < e ≤ 25	200	250	8	6	75
	Hollow profile	≤ 5	215	255	8	6	85
		5 < e ≤ 15	200	250	8	6	75

*Temper designation according to EN515: T4-Naturally aged to a stable condition, T5-cooled from an elevated temperature forming operation and artificially aged, T6-Solution heat treated, quenched and artificially aged, (T6 properties can be achieved by press quenching)
** Hardness values are for indication only
***For different wall thicknesses within one profile, the lowest specified properties shall be considered as valid for the whole profile cross section

Physical properties (approximate values, 20°C)

Density [kg/m^3]	Melting range [°C]	Electrical Conductivity [MS/m]	Thermal Conductivity [W/m.K]	Co-efficient of thermal Expansion 10^{-6}/K	Modulus of Elasticity [GPa]
2700	585-650	26-32	180-220	23.4	~70

Weldability[1]
Gas: 3   TIG: 2   MIG: 2   Resistance welding: 3   Spot welding: 3
Typical filler materials (EN ISO18273): AlMg4.5Mn0.7(A)Cr(A) Due to the heat input during welding the mechanical properties will be reduced by approximately 50% (ref. EN1999-1).

Machining characteristics[1]
T4 temper: 3   T6 temper: 2

Coating properties[1]
Hard protecting anodising: 1   Decorative/bright/colour anodising: 4

Corrosion resistance[1]
General: 1   Marine: 2

[1]Relative qualification ranging from 1-very good to 6 unsuitable

November 2017
Rev. 01

a HunterDouglas company   Extrusion & Lighting columns

QSTE 380 TM

QStE 380 TM

High-strength steels for cold-forming, thermomechanically-rolled

Material no.	1.0978
according to	SEW 092[1]
Tensile strength class	B

[1] No valid norm

Usage

The steel grade QStE 380 corresponds to S380MC according to DIN EN 10149-2. These steels are used for cold-formed components of the most varied designs. Their fields of application include the manufacture of :

– Longitudinal beams
– Frames
– Cold-pressed parts
– Cold-rolled sections
– and Structural pipes

The user of these steel grades must make sure that his calculation, design and processing methods are appropriate for the material. The forming process used must be suitable for the intended application and comply with the state-of-the-art; it is of fundamental importance to the processing behaviour of these steel grades.

These steel grades offer excellent bending, flanging, cold-bordering and folding properties in both longitudinal and transverse direction. The bending radii specified below should be observed as minimum values.

Chemical composition [1)2)]

(in percent by weight)

	min.	max.
C		0.12%
Si		0.50%
Mn		1.50%
P		0.025%
S		0.020%
Al	0.015%	
Nb		0.09%
Ti		0.22%

1) Heat analysis

2) The maximum content of Nb+V+Ti shall not exceed 0.220%.

Mechanical properties [1)]

Nom. thick. e	Yield strength $R_{eL}/R_{p\,0.2}$
	≥ 380 MPa

Nom. thick. e	Tensile strength R_m
	450 – 590 MPa

Nom. thick. e	Total elongation A[2)]
<3 mm	≥ 18 %
≥3 mm	≥ 22 %

1) The tensile test values given in the table apply to longitudinal samples (l); in case of strip and sheet steel of widths of ≥600 mm they apply to transverse samples (t).

2) It applies to nominal thickness e:
e < 3 mm: A_{80}
e ≥ 3 mm: A_5

Notch impact energy

If agreed in the order, the notch impact energy is proved using longitudinal samples at -20 °C. The average notch impact energy from 3 samples must be 40 J minimum. One individual value may fall short of the required minimum value by not more than 30%. The sample width shall equal the product thickness if the latter is between 6 and 10 mm. The tests are performed by using samples similar to Charpy-V samples. The required minimum values are to be reduced proportionally to the sample width.

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GJL 200

GREY CAST IRON EN-GJL-200

Chemical Composition

Chemical composition can be defined by the manufacturer, as long as the material produced meets required mechanical property. A typical chemical composition to obtain a graphitic microstructure is 2.5 to 4.0% carbon and 1 to 3% silicon by weight. Graphite may occupy 6 to 10% of the volume of grey iron. Silicon is important to making grey iron because silicon is a graphite stabilizing element in cast iron, which means it helps the alloy produce graphite instead of iron carbides; at 3% silicon almost no carbon is held in chemical combination with the iron.

Typical Mechanical Properties	
Tensile Strength	200 - 300 MPa
Yield Strength	130 - 195 MPa
Elongation	0.3 - 0.8% min.
Conpressive Strength	720 Mpa

Comparative Specifications

Material	Country/Standards
EN-GJL-200	European Union / EN
EN-JL1030	European Union / EN
EN-GJL-200	Germany / DIN
JL 200	International / ISO
JL 250	International / ISO
FC200	Japan / JIS
SA-278 Class No. 200	USA / ASME
HT200	China

About NovaCast

NovaCast has over 35 years of ferrous and non-ferrous metal casting experience extending into markets as diverse as transport, utilities, offshore and general engineering. The company's non-ferrous sand and gravity die casting foundry, based in Melksham, England, is supported by a fully risk-managed supply chain that expends out to the Far East allowing NovaCast to provide a single source solution for precision cast and machined components. NovaCast has particular expertise in the production of pressure-tight valve and industrial pump components, complex non-ferrous castings and a wide range of precision castings for many engineering applications. Metals cast include alloys of Carbon and Stainless Steel, Copper, Aluminium and many others with a full range of testing, machining, surface treatment and finishing options.

To discuss your requirements, call a member of NovaCast's team on +44 (0) 1225 707466, or email sales@novacast.co.uk

WWW.NOVACAST.CO.UK

A Single Source Solution for Precision Cast Components