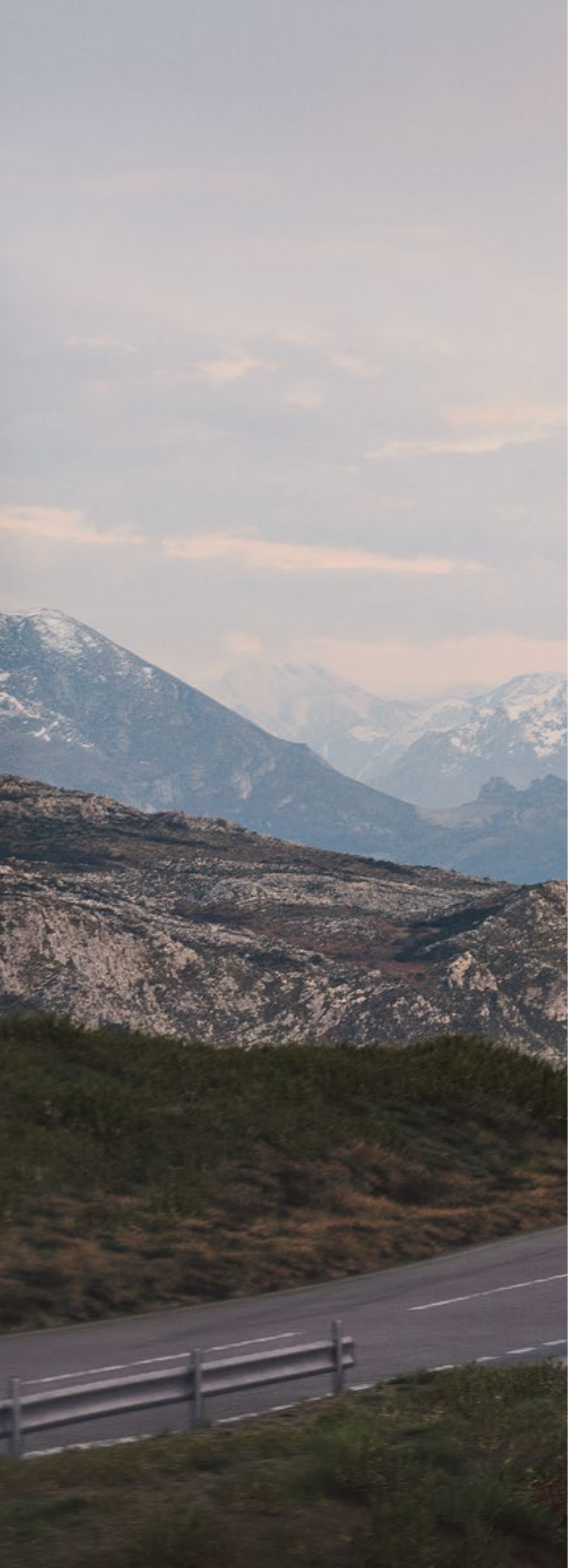
VOLVO

Carbon footprint report

Volvo EX30



1. Contents

2. List of abreviations

ABS:
Acrylonitrile Butadiene Styrene

APS:
Announced Pledges Scenario

BEV:
Battery Electric Vehicle

BOM:
Bill of Materials

EoL:
End-of-Life

GEC:
Global Energy and Climate

GHG:
Greenhouse Gas

GWP:
Global Warming Potential

IEA:
International Energy Agency

IMDS:
International Material Data System

IPCC:
Intergovernmental Panel on Climate Change

LCA:
Life Cycle Assessment

LFP:
Lithium Iron Phosphate

NMC:
Nickel Manganese Cobalt

NZE:
Net Zero Emissions by 2050 scenario

OEM:
Original Equipment Manufacturer

PC:
Polycarbonate

PCB:
Printed Circuit Board

PET:
Polyethylene Terephthalate

PE:
Polyethylene

PP:
Polypropylene

RER:
Rest of Europe

RWD:
Rear-Wheel Drive

STEPS:
Stated Policies Scenario

VCC:
Volvo Car Corporation

WLTP:
Worldwide Harmonized Light Vehicle Test Procedure

WTW:
Well-to-Wheel

3. Executive summary

At Volvo Cars, sustainability is as important as safety. We aim to be pioneers in protecting people and the planet by working towards net zero greenhouse gas (GHG) emissions by 2040, embracing the circular economy, and conducting business responsibly.

We plan to be a fully electric car company by 2030 and are committed to accompanying the release of each battery electric vehicle (BEV) with a comprehensive life cycle assessment (LCA) of its carbon footprint. In doing so, we intend to enhance transparency for our customers, employees, investors, other automotive companies, and stakeholders interested in our cars' environmental performance.

This report presents the carbon footprint of the new, fully electric Volvo EX30, which went into production in 2023 and possesses a carbon footprint that is significantly lower than any of our previous fully electric models. The EX30 comes with two battery options: a lithium iron phosphate (LFP) battery with a 51 kWh capacity and a nickel, cobalt, and manganese (NMC) option with a 69 kWh capacity.

The scope of the report covers the car's life cycle from extracting and refining raw materials to end-of-life (EoL) solutions. This report uses an LCA methodology based on the ISO 14067 standard to focus exclusively on GHG emissions and global warming potential (GWP) over a driving distance of 200,000 kilometres. The LCA follows guidelines from the Intergovernmental Panel on Climate Change (IPCC, 2021) for calculating the impact of these emissions.

Figure 1 illustrates LCA results for the car traveling one kilometre, with two different batteries and three electricity mixes. Variations in GHG emissions are given for three electricity sources: global, European and wind power electricity.

These findings reveal that in the scenarios studied, the global electricity mix produces the greatest impact, 0.18 kg CO_2-eq for NMC 69 kWh battery-equipped cars and 0.16 kg CO_2-eq for LFP 51 kWh battery-equipped cars, throughout their life cycles.

Looking specifically at the NMC-equipped model, when using a European electricity mix, there is a 23 per cent reduction in GHG emissions in comparison to the use of a global electricity mix. When using wind power electricity, there is a 40 per cent decrease during the use phase, relative to the use of a global electricity mix.

In comparison, GHG emission reductions in the LFP-equipped model are approximately 26 per cent when opting for European electricity mix and 45 per cent when using wind power during the use phrase, relative to the use of a global electricity mix.

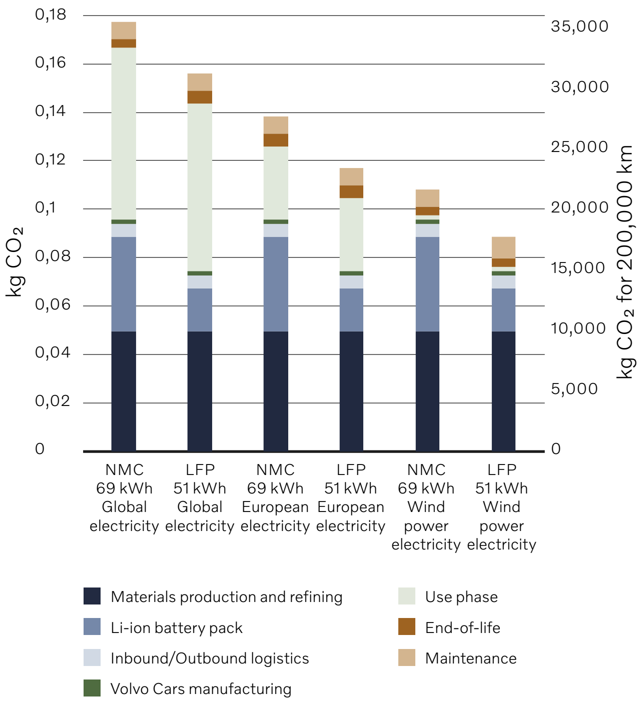


Figure 1 *Climate impact from all included life cycle phases for the two vehicle models.*

Key findings

- Life cycle assessment (LCA) of the Volvo EX30's carbon footprint ranges from 0.11 to 0.18 kg CO_2-eq/km (22 to 36 tonnes of CO_2-eq per 200,000 km) for the NMC-equipped model and 0.089 to 0.16 kg CO_2-eq/km (18 to 31 tonnes of CO_2-eq per 200,000 km) for the LFP-equipped model.
- Over 200,000 km and based on use of charging electricity from the European electricity mix, the 51 kWh LFP battery-equipped model has a carbon footprint of 23 tonnes, relative to the 69 kWh NMC battery-equipped model's 28 tonnes.
- On average, the LFP-equipped model has a 16 per cent lower carbon footprint than the NMC-equipped model. These differences are due to energy consumption in the material acquisition, refining and use phases, each impacting carbon intensity.
- Electricity sources in the use phase significantly impact the car's carbon footprint. Wind-generated electricity significantly reduces carbon footprint, compared to global or European electricity mixes. This underlines the need for accelerated global investment in renewable energy infrastructure.
- Future carbon footprint reductions in our battery supply chain could further mitigate the car's overall impact. By 2025, our battery suppliers plan to reduce emissions from manufacturing the LFP battery by 20 per cent and by 46 per cent in the case of the NMC battery.

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4. Methodology

4.1 The product

This study assesses the climate impact of the battery electric vehicle (BEV) EX30.

The EX30 can be delivered with different battery types and sizes. In this assessment, the following alternative battery configurations are assessed:

Table 1 *Information about battery packs and types in the study.*

Battery pack size (kWh)	Battery pack mass (kg)	Battery type
69	390	NMC (523) (Lithium Nickel Cobalt Manganese Oxide)
51	410	LFP (Lithium Iron Phosphate)

To assess a baseline vehicle, a model with a total weight of 1,775 kg and NMC type battery modules with a capacity of 69 kWh is used.

The development of the methodology for this study was initiated jointly by Volvo Cars and Polestar when performing carbon footprint studies of Volvo XC40 Recharge and Polestar 2 in 2020. This methodology has been further developed and significant changes will be explained in the sections below.

4.2 Goal of the study

Volvo Cars has the ambition to become a net zero greenhouse gas emissions (GHG) company by 2040 and strive to be transparent about the climate impact of its vehicles. The goal of this study is to contribute to transparency by disclosing the carbon footprint of the EX30, which has the intended function to transport passengers and their belongings.

The intended audience of this report are customers, employees at Volvo Cars, investors, automotive OEMs (original equipment manufacturers), and other stakeholders who are interested in the environmental performance of our vehicles. The study was carried out to increase understanding of the carbon footprint of the EX30, and which underlying materials and processes contribute the most. The aim is that this information can be used to make informed decisions, for example on where to put effort in reducing climate impact.

4.3 Scope of the study

The performed study is a life cycle assessment (LCA), but it only considers GHG emissions, making it a carbon footprint study. The study has been performed according to the carbon footprint standard ISO 14067 and explores the global warming potential (GWP), using characterisation factors for 100-year global warming potential (GWP) from the Intergovernmental Panel on Climate Change (IPCC, 2021). According to ISO 14067, emissions and removals in the following categories are included:

- Fossil GHG emissions and removals
- Biogenic GHG emissions and removals
- GHG emissions and removals from direct land use and land use change
- Aircraft GHG emissions

The biogenic carbon content of the vehicle is not reported since this is considered negligible as the main materials are metals and fossil-based plastics. No carbon offsetting is included within the system boundaries of this carbon footprint study. The GHG emissions and removals due to the net changes in soil and biomass carbon stocks are not assessed in this study as it has been considered as not applicable for this study. During the assessment period, greenhouse gas emissions and removals have been calculated as though they occurred at the beginning of the assessment period, without considering the impact of delayed emissions and removals of GHG emissions.

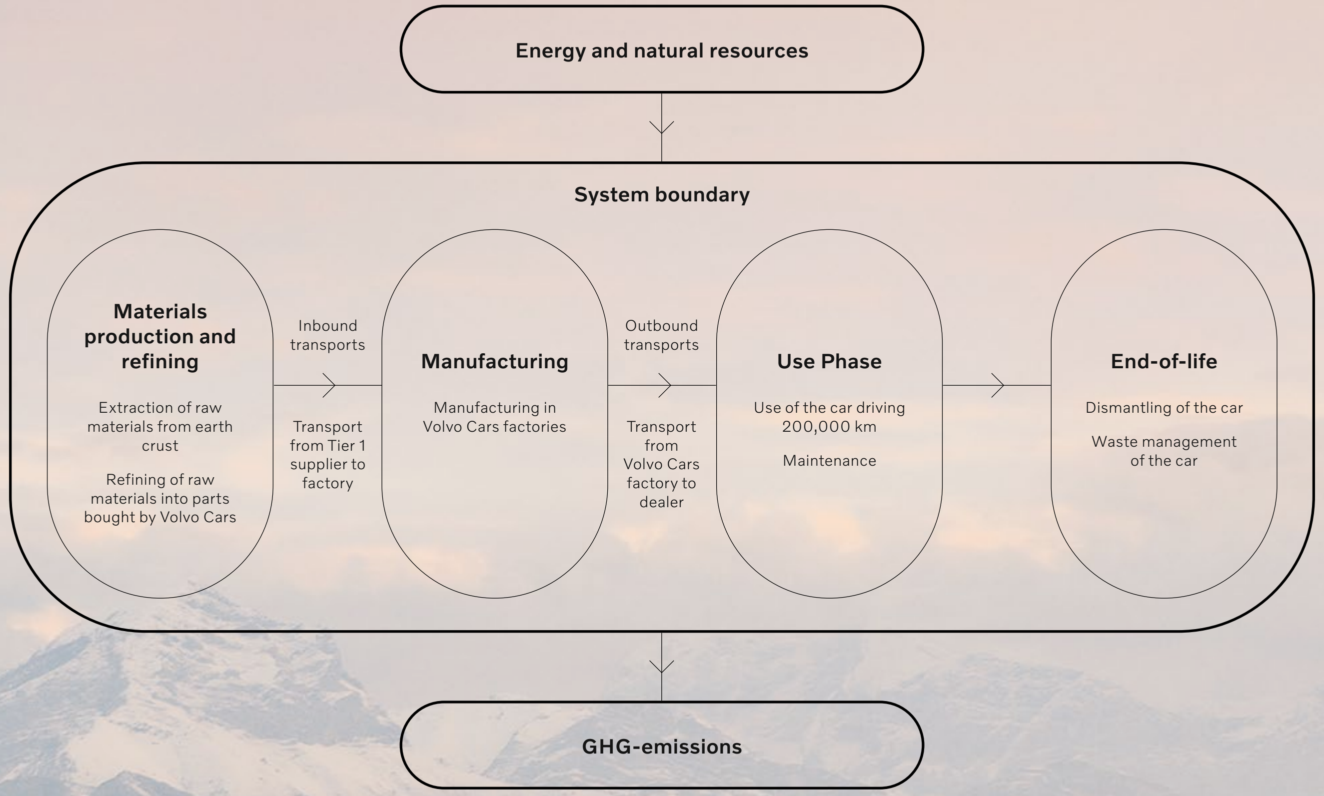

Figure 2 *System boundary of study.*

The study follows an attributional approach, meaning that it is not aimed at capturing systemic changes. The study includes the vehicle life cycle from cradle-to-grave, starting at extracting and refining of raw materials and ending at the end-of-life of the vehicle (see Figure 2). In the use phase, planned maintenance of the vehicle is also considered, such as what is expected to be exchanged during the lifespan due to wear and tear of the vehicle. This includes change of tyres and windscreen wipers, but not changes due to accidents.

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No cut-off criteria have been applied for the mass of the product content or energy use. In other words, the intent is that the included inventory together gives rise to the full carbon footprint. Mass that has not been declared as a specific material by the suppliers is still included and approximated by modelling it as a polymer material. In total, 2 per cent of the total mass of the vehicle is not specified. For more information on how materials have been handled in modelling, see Section 5 – Life cycle inventory analysis and Appendix 3 – Chosen datasets.

The time boundary of the study aims to reflect manufacturing in 2023 using recent manufacturing data and including electricity sources used. The use phase considers a lifespan of 15 years of the vehicle. The end-of-life handling aims to reflect global conditions in 2040, based on current conditions in 2023 in Sweden. This is despite the vehicles probably being scrapped closer to 2040 and represents a conservative approach, given end-of-life handling will likely have improved by 2040. On the other hand, the end-of-life handling varies in different countries, which is not captured in the modelling and might therefore underestimate the impact. Overall, this is assumed to be a reasonable approach.

Generic data, as opposed to supplier-specific data, has been used for most of the upstream processes. This means that the modelling of production of components in the vehicle have been based on the material composition of the components, using generic datasets for materials, and adding a generic manufacturing process for each material. Hence, there are steps in some of the manufacturing value chains, specific to vehicle components, that might not be included, such as assembly processes at Tier 1 suppliers. However, the contribution of these processes to the total carbon footprint is likely to be very small.

Regarding production, this study takes a regional approach. This means that the generic datasets used for raw material production/refining are specific to a certain region when it is known or likely that production/refining takes place in a certain region and that there are datasets available for the certain region. If the origin is not known, conservative datasets are used. This is one step towards better data quality.

This study considers use of recycled aluminium, steel, and polymers, as well as use of primary aluminium produced with a high share of electricity from renewable energy sources in the smelting step. Use of biobased materials has been considered in the modelling of the tyres in the vehicles; due to lack of data on the specific amount of biobased material in the remainder of the vehicle, these materials have not been considered. This means that the climate impact is slightly overestimated for the polymers, but the effect on the overall result is minor.

For the use phase, the study explores use of the vehicle in Europe as well as a global average scenario. In addition, a scenario with electricity from wind power is included. Since the use phase considers a lifespan of 15 years of the vehicle, probable changes in the global and European electricity mix during this time are considered in the study based on the stated policies scenario (STEPS) from the International Energy Agency (IEA). For wind power, electricity during the use phase is based on technology level available in 2023.

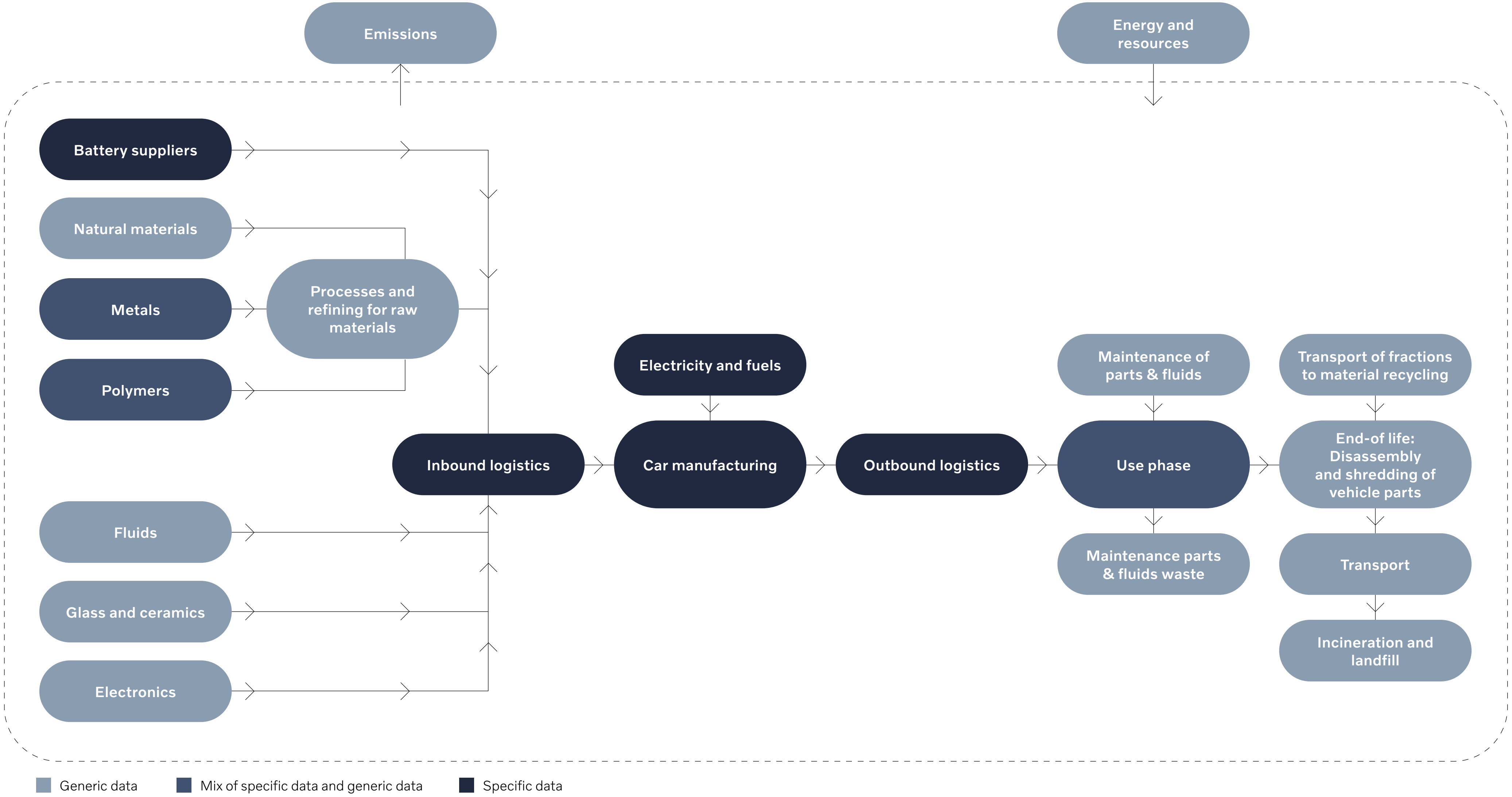

Figure 3 *Flowchart for the vehicle life cycle cradle to grave.*

4.4 Function and functional unit

The functional unit is one vehicle-kilometre (vkm). In previous carbon footprint studies from Volvo Cars, the vehicle lifetime mileage was used as the functional unit. The functional unit has been changed since vkm better captures the function of the vehicle (i.e. mobility), as well as capturing the effect of lifetime mileage of the vehicle; the longer the lifetime mileage, the lower life cycle impact per vkm. In practice, this means that the climate impact is calculated for the total life cycle and divided by the total km driven during the lifetime of the vehicle. For transparency, the result will also be provided per total lifetime climate impact of the vehicle. The effect of including the number of passengers in the functional unit will be explored in the sensitivity analysis. The reason for not including it in the main result is due to the lack of data on the number of passengers in Volvo vehicles across our markets. Still, by including it in the sensitivity analysis, the reader can assess the results in relation to their own practice of number of passengers in the vehicle.

The reference flow[1] in the study is the weight of the vehicle divided by the lifetime milage of 200,000 km.

4.5 Allocation

When it comes to material sent to recycling, the emissions from producing this material have been allocated to the vehicle. That means that, for example, the produced amount of steel and aluminium included in the carbon footprint calculation does not only include the amount of the material in the vehicle, but also any metal that is removed during processing and sent to recycling throughout the whole manufacturing chain.

More specifically, this study uses the simple cut-off or recycled content approach, which is the recommended method according to the International EPD[2] system. This method follows the "polluter pays" principle, meaning that if there are several product systems sharing the same material, the product causing the waste shall carry the environmental impact. This means that the system boundary is specified to occur at the point of "lowest market value". However, if the material does not go to a new product system, the final disposal is included within the life cycle of the vehicle.

The user of recycled material carries the burden of the recycling process, and no credit is given to the system that generates the material that is sent to recycling. This is applied both for the material that is sent to recycling from the manufacturing process and at end-of-life of the vehicle.

In the vehicle manufacturing facility, the total number of completed cars is used as the allocation basis and no consideration is given to the mix of different models being manufactured.

For the vehicle with 69 kWh battery, the battery cells are manufactured by two different suppliers. The impact of the battery cells has been allocated between these two based on estimated future sales.

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[1] *Reference flow: Measure of the inputs to or outputs from processes in a given product system required to fulfil the function expressed by the functional unit.*

[2] *https://www.datocms-assets.com/37502/1617181375-general-programme-instructions-v-4.pdf*

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4.6 System expansion

No system expansion has been applied in this study, meaning no credits have been given for materials being recycled and potentially avoiding other material production, or for energy generated in waste incineration potentially avoiding other energy production.

4.7 Main assumptions, limitations and exclusions

In general, assumptions have been made in a conservative fashion following the precautionary principle, to not underestimate the impact from unknown data. For example, when no suitable dataset has been available to represent the manufacturing process for a certain material (from raw material to finished vehicle component), the emissions from the raw material production has been multiplied by two to compensate for the emissions from further processing. This is explained more in Section 5 – Life cycle inventory analysis.

The use phase considers a lifespan of 15 years of the vehicle; probable changes in the global and European electricity mix during this time is considered in the study based on the stated policies scenario (STEPS) from the International Energy Agency (IEA). This scenario is a slightly conservative benchmark for the future, since it does not take for granted that governments will reach their announced commitments, Nationally Determined Contributions, or other long-term climate targets. Instead, it only considers forecasted effects of decided policies. For wind power, electricity during use phase is based on the technology level available in 2023.

The energy use in the use phase of the vehicle is based on the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) test cycle. This includes losses that occur during charging and in the drivetrain during driving, with only essential auxiliary systems running whilst driving (excluding infotainment, air conditioning). In evaluating the performance of the vehicles, differences between regulatory standards such as the WLTP and real-world operating conditions are important to note. As on-road performance is influenced by several dynamic factors such as driving habits, environmental conditions and differences in available infrastructure, the use phase could be affected by additional factors that are not expressed in the WLTP data. However, the report's scope is deliberately limited to the WLTP data so to conform to the scope of other LCA studies by Volvo Cars. The analysis delves into differences in geographical context when the impact from the use phase is quantified, encompassing European and global average geography. Additionally, the impact related to use phase maintenance is included in the study. In the sensitivity analysis the impact of changes in WLTP measurements are examined.

The lifetime mileage of the vehicle is 200,000 km. The battery is assumed to last the full lifetime mileage of the vehicle.

The study does not include:

- Data from infrastructure and capital goods as machinery or personnel food or transportation
- Non-manufacturing operations at Volvo Cars such as business travels, R&D activities, or other indirect emissions
- Volvo Cars infrastructure e.g., the production and maintenance of buildings, inventories or other equipment used in the production
- Construction and maintenance of roads and production of charging infrastructure in the use phase

4.8 Data quality requirements

The data quality requirements used in the study are shown in Table 2 below.

Table 2 *Data quality requirements used in the study.*

Aspect	Description	Requirements in this study
Time-related coverage	Desired age of data and the minimum length of time over which data should be collected.	General data should represent the current situation of the date of study (2023), or as close as possible. All data should be less than 10 years old.
Geographical coverage	Area from which data for unit processes should be collected.	Material production and refining should be representative of region where the material/component is produced, when known. Vehicle manufacturing should be representative of the manufacturing site location. The use phase data should be representative of the largest markets for the product, as well as a global average. End-of-life data should be representative of global average.
Technology coverage	Type of technology (specific or average mix).	Data should be representative of the technology used in production processes.
Representativeness	Degree to which the dataset reflects the true population of interest.	Primary data that is representative of the process should be used for processes under VCC financial control. Secondary data may be used for upstream and downstream processes but fulfilling the requirements above on time-related, geographical and technology coverage.
Precision	Measure of the variability of the data values.	Data that is as representative as possible will be used. Data will be derived from credible sources, and references will be provided.
Completeness	Assessment of whether all relevant input and output data are included for each dataset.	Generic data will be derived from credible sources, such as recognised LCI databases. Internal data should cover all relevant inputs and outputs. The data collected from battery module supplier should be verified in close collaboration with the supplier.
Reproducibility	Assessment of the method and data, and whether an independent practitioner will be able to reproduce the results.	Information about the method and data (reference source) should be provided.
Data sources	Assessment of the data sources used.	Data will be derived from credible sources, and references will be provided.
Uncertainty of the information	For example, data, models, and assumptions.	Data will be derived from credible sources, and references will be provided.

Considering the data quality requirements, the data used in this study fulfil the requirements except for the following:

- Some of the datasets used in material production and refining are more than 10 years old. They are however, reviewed annually and updated to compensate for any changes, such as new energy mixes.
- Some of the datasets used in the material production and refining are not representing the location of production.

This is due to both uncertainty of material origin, uncertainty of waste handling practises globally, and lack of geographical coverage in databases. For more details about the data quality assessment, see Appendix 4 – Data quality assessment.

4.9 Critical review

Compliance with ISO 14067 has been critically reviewed by a third party, see Appendix 8.

4.10 Way of working overview

Figure 4 shows a high-level overview of how Volvo cars works to derive carbon footprints of vehicles.

There are four main ways that data needed for the final carbon footprint are retrieved. The import to LCA for Experts (LCA FE) (see Terms and definitions) is made in a specific mapping tool, provided by Sphera, called LCA BOM Import (GaBi-DFX)[3]. The input to LCA FE comes from:

- IMDS[4] (International Material Data System) datasheets which contain information on material compositions of the components in a car.
- LCI databases from Ecoinvent[5] (version 3.9.1) and Sphera[6].
- Data from operations run by Volvo Cars, such as manufacturing plants and logistics.
- Carbon footprint of Li-ion battery modules, performed by the supplier with guidance and support from Volvo Cars.

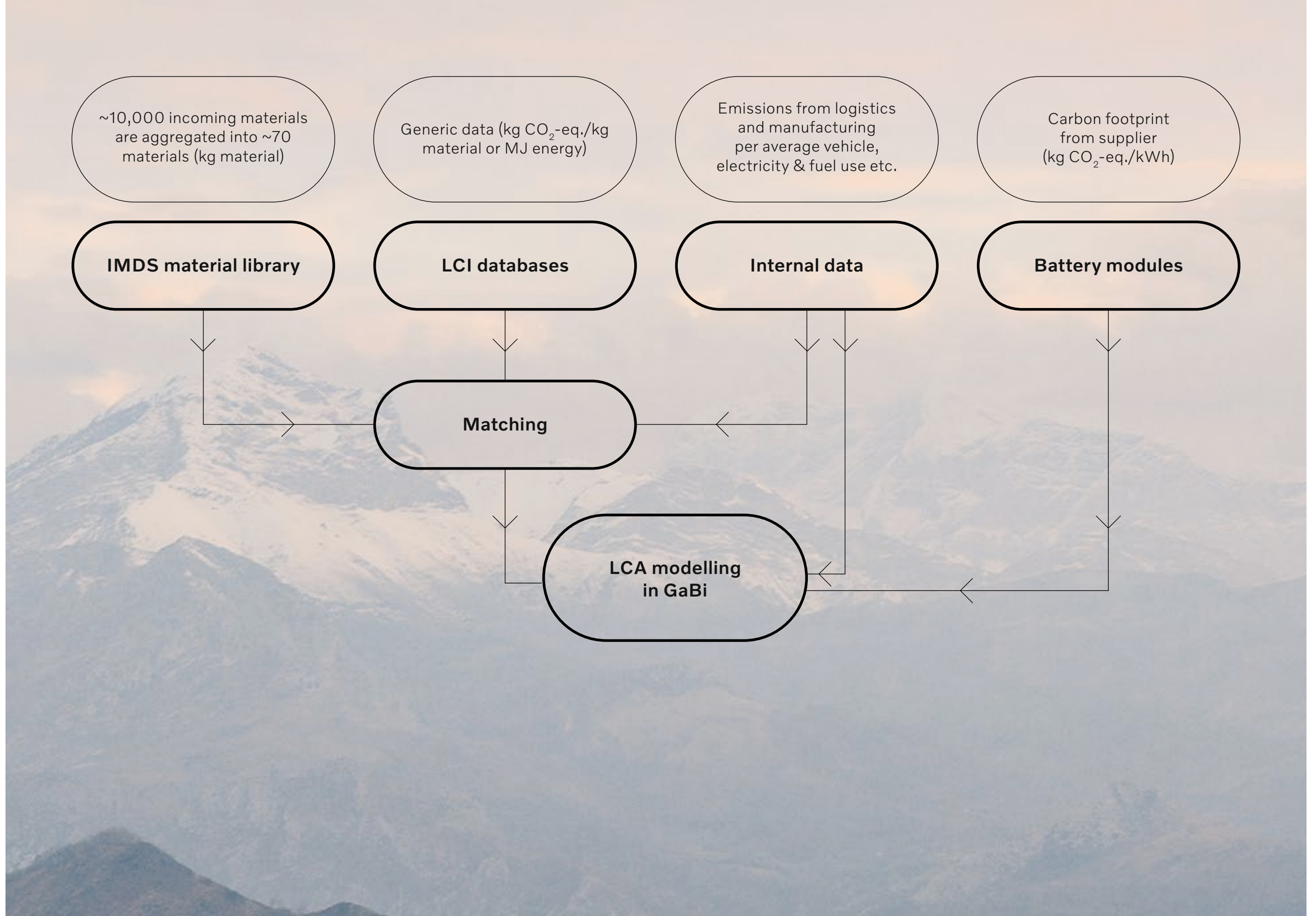

Figure 4 *Overview of deriving the carbon footprint of the vehicles.*

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[3] *https://envision.thinkstep.com/web/envision/help/help-user/index.htm#t=Recycle_bin%2FLCA_solutions_-_LCA_software_and_LCA_data.*

[4] *IMDS, www.mdsystem.com*

[5] *Ecoinvent, www.ecoinvent.org*

[6] *Sphera LCA databases https://sphera.com/product-sustainability-gabi-data-search/*

4.11 Methodology to define vehicle material composition

The Bill of Materials (BoM) is an important component of the LCA and consists of the parts used in the vehicle and their respective weights and materials composition. The “part number vehicle BoM” is extracted from the product data management system. However, this BoM cannot be used as direct input to the LCA-model in LCA for Experts, but must be modified and aggregated in several steps towards a suitable “material BoM”. A mass balance was performed where the total weight of the car was checked with the information of IMDS datasheets for respective materials.

The material information, except for the Li-ion battery modules, comes from datasheets in IMDS. A complete vehicle in IMDS consists of about 10,000 different materials. To make the number of materials manageable in LCA for Experts, they are aggregated to about 70 defined material categories in a material library developed by Volvo Cars (IMDS ML). The “part number BoM” from the product data management system is uploaded to the IMDS ML system iPoint Compliance Agent (iPCA). In iPCA a “material BoM” is generated that is imported to IMDS ML where all materials are mapped against the 70 defined material categories.

To have an efficient and systematic approach, this mapping is done via automation. The rules to categorise the materials are set up based on IMDS material category, material name and substance content. It is also possible to manually allocate materials in the IMDS ML. However, this is done in the most restrictive way possible. For this carbon footprint study, IMDS ML release 8 is used with the material categories listed in Table 3. For the complete list of material categories, see Appendix 1.

Table 3 *Material categories defined by Volvo Cars in Volvo IMDS ML release 8.*

Material group	Number of material categories
Steel and Iron	5
Aluminium	1
Other metals	4
Copper	2
Polymers	About 35 (including filled/unfilled)
Natural materials	3
Ceramics and glass	4
Electronics	1
Fluids and undefined	7

The material composition is visualised in Figure 5. The “materials BoM” from IMDS ML must then be further formatted to be imported into LCA for Experts. An automated formatting tool is used to apply the format required by LCA for Experts.

The import to LCA for Experts is made in a specific mapping tool, provided by Sphera, called LCA BOM Import. In the mapping, each material is connected to a specific LCI dataset and, if relevant, a manufacturing process dataset.

For the Li-ion battery modules, specific supplier carbon footprint data was used instead of IMDS data (see Figure 2). The production of the Li-ion battery modules and the ingoing materials potentially have a significant impact on the result and consists of complex manufacturing steps[7]. The variety and accuracy of generic datasets for Li-ion batteries is limited, but through collaboration with the battery module supplier the risk of inaccuracies has been minimised as best as we can.

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[7] *Dai et at., 2019.*

5. Life cycle inventory analysis

5.1 Material production and refining

Material production and refining (see Figure 2) is based on a Bill of Materials (BoM) containing material composition and material weight. The BoM used for the LCA model is specifically developed for the purpose of the LCA and states the composition of the vehicle divided into about 70 material categories. The total weight of the vehicle is then divided into these material categories. A mass balance was performed where the total weight of the car was controlled with the information of IMDS datasheets for respective materials. The source of the BoM data derives from IMDS sheets provided by the suppliers and is described in Section 4.10 – Way of working overview.

In the LCA software (LCA for Experts) and LCA BOM Import (GaBi Dfx), each material has been coupled with one or several datasets (containing LCI data) representing the production and refining of the material in each specific material category. See Appendix 4 – Chosen datasets for more details on this.

Material production and refining is modelled using datasets from Sphera Professional database and Ecoinvent 3.9.1 data. The datasets have been chosen according to the Volvo Cars methodology for choosing generic datasets. This methodology can be found in Appendix 3.

The material content corresponding to the entire weight of the vehicle is included in the LCA, but a small number of materials have been categorised as “undefined material”. The share of undefined material of the total vehicle weight (including battery modules) for the car in this study is 2 per cent. Since the undefined category seems to contain mostly undefined polymers, a dataset for polyamide (nylon 6) has been used as an approximation. This assumption is based on the fact that polyamide is the polymer with the highest carbon footprint, out of the polymer data used in the LCA. In Figure 5 the share of each material category is visualised.

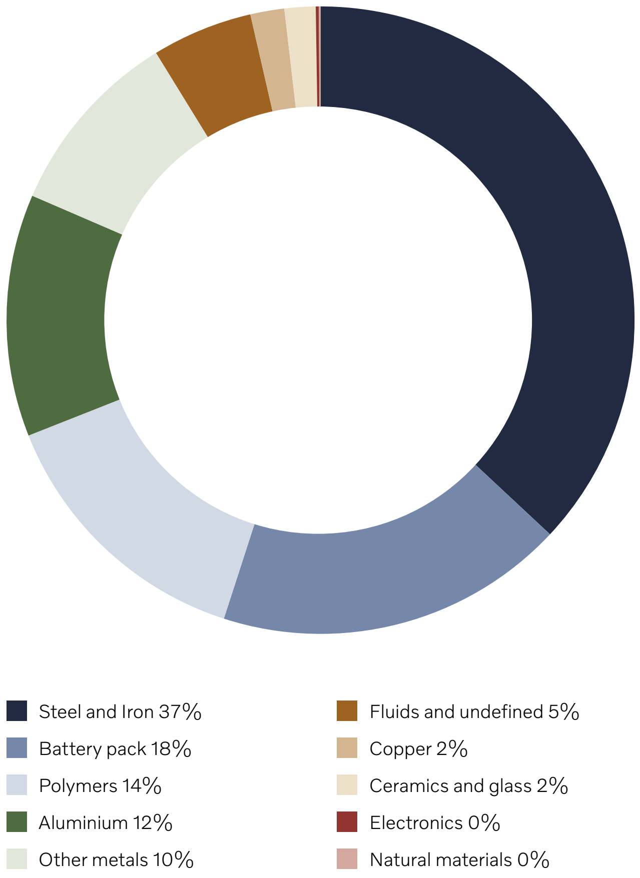

Figure 5 *Shares of material categories of the entire weight of the car.*

In most cases, datasets that include both production of raw material as well as component manufacturing ready to be assembled in the vehicle are not available. Therefore, several datasets representing the refining and production of parts have been used for most material categories. The datasets used to represent further refining and manufacturing of parts are listed in Appendix 2.

For most of the datasets representing materials production and refining processes, it has not been possible to modify the electricity or the built-in electricity that has been used. When changes have been possible, a Sphera dataset [Electricity grid mix 1kV–60kV (CN)] has been used.

5.2 Aluminium production and refining

The share of aluminium that is cast aluminium and wrought aluminium has been calculated to be 37 per cent cast aluminium and 63 per cent wrought aluminium, according to specific VCC data. This is based on the aluminium contents in the entire car. All wrought aluminium has been assumed to go through the process of making aluminium sheets. The assumption of wrought aluminium being aluminium sheets is conservative since sheet production has a higher amount of losses than most other wrought processes. The cast aluminium undergoes a process for die-casting aluminium.

The losses occurring from manufacturing aluminium parts for the car is included in the carbon footprint, and since a cut-off is applied at the point of scrap being produced in the factory, the total footprint of producing the scrap is allocated to the car even though the aluminium scrap is sent to recycling and used in other products. The material utilisation rate for the manufacturing processes of both cast aluminium and wrought aluminium can be seen in Appendix 2. In the EX30, 37 per cent of the aluminium is primary aluminium, 31 per cent is recycled, and 32 per cent is primary aluminium produced with renewable electricity. It has been assumed that the sourcing of all aluminium comes from China.

5.3 Steel production and refining

The raw material dataset used for the material category “unalloyed steel” has an output of rolled and galvanised steel. A processing dataset has then been added to all steel. Which manufacturing process that has been chosen depends on whether the steel is stamped in the factory or not. Hence, the steel categorised as unalloyed steel has been divided into two sub-groups depending on the manufacturing process following the rolling and galvanising of the steel:

1. The steel that is processed and stamped in the VCC factory. The material utilisation degree is according to Volvo Cars data (see Appendix 2).
2. The rest of the steel, which is distributed in various components of the car. The material utilisation degree is collected from suppliers and average values based on VCC data.

The modelling of steel includes recycled and primary steel alongside hot-dip galvanised steel, it is assumed that all zinc in the car is accounted for in hot-dip galvanized steel. A list of the datasets used to model the different types of steel can be found in Appendix 3. The recycled steel has been both hot and cold rolled, and any losses that have occurred during these manufacturing steps have been accounted for. Because unrecycled steel datasets contain shares of recycled steel, the overestimation of recycled steel content has been addressed. According to the scrap content in the used datasets, the modelled recycled steel content has been adjusted in order to reduce the exceeding recycled content. Based on data from VCC, 17.5 per cent of the steel in the EX30 is recycled. Additional data on shares of types of steel is presented in Table 29 in Appendix 6.

5.4 Electronics production and refining

The material category called “electronics” includes printed circuit boards (PCB) and the components mounted on them. It does not include chassis, cables or other parts that are present in electronic components. All materials that are used in electronic devices that are not PCBs have been sorted into other categories, such as copper or different types of polymers.

For the category “electronics” a generic dataset from Ecoinvent 3.9.1 has been used. This dataset represents the production of lead-free, mounted PCBs.

5.5 Plastics production and refining

For polymer materials, an injection moulding process has been used to represent the manufacturing of plastic parts from a polymer raw material. Among the polymers, three materials contain recycled content based on VCC data. Filled polypropylene (PP), unfilled polyethylene terephthalate (PET), and unfilled polycarbonate and acrylonitrile butadiene styrene (PC+ABS). The recycled plastics have been modelled with the Sphera dataset [Plastic granulate secondary (low metal contamination) (RER)]. The average recycled content in the polymers in the EX30 is 19 per cent. The recycled content of the specific plastics can be seen in Table 30 in Appendix 6. All other plastics consist solely of virgin materials. The same dataset has been used to model the recycled plastics, as presented in Appendix 3. The material utilization rate for the manufacturing processes of plastics can be seen in Appendix 2 and the degree is according to the chosen database dataset.

All filled polymers have been assumed to contain 80 per cent polymer, 7 per cent glass fibre and 13 per cent talc representing an average of filled polymers based on information from VCC.

5.6 Minor material categories, production and refining

There are raw materials for which data on manufacturing is missing in the LCA databases. In those cases, the material weight was doubled as an estimation for the manufacturing. This means that the manufacturing process is assumed to have the same carbon footprint as the production of the raw material itself. This has been applied only for minor materials which together constitutes 5 per cent of the weight of the car.

5.7 Electricity use in materials production and refining

The electricity mix used in the manufacturing processes in the supply chain is based on the locations of the production facilities. All components are sourced from China, except one component which weighs 88 g, which is from Europe. As a basis for calculation, it is assumed that all raw materials in the vehicle are sourced from the country where the production takes place (China), and the assumption is based on the high probability expressed when discussing with VCC experts. The electricity used in manufacturing has been adjusted according to a Sphera dataset [Electricity grid mix 1kV-60kV (CN)], where possible.

5.8 Battery packs

The EX30 battery, also referred to as a battery pack, consists mostly of lithium-ion (Li-ion) battery cells assembled into battery modules, but also a tray/carrier, a battery management system, a thermal management system, a switch box, busbars, thermal barriers, and a lid. The cathode active material is either an oxide containing nickel, manganese, and cobalt (commonly referred to as NMC) or lithium iron phosphate (commonly referred to as LFP), while the anode active material consists of graphite.

The LCA study include vehicles with two different battery types, P4 RWD 51 kWh (Li-ion LFP) for single motor and P6 RWD 69 kWh (Li-ion NMC-523) for single motor with extended range for markets in mid EU and the Nordics, and P6 RWD 69 kWh for overseas markets. The impacts from the P6 RWD 69 kWh are allocated based on market shares, i.e. the shares for overseas markets and EU and the Nordics.

Each of the vehicle models are similar, except for the battery packs, and one component that is included in the NMC vehicle with 69 kWh battery. It is assumed that P6 RWD BoM adequately and conservatively reflects the materials used in the other model.

The battery pack supplier has performed a cradle-to-gate (up until VCC logistics take over) carbon footprint assessment of their battery packs. The studies of all three batteries have been divided into impact from the packs and impact from the cells. The entire carbon footprint report from the battery pack manufacturer, which was conducted during 2024, has followed an LCA methodology framework. In Figure 6, a flowchart visualising the battery LCA is shown.

The pack manufacturers have performed LCA studies following ISO14040:2006, ISO14044:2006, ISO14067:2018, GHG Protocol: Product Life Cycle Accounting and Reporting Standard, and Volvo Cars guideline on carbon footprint calculation of components and materials.

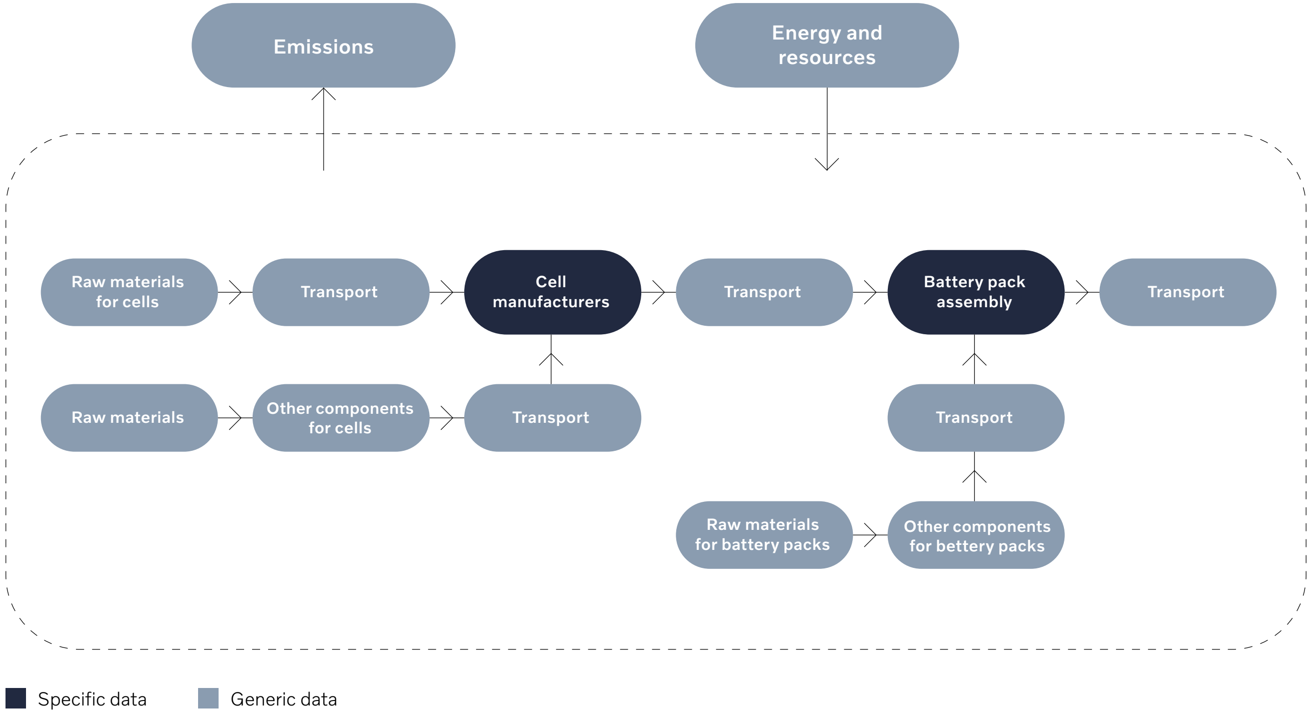

Figure 6 *Flowchart for battery manufacturing.*

As a first step, a boundary cradle-to-gate was used, and the functional unit was 1 kWh.

The life cycle main activity data has been acquired primarily from field research conducted by the company. Information regarding production and transportation stages has been calculated through allocation based on the annual production and operational circumstances of the pack manufacturer's factory in 2022. Emission factor data concerning product raw materials is primarily drawn from databases such as Ecoinvent and Sphera. The activity data and emission factors selected for this evaluation are widely recognised and extensively used in LCA research.

Module and pack assembly electricity impact is estimated by using a Sphera dataset for Chinese electricity grid mix, with an emission factor of 0.69 kg CO_2 eq per kWh. The impacts from natural gas are retrieved from Sphera and IPCC datasets. The suppliers plan to gradually increase the amount of renewable energy purchased in the near future, based on market conditions. Cell manufacturers have provided to pack manufacturing the results of the carbon footprint in terms of emissions factors for the cells.

The impacts from the additional 17 materials, which are included in the battery, have been assessed using Sphera datasets. The impacts from the materials are in line with the impacts calculated for each corresponding material within the current model, though slightly higher. The weight of the NMC battery pack is 390 kg and the LFP battery pack weighs 410 kg.

As battery suppliers have only given the value for total carbon footprint, it has been assumed that all impacts from battery raw materials and production are fossil, which is considered a conservative approach. The battery packs have therefore been removed from the BoM based on IMDS data and are modelled separately in the Complete Vehicle LCA. Both battery cell and battery pack suppliers have planned for large measures to substantially decrease carbon footprint from materials and production in the coming years. These measures are not considered in this study but are elaborated on in a sensitivity analysis.

The climate impact per battery pack differs between the different chemistries. The NMC battery has an impact that is almost twice as high as the LFP battery, per pack. For the NMC battery the climate impact from the battery pack (excluding cells) is lower per kWh compared to the LFP variant. On the other hand, the impact from manufacturing the LFP battery cells is about half that of the impact from production of the NMC battery cells per kWh. This is because of the different impacts related to the different cathode materials used.

The presented results suggest an impact from the NMC battery that is higher than expected in relation to similar batteries on the market. One possible explanation for this could be a higher use of fossil-based energy during manufacturing of the NMC battery cells. The reduction in emissions associated with LFP battery production is primarily attributable to the utilisation of aluminum sourced from smelters powered by renewable electricity.

In the EU, a new battery regulation was adopted in summer 2023[8] which requires the disclosure of the carbon footprint of batteries. Goal and scope, methods, data requirements and various assumptions are outlined in the regulation, delegated acts and other frameworks being referred to, and it is important to be aware that those are different from what has been used in this LCA study. Therefore, the carbon footprint for the battery pack presented in this report is not to be regarded as representative of the carbon footprint of the battery pack according to the EU battery regulation.

5.9 Manufacturing and logistics

5.9.1 Logistics

Volvo Cars specific data from production under 2022 has been used to calculate the impact for transports from Tier 1 suppliers to the manufacturing site (inbound transport). The impact related to the inbound logistics were calculated based on the distance shipped and weight of all items. Volvo Cars data has been used to calculate GHG emissions for transports from the manufacturing site to customer handover (outbound transport). Volvo Cars' total emissions from transports of Volvo Cars vehicles from Volvo Cars manufacturing sites to Volvo Cars dealers divided by the total number of Volvo Cars vehicles sold during the same year has been applied, this amount to 601 kg CO_2-eq/vehicle. As the impact is not specified into emissions categories, such as biogenic emissions or fossil emissions. The impact has conservatively been assumed to be associated with fossil emissions.

5.9.2 Manufacturing of vehicles

The impact from use of auxiliary material (other than what is included in the vehicle), water, electricity, heat and different fuels in the manufacturing plant was calculated using site-specific input data from production 2022. The car is only manufactured in one factory in Zhangjiakou in China. The input per vehicle were then calculated by dividing the total input of auxiliary materials from the factory by the total amount of produced vehicles during the same year (2022). The same procedure was used for the output, e.g. manufacturing waste and wastewater. As the vehicle under study was not manufactured in the factory during 2022, an assumption was made that manufacturing energy, auxiliaries and waste for one vehicle produced in the factory during 2022 is applicable for EX-30. 100% of the electricity used in manufacturing comes from wind power, certificate for this is presented in Appendix 9, which is a certificate of the power purchase agreement used. The electricity has been modelled by using the Sphera dataset from 2018 [Electricity from wind power (CN)]. The emission factor corresponding to this dataset is 11.3 g CO_2-eq /kWh.

5.10 Use phase

5.10.1 Electricity consumption

To be able to calculate the emissions in the use phase of the car, the well-to-wheel emissions from electricity production are needed. During the lifetime of the car (15 years) it is expected to be driven 200,000 km.

The energy-related emissions associated with the actual driving of the car consists of the environmental impact caused during production and distribution of the of the electricity used.

Electricity production is modelled according to three cases: regional (global and Europe) grid mixes and a

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[8] *https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202302/t20230207_1015569.html*

specific energy source (wind). Current and future global and European electricity generation mixes are based on the World Energy Outlook 2022 Extended Dataset[9] from the International Energy Agency (IEA). Amounts of electricity from different energy sources have been paired with appropriate LCI datasets from Ecoinvent (see Appendix 3) to determine the total impacts from different electricity generation mixes, both direct (at the site of electricity generation) and upstream. It has been assumed that 50 per cent of the lifetime milage of the vehicle is driven in the first five years (i.e. 20,000 km per year in the first five years), and 30 per cent during the subsequent five years (i.e. 12,000 km per year). During the last five years of the car's life, it is assumed that the annual milage is 8,000 km, as illustrated in Figure 7.

By accounting for the changes in electricity production (i.e. reduction in fossil electricity and increase of renewable electricity from 2024), the emissions per year are expected decrease. The distances driven are multiplied with the specific emissions factor for the same year for the global and European electricity changes, which results in the chart in Figure 17.

IEA uses the Global Energy and Climate (GEC) Model to explore possible future energy related scenarios based on different assumptions. For this study, the Stated Policies Scenario STEPS has been used to determine the electricity generation mixes used to charge the vehicles in the use phase. STEPS reflects current policy settings based on a sector-by-sector and country-by-country assessment of the specific policies that are in place, as well as those that have been announced by governments around the world. Two other IEA scenarios have been explored in a sensitivity analysis.

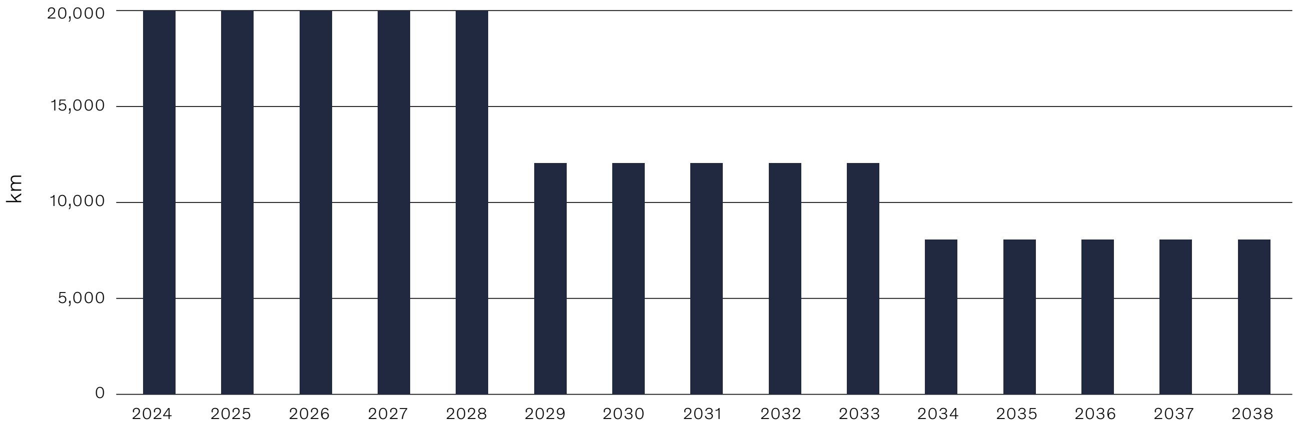

Figure 7 *Assumed driving distances per year during the lifetime.*

In Figure 8 and Figure 9, the presented development in electricity sources has been visualised. It shows that electricity generated from fossil sources will decline and electricity from renewable sources will take its place according to the IEA STEPS data.

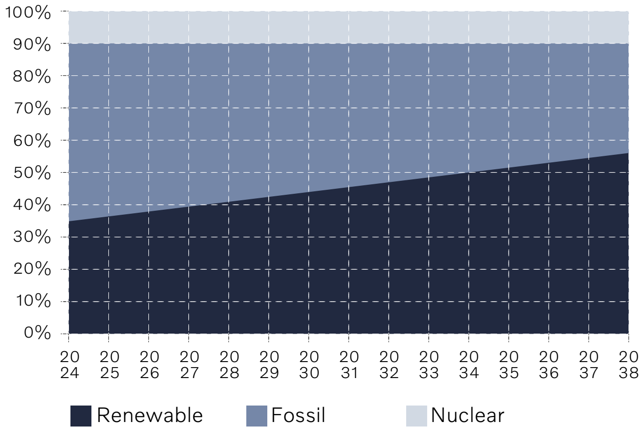

Figure 8 *Stated electricity mix development aggregated in three categories for Global mix.*

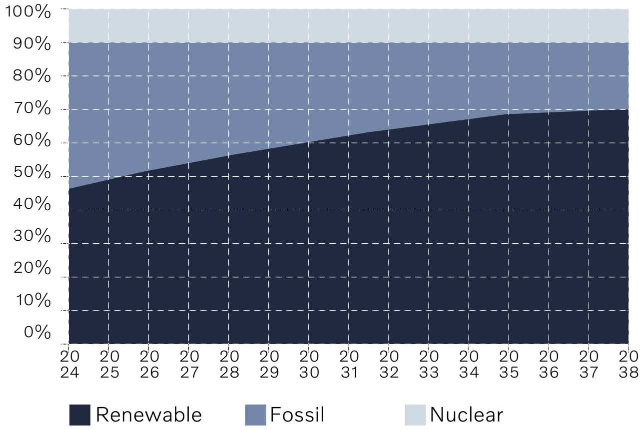

Figure 9 *Stated electricity mix development aggregated in three categories for European mix.*

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[9] *https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2022-extended-dataset*

The well-to-wheel (WTW) emission data for the EX30 electricity consumption figures for the two compositions are based on the WLTP driving cycle (Worldwide Harmonized Light Vehicle Test Procedure used for certification of vehicles in EU). Losses during charging are included in the electricity use of the BEV. The electricity use of the vehicles is shown in Table 4.

Table 4 *Energy use in the use phase.*

Battery type	For motor	Electricity use kWh/ 100 km	Vehicle unladen mass
P6 RWD NMC 69 kWh	Single motor extended range	17.5	1,775
P4 RWD LFP 51 kWh	Single motor	17.1	1,765

5.10.2 Maintenance

During the 15-year lifespan of the car, it is assumed that some vehicle parts are required to be replaced. The data for maintenance of the car is based on maintenance figures associated with the EX90, which was chosen due to the accessibility of its LCA study. The maintenance list is presented in Table 32 in Appendix 6. It is assumed that the number of items represents groups of items. For example, one wiper blade represents the complete set of the three wiper blades (i.e. two front and one rear). The car tyres are all year tyres and are designed to last 40,000 km in the EU. It is assumed that the tyres are not changed just before end-of-life, therefore 16 tyres need to be changed during the lifetime. For each part, the corresponding item is found in the BoM and specific material data is used.

The same mapping list as for the entire car has been used when importing the BoM to LCA for Experts. The same end-of-life treatments as for the entire car have been used. Four parts from the list did not appear in the BoM, including brake pads, steering joint, link arm, and cabin filter. The material compositions of these components have been found in the EX90, for which a corresponding LCA is being carried out and the easy accessibility of the information from this study. The difference in weight of the cabin filters have been scaled based on the difference in volume between the cars. For the other three components they have been reduced to 80 per cent of the weight, compared to the EX90. This reduction is due to the EX30 weighing about 40 per cent less than the EX90. We also assume that difference in mass is seen in other parts than the link arm, brake pads and steering joint. The data on cabin filters from IMDS suggests that 73 per cent of the composition is made up of undefined materials. It is assumed that one third of the unidentified materials could respectively be modelled as filled polypropylene (PP), polyamide (PA), and polyethylene (PE).

Due to development in the brake discs' performance, they do not need to be replaced within the lifetime milage of 200,000 km.

5.11 End-of-life of the vehicle

5.11.1 Process description

It is assumed that all vehicles, at their end-of-life, are collected and sent to end-of-life treatment.

The same allocation methodology as described in Section 4.5 – Allocation is applied. The "polluter pays principle" implies that several steps are included within the process, like dismantling and pre-treatment (including shredding and specific component pre-treatment). However, it does not include material separation, refining, or any credit for reuse in another product system.

The end-of-life was modelled to represent global average situations as far as possible. The handling consists of a disassembly step to remove hazardous components and components that are candidates for specific recycling efforts. After this the disassembled parts are treated, and the remaining vehicle is shredded. According to material type the resulting fractions go either to material recycling, incineration, or landfill. Figure 10 gives an overview of the entire stage.

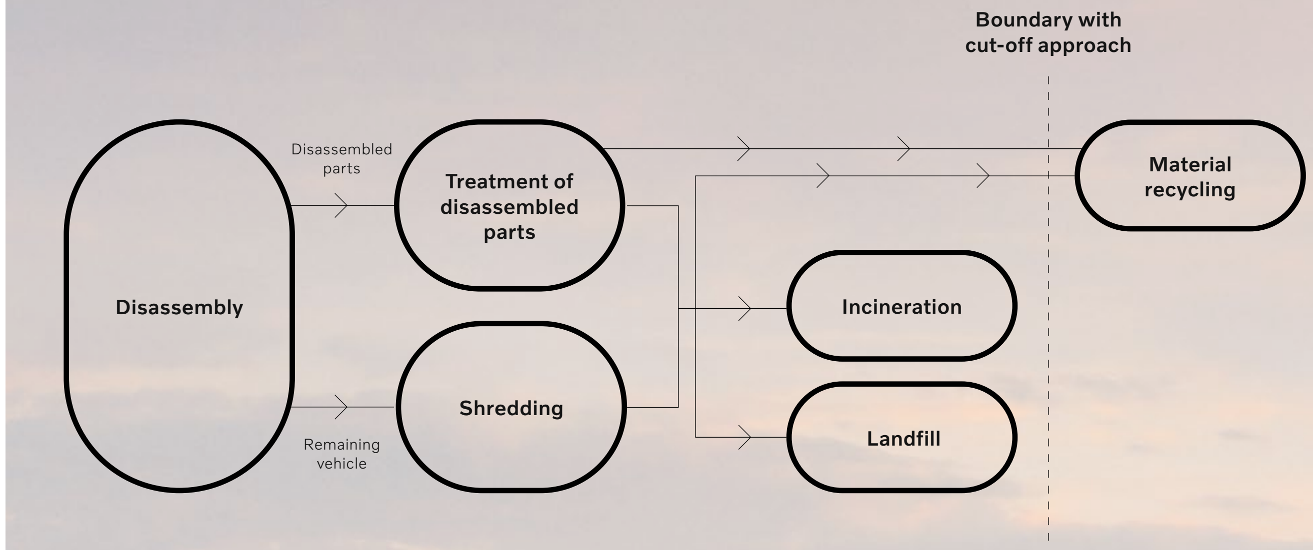


Figure 10 *End-of-life system boundaries.*

In the disassembly stage, hazardous and/or valuable components are removed from the vehicle including:

- Batteries, wheels, tyres
- Liquids: coolants, antifreeze, brake fluid, air-conditioning gas, shock absorber fluid and windscreen wash
- Oils: transmission and hydraulic oils
- Oil filters
- Airbags and seat belt pretensioners removed or set off

From a global perspective, the treatment of oils and coolant generally implies incineration. The tyres are assumed to be salvaged for rubber recovery, with potentially 55 per cent of the tyre being recycled. In the case of lead batteries, it has also been assumed that they can be sent for lead recovery. Oil filters are assumed to be incinerated, as are airbags and seat belt pretensioners, which are disassembled for safety reasons rather than their potential recycling value. The Li-ion battery is assumed to be taken out of the car and sent to recycling, given that the batteries contain valuable materials. The extraction and refinement of the materials are resource intensive and economically costly. Furthermore, legislation mandating recycling is likely to be put into effect, and it is assumed that the legislation will be more stringent at the end-of-life of the vehicle.

All other parts of the vehicle are sent to shredding. In this process, the materials in the vehicle are shredded and then divided into fractions, depending on different physical and magnetic properties. The electricity requirements of the shredding are modelled with a global grid mix plan. Typical fractions are:

- Ferrous metals (steel, cast iron, stainless steel, etc.)
- Non-ferrous metals (aluminium, copper, etc.)
- Shredder light fraction (plastics, ceramics, etc.)

The metal fractions can be sent for further refining and, in the end, material recycling. The combustible part of the light fraction can be incinerated for energy, or the entire fraction can end up in a landfill. For the purposes of this study, it is assumed the combustible streams of materials are incinerated, while the non-combustible materials are landfilled. In Figure 11 the different shares of end-of-life treatments per mass is presented. Most of the materials in the vehicle (81 per cent) is assumed to be recycled in the context of global averages.

Due to the global focus of the study, no energy recovery is included for the incineration steps, even though in some VCC markets, there is indeed energy recovery from incineration of waste. This somewhat conservative assumption has been made due to there being many markets with no energy recovery, and data on how common energy recovery is for combustible streams is unknown. Assessment of material losses after shredding and in refining are outside the system boundaries set by the cut-off approach. Further methodological choices and assumptions are presented in Appendix 5.

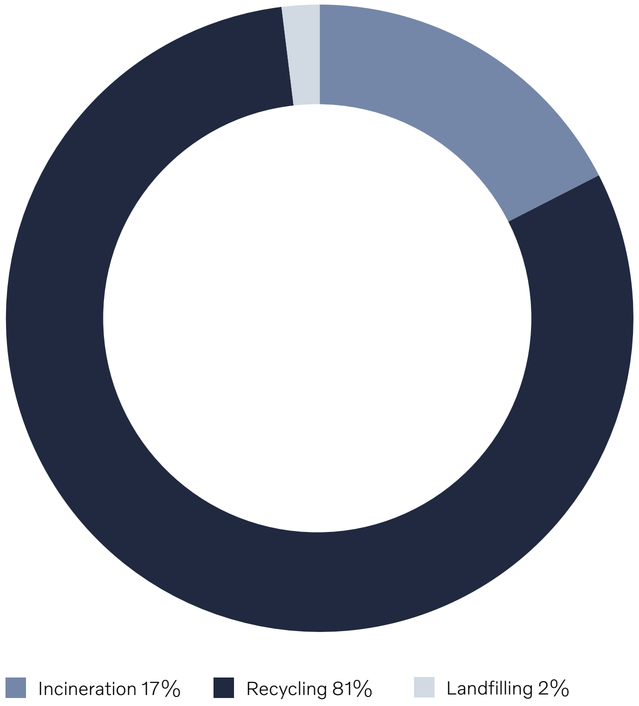


Figure 11 *Percentage of mass of vehicle sent to different End-of-life treatments.*

6. Impact assessment

For the impact assessment phase, where the inventory data is interpreted in terms of potential environmental impacts, the characterisation factors used in this assessment can be found in Appendix 7. The results are based on available data at the time of study. The results are considered to be representative until 15 years after publication (i.e. until 2038).

7. Results

In the following section the result of the study is presented. In adherence to ISO standards, the quantification results in this report have been rounded to two significant digits, a practice aimed at enhancing clarity and consistency in report. The rounding of the digits is used as to increase the readability of the report as well as acknowledging the inherent uncertainties in the results.

7.1 LCIA results

The results of the life cycle assessment for one vehicle driving 1 km, with two different batteries and three different electricity mixes are shown in Figure 12. The results indicate that global electricity mix scenarios present the greatest impact with 0.18 kg CO_2-eq/vkm for the vehicle with the NMC 69 kWh battery and 0.16 kg CO_2-eq/vkm for LFP 51 kWh battery, during the entire life cycle. The result shows that the use phase is the life cycle phase with the highest impact in the global electricity mix scenario. The use phase includes the energy consumption during the lifetime of the vehicle (15 years) and the distance (200,000 km). The materials production and refining phase has the second largest impact in the global electricity mix scenario and the greatest impact on a vehicle's life cycle for the European and wind power electricity mixes. The impact from the materials production and refining phase amounts to 0.050 kg CO_2-eq/vkm for both models; this stage includes all the resources and energy needed to extract, refine, and manufacture raw materials and components necessary for automobile production. The production of batteries has the second and third largest impacts respectively, with 0.039 kg CO_2-eq/vkm for NMC 69 kwh battery and 0.018 kg CO_2-eq/vkm for LFP 51 kWh battery. The other life cycle phases, such as production, logistics and end-of-life, each have a marginal impact.

In Figure 12, GHG emissions are shown for three different scenarios with distinct types of electricity sources (global mix of production, European mix of production, and wind power production). With European mix electricity, 23 per cent of GHG emissions are reduced, and 39 per cent if electricity from wind power sources is used during use phase, compared with global mix electricity for the car with a 69-kWh battery. In the case of 51 kWh battery vehicle, the decrease in emissions is about 25 per cent and 44 per cent for the use of European electricity and wind respectively, relative to the global mix electricity. In total, the impact of the NMC model with global electricity amount to 0.18 kg CO_2-eq /vkm for the entire life cycle and the LFP model account for 0.16 kg CO_2-eq/vkm.

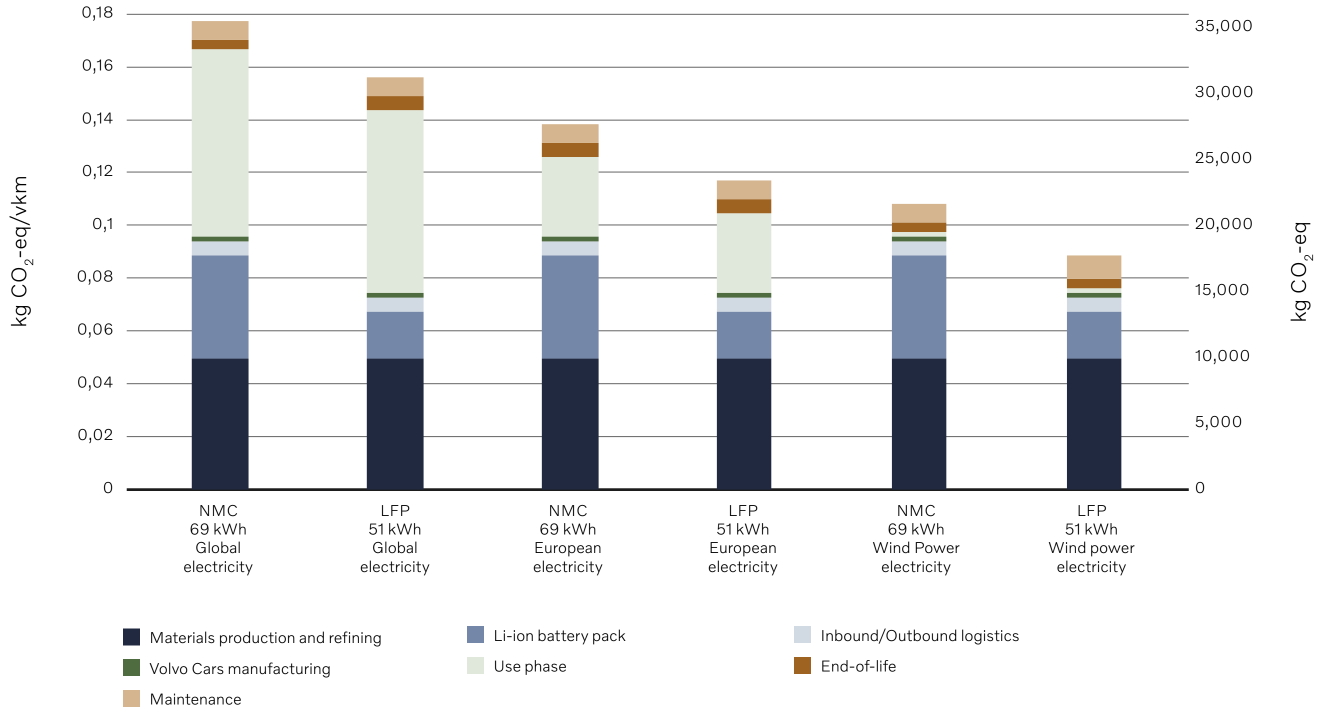
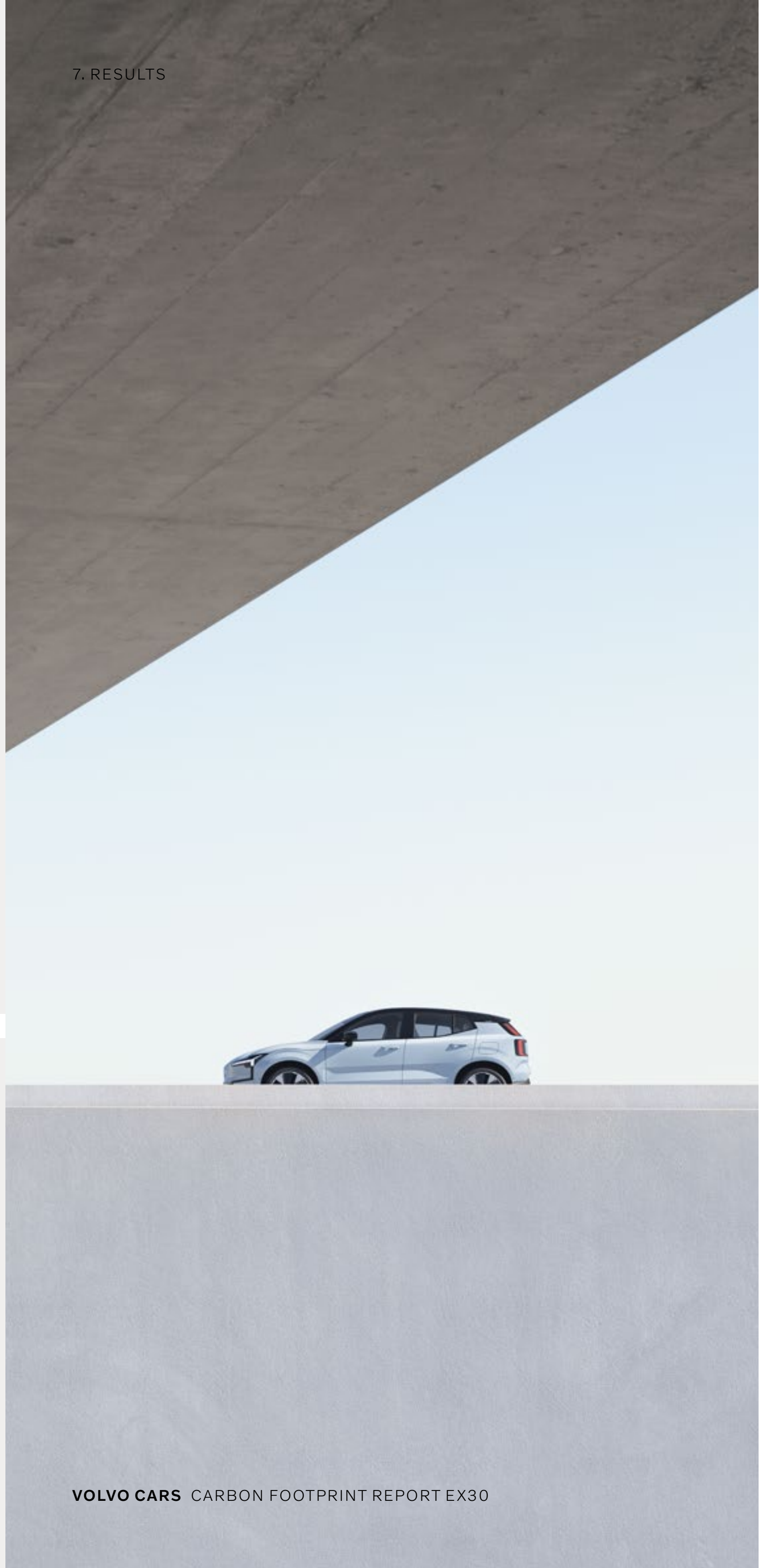


Figure 12 *Total climate footprint per vehicle-km and per total lifetime mileage, in kg CO_2-eq.*

The same result is presented in Table 5 for both vehicle-km and for 200,000 km, lifetime milage. The impact is presented in kg CO_2-eq and tonnes CO_2-eq respectively.

Table 5 *Total impact in CO_2-eq for the entire life cycle of the vehicles.*

		Materials production and refining	Li-ion battery pack	Inbound/ Outbound logistics	Volvo Cars manufacturing	Use phase	End-of-life	Maintenance	Total
NMC 69 kWh Global electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	14	0.89	1.5	36
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.072	0.0044	0.0073	0.18
LFP 51 kWh Global electricity	Tonnes CO_2 for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	14	0.89	1.5	31
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.070	0.0044	0.0073	0.16
NMC 69 kWh European electricity	Tonnes CO_2 for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	6.4	0.89	1.5	28
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.032	0.0044	0.0073	0.14
LFP 51 kWh European electricity	Tonnes CO_2 for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	6.2	0.89	1.5	23
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.031	0.0044	0.0073	0.12
NMC 69 kWh Wind power electricity	Tonnes CO_2 for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	0.48	0.89	1.5	22
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.0024	0.0044	0.0073	0.11
LFP 51 kWh Wind power electricity	Tonnes CO_2 for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	0.47	0.89	1.5	18
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.0024	0.0044	0.0073	0.088



In Figure 13, the impact per life cycle phase is presented for the different vehicles with a global electricity mix used during the use phase. Differences can be seen in the use phase and in the impact related to the batteries. The largest difference in impact between the models is seen in the batteries, where the difference is 54 per cent, with the 51 kWh battery model having the lowest impact.

The difference between the use phase emissions is < 2 per cent and at the threshold of statistical significance.

For the vehicle with the NMC battery, the impact during the entire life cycle is 13 per cent greater than the LPF model. In addition, the LFP model has a 2 per cent lower impact during the use phase.

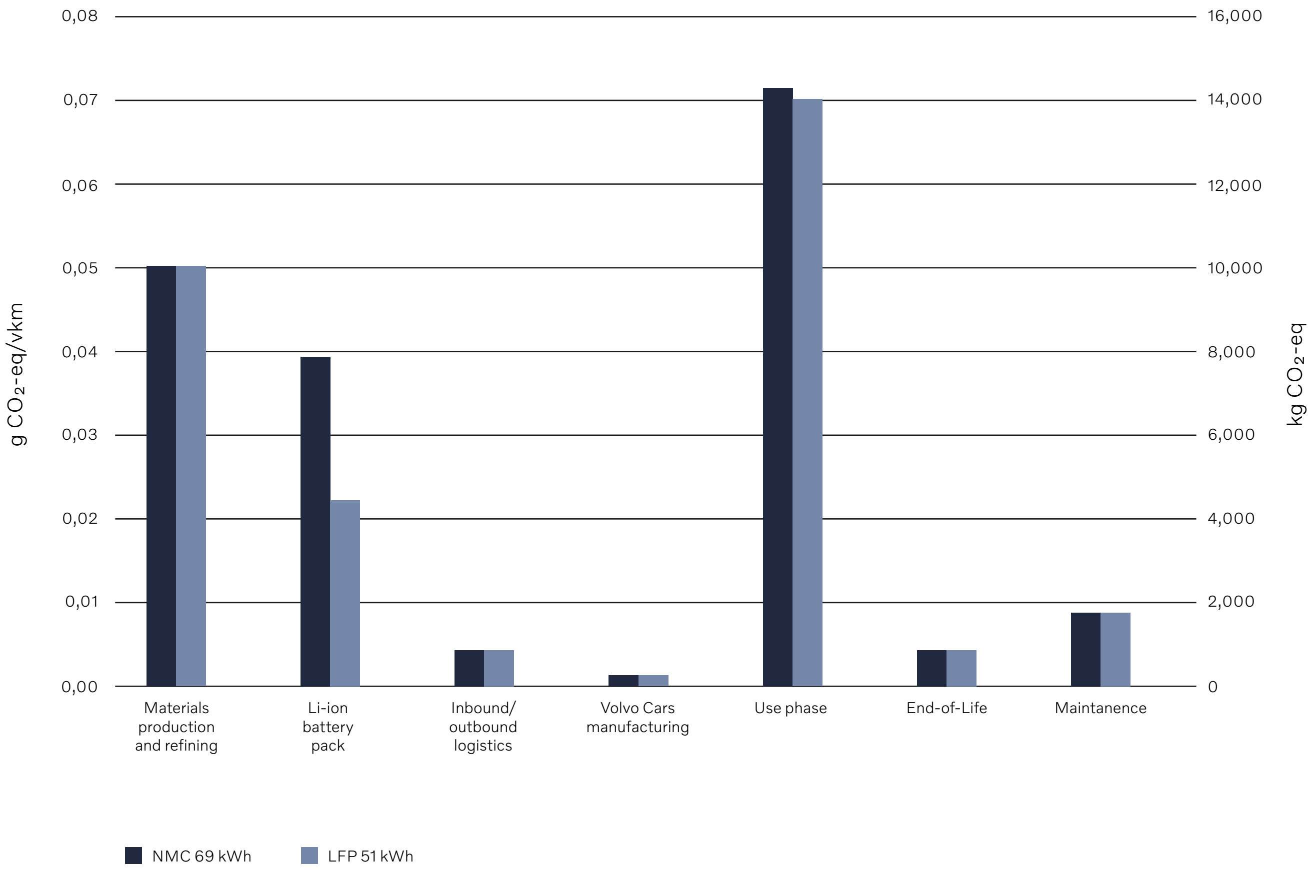


Figure 13 *Impact per life cycle phase, per vehicle-km and per total lifetime mileage, in kg* CO_2*-eq.*

7.1.1 Climate impact

The study includes five climate change impact categories shown in Figure 14, including fossil GHG emissions, emissions from land use change, biogenic GHG emissions and removal, and aircraft emissions. The most impacts, excluding removals (96 per cent), is found in the fossil impact category. The biogenic emissions make up 3.6 per cent. That fossil GHG emissions have the greatest impact on the environment and the other categories have the least impact, this could be due to there not being as many biobased materials in cars. The other impact categories have an impact that is less than 1 per cent. Figure 14 shows the impact of the vehicle with the NMC battery with global electricity during the use phase. Because few materials in the vehicle consist of bio-based materials, the impact from biogenic emissions is low. Henceforth the sum of the climate change impact will be presented and referred to as climate change impact.

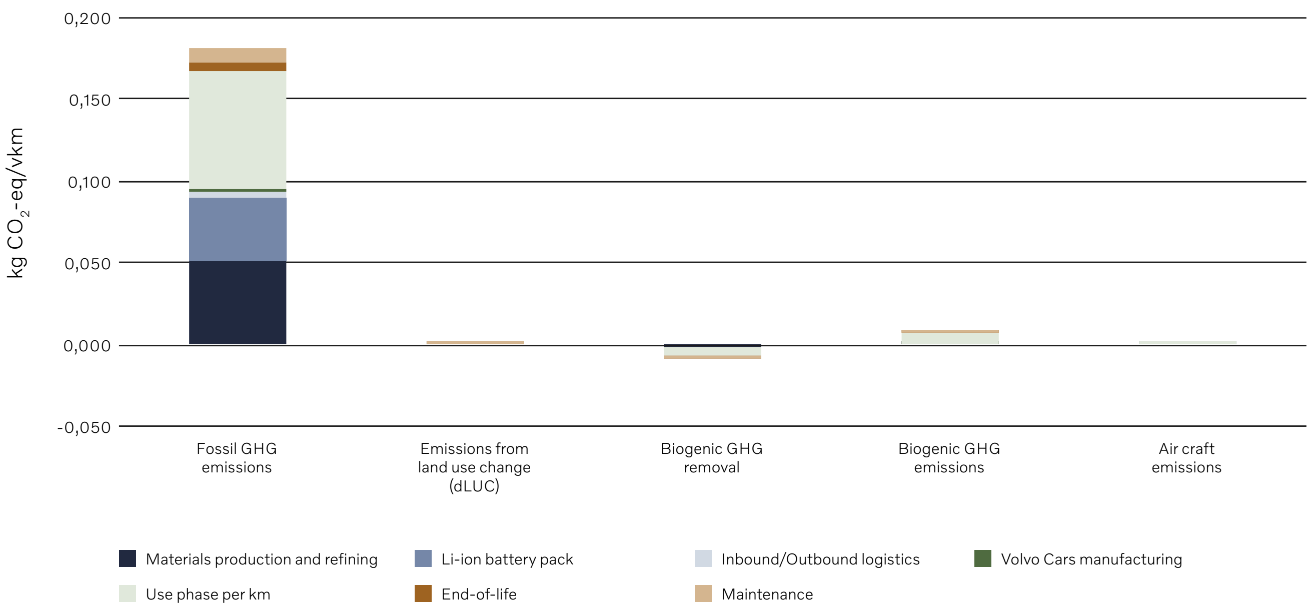


Figure 14 *Absolute emissions per impact category.*

Table 6 *Results for the five impacts categories according to ISO 14067.*

	Materials production and refining	**Li-ion battery pack**	**Inbound/ Outbound logistics**	**Volvo Cars manufacturing**	**Use phase**	**End-of-life**	**Maintanence**
Fossil GHG emissions	5.0E-02	3.9E-02	4.2E-03	1.4E-03	7.2E-02	4.5E-03	7.6E-03
Emissions from land use change (dLUC)	2.1E-04			7.59E-08	2.7E-06	4.2E-06	7.4E-04
Biogenic GHG removal	-1.4E-03			-3.1E-06	-5.5E-03	-5.0E-05	-1.3E-03
Biogenic GHG emissions	9.9E-04			3.7E-05	5.5E-03	4.4E-05	2.1E-04
Aircraft emissions	1.2E-07		6.0E-05	4.4E-08	7.9E-08	2.9E-10	9.3E-09

In the biogenic and fossil impact categories, the use phase has the greatest impact, with the bioenergy electricity source contributing most to the impacts. In the land use change category, the highest impact is related to maintenance, which in turn is related to the changing of tyres and more specifically to the natural rubber included. Most of the aircraft emissions are related to the inbound and outbound logistics. Material production and refining and use phase contribute the most to the fossil GHG emissions. In Figure 15 the relative impacts in all impact categories are presented for the NMC 69 kWh battery with a global electricity mix during use. The figure shows the shares of impact in each impact category but does not show the relationship between the impact categories, as presented in Figure 14.

7.1.2 Materials production and refining

Figure 16 shows the results of global warming potential for fossil emissions for the different materials and the battery pack for the NMC battery. Note that the battery pack contains not only cell modules but also a tray/carrier, a battery management system, a thermal management system, a switch box, busbars, thermal barriers, and a lid. The main contribution to GHG emissions come from steel, iron, and aluminium with more than 50 per cent of the impact. The third largest impact is related to the polymers used in the vehicles with 18 per cent of the impact followed by electronics and fluids and other minor categories as copper, other metals tyres, glass, and natural materials.

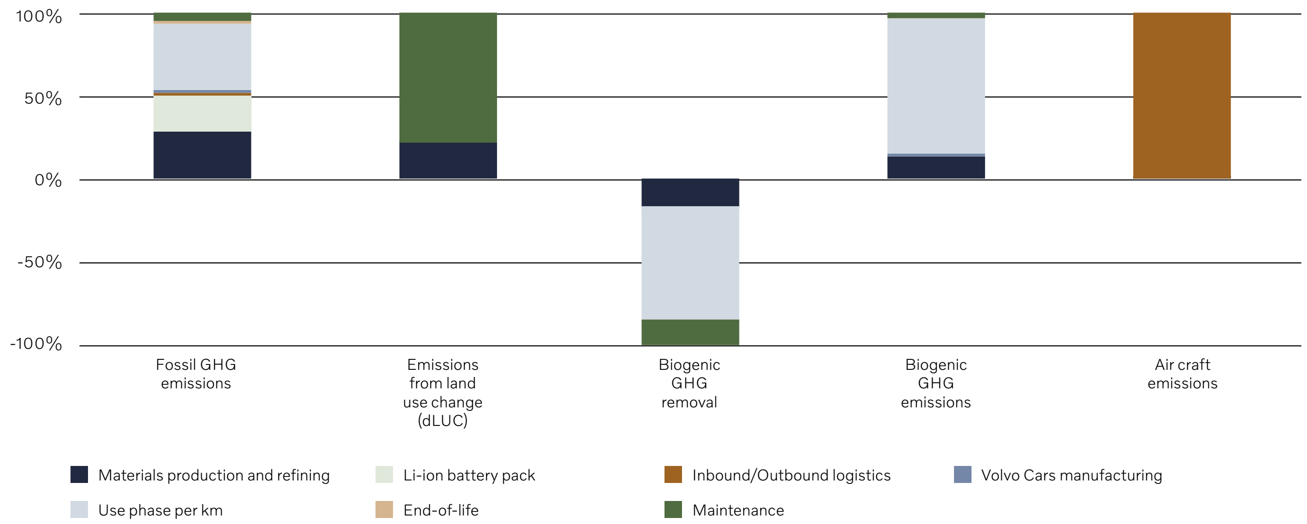


Figure 15 *Relative share of total emissions per impact category.*

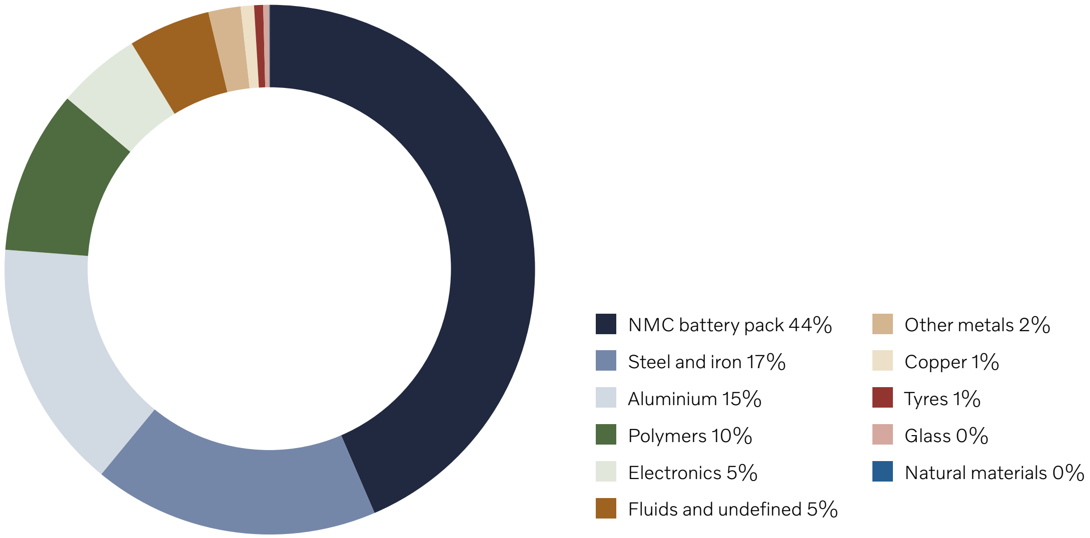


Figure 16 *Relative impact from all material categories.*

Table 7 *GWP 100 results in kg CO_2 eq for different materials categories in one vehicle.*

	NMC battery pack	Steel and Iron	Aluminium	Polymers	Electronics	Fluids and undefined	Other metals	Copper	Tyres	Glass	Natural materials
Tonnes CO_2-eq for the entire lifetime (200,000 km)	7.8	3.1	2.7	1.8	0.91	0.89	0.35	0.14	0.01	0.06	0.005
kg CO_2-eq per vehicle-km	0.04	0.01	0.014	0.001	0.004	0.004	0.0018	0.0007	0.0005	0.0003	0.00003

7.1.3 Use phase

The use phase of the vehicle has the highest emissions over its entire life cycle. The use phase includes the vehicle's lifetime usage and the electricity consumed during this time. The impact in this category depends on the source of the electricity production, where wind power is the electricity source that has the least impact during the use phase followed by the European mix production, showed in Figure 17.

Based on the change in electricity mix from 2024 to 2038, the resulting average carbon footprint in the use phase is 0.41 kg CO_2-eq/kWh for the global electricity mix and 0.18 kg CO_2-eq/kWh for the European electricity mix.

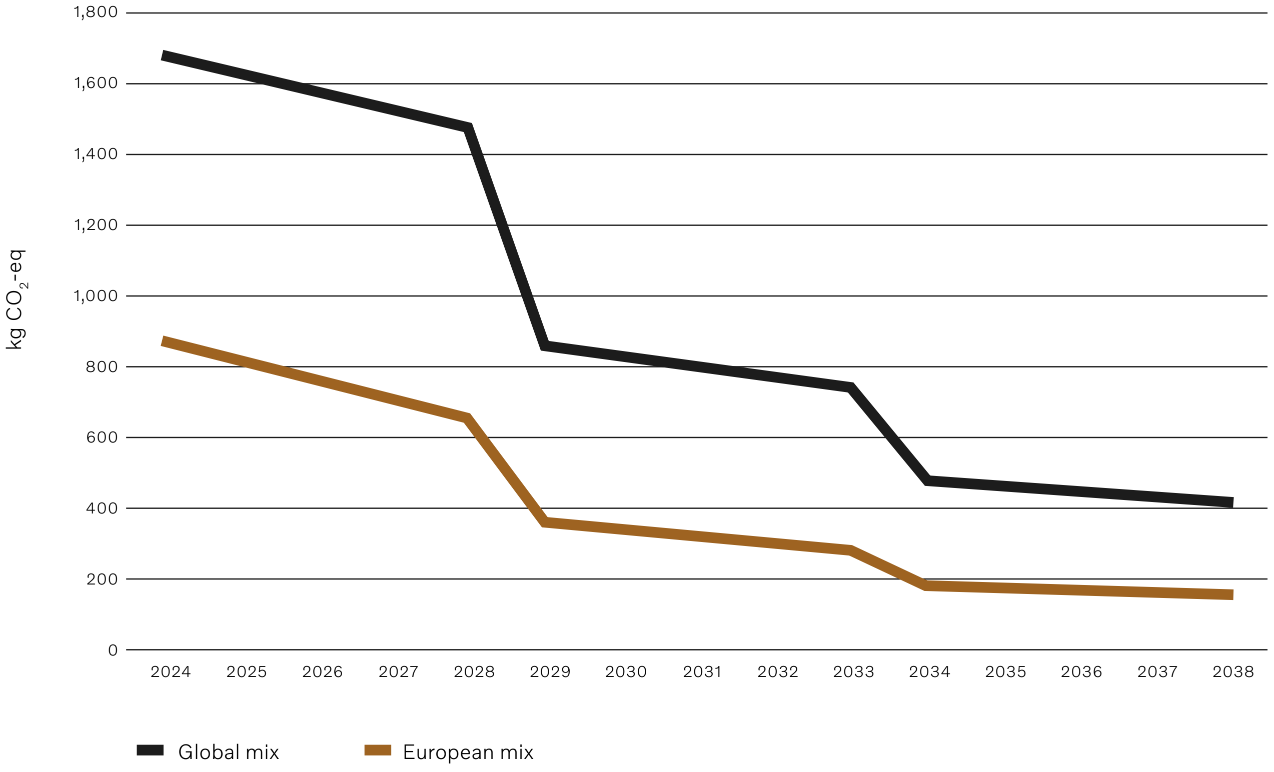


Figure 17 *Carbon dioxide equivalents emissions per year during the lifetime of the vehicle with NMC battery for different electricity mixes.*

7.2 Sensitivity analysis

Considering that most of the data in this study is conservative, it has been interesting to investigate how more probable data would affect the results. A sensitivity analysis was conducted on different aspects, including the lifetime mileage, battery improvements, electricity source during use phase, and the number of passengers.

7.2.1 Development of electricity generation mixes

As it is uncertain how electricity mixes will evolve over time, a sensitivity analysis examines how two additional IEA scenarios to the STEPS scenario affect the carbon footprint. All three scenarios are descripted in Table 8.

In Figure 18, Figure 19, and Figure 20 the NZE and APS scenarios for global and European electricity mix development is visualised. IEA only provides NZE scenarios for the global electricity mix development.

Table 8 *Definitions and objectives of the GEC Model 2022 scenarios*[10]

	Stated Policies Scenario (STEPS)	**Announced Pledges Scenario (APS)**	**Net Zero Emissions by 2050 Scenario (NZE)**
Definitions	A scenario which reflects current policy settings based on a sector-by-sector and country-by-country assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.	A scenario which assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met in full and on time.	A scenario which sets out a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. It does not rely on emissions reductions from outside the energy sector to achieve its goals. Universal access to electricity and clean cooking are achieved by 2030.
Objectives	To provide a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy.	To show how close do current pledges get the world towards the target of limiting global warming to 1.5 °C, it highlights the "ambition gap" that needs to be closed to achieve the goals agreed at Paris in 2015. It also shows the gap between current targets and achieving universal energy access.	To show what is needed across the main sectors by various actors, and by when, for the world to achieve net zero energy related and industrial process CO_2 emissions by 2050 while meeting other energy-related sustainable development goals such as universal energy access.

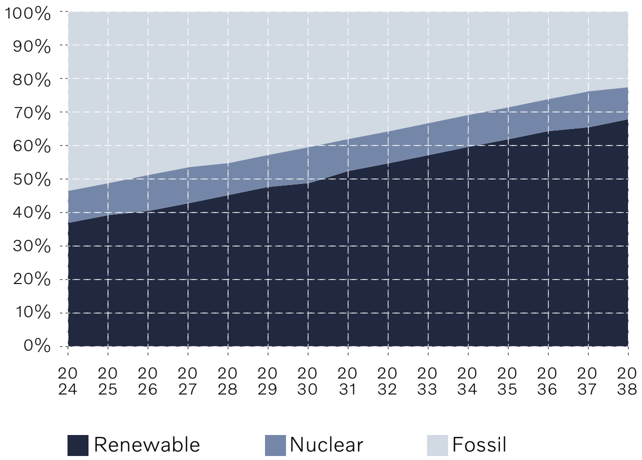


Figure 18 *Changes in global electricity mixes according to APS.*

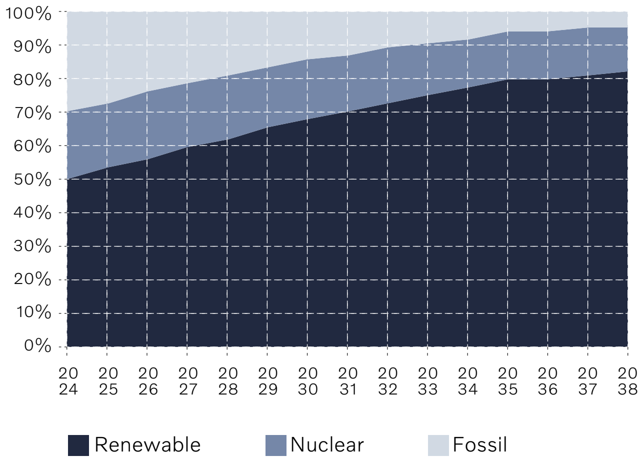


Figure 19 *Changes in European electricity mix according to APS.*

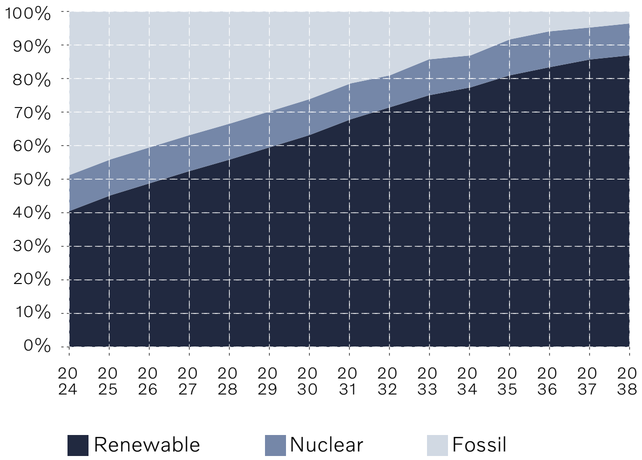


Figure 20 *Changes in global electricity mixes according to NZE.*

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[10] *IEA (2022), Global Energy and Climate Model, IEA, Paris https://www.iea.org/reports/global-energy-and-climate-model License: CC BY 4.0 Table 1.1. Definitions and objectives of the GEC Model 2022 scenarios.*

The impact during the use phase depending on the previously mentioned scenarios and STEPS as a baseline are visualised in Figure 21.

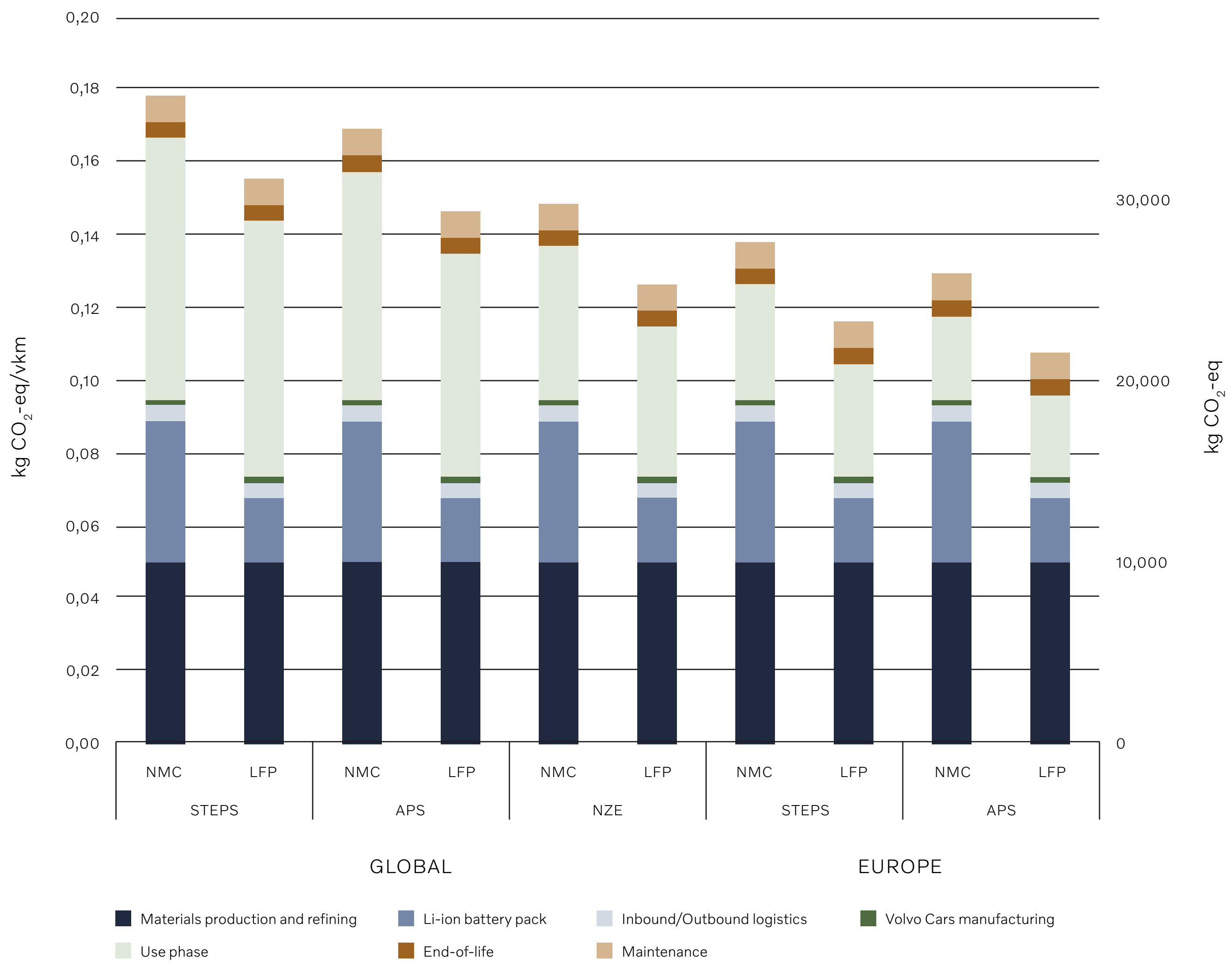

Figure 21 *Effects of changing use phase electricity to NZE and APS on the entire life cycle per km.*

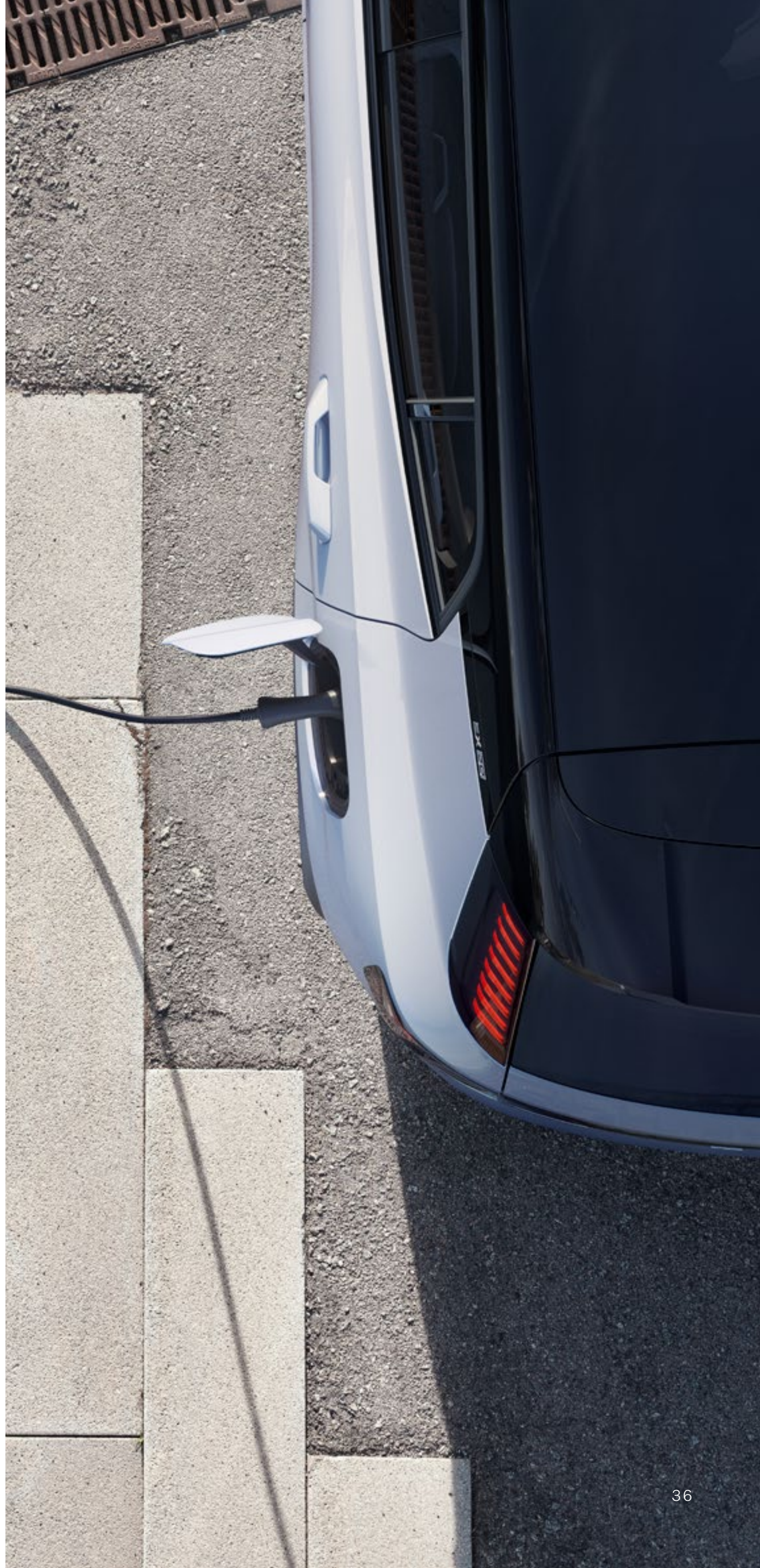

Table 9 *Emissions per functional unit: vehicle-km and for 200,000 km for different electricity scenarios: STEPS, APS and NZE for two battery models.*

		Materials production and refining	Li-ion battery pack	Inbound/ Outbound logistics	Volvo Cars manufacturing	Use phase	End-of-life	Maintenance
NMC 69 kWh Global electricity STEPS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	14	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.072	0.0044	0.0073
LFP 51 kWh Global electricity STEPS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	14	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.070	0.0044	0.0073
NMC 69 kWh Global electricity APS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	13	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.063	0.0044	0.0073
LFP 51 kWh Global electricity APS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	12	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.061	0.0044	0.0073
NMC 69 kWh Global electricity NZE	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	8.5	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.042	0.0044	0.0073
LFP 51 kWh Global electricity NZE	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	8.3	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.041	0.0044	0.0073
NMC 69 kWh European electricity STEPS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	6.4	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.032	0.0044	0.0073
LFP 51 kWh European electricity STEPS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	6.2	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.031	0.0044	0.0073
NMC 69 kWh European electricity APS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	7.8	0.86	0.29	4.6	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.039	0.0043	0.0015	0.023	0.0044	0.0073
LFP 51 kWh European electricity APS	Tonnes CO_2-eq for the entire lifetime (200,000 km)	10	3.5	0.86	0.29	4.5	0.89	1.5
	kg CO_2-eq per vehicle-km	0.050	0.018	0.0043	0.0015	0.023	0.0044	0.0073

The results show that for the global electricity mix, the STEPS scenario has the greatest impact during the life cycle for both vehicles.

The lifetime impact for the NMC battery vehicle is always larger than the LFP variant. Its impact during the use phase is marginally higher for the NMC battery vehicle as illustrated Figure 22.

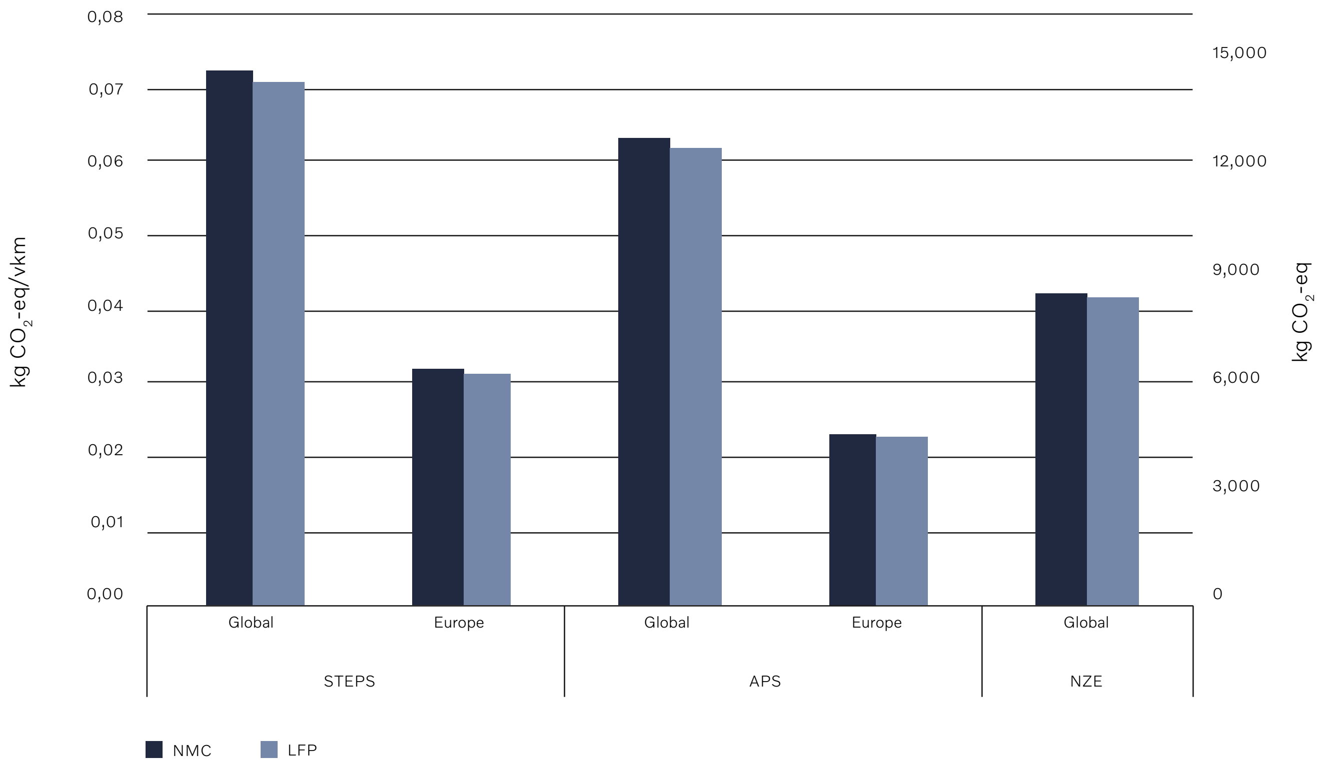

Figure 22 *Effects of changing use phase electricity to NZE and APS for the use phase.*

Table 10 *Use phase emissions per functional unit: vehicle-km for different electricity scenarios: STEPS, APS and NZE for two battery models.*

	Emission during use per vehicle-km [kg CO_2-eq]
NMC 69 kWh Global electricity mix STEPS	0.072
LFP 51 kWh Global electricity mix STEPS	0.070
NMC 69 kWh Global electricity mix APS	0.063
LFP 51 kWh Global electricity mix APS	0.061
NMC 69 kWh Global electricity mix NZE	0.042
LFP 51 kWh Global electricity mix NZE	0.041
NMC 69 kWh European electricity mix STEPS	0.032
LFP 51 kWh European electricity mix STEPS	0.031
NMC 69 kWh European electricity mix APS	0.023
LFP 51 kWh European electricity mix APS	0.023

7.2.2 Lifespan milage

The current study assumes a lifetime milage of 200,000 km, as that is a common distance to use in personal vehicle LCA studies. Larger personal vehicles as the one studied here can, however, be argued to have a longer lifetime milage[11]. For that reason, a sensitivity analysis with a 250,000 km and 300,000 km lifetime milage was carried out. To explore the effects of a shorter lifetime milage, a sensitivity analysis of 150,000 km was also carried out.

The vehicle parts required for maintenance for the different scenarios are presented in Table 32 in Appendix 6. The emissions per km during the use phase is naturally static for all lifetime distances.

In Figure 23 the changes in impact depending on lifetime milage is presented. The figure shows the NMC battery scenario with a European electricity mix during the use phase.

The analysis shows that as lifetime mileages increase, the total impact per vehicle-km decreases. Conversely, the relative impact from maintenance and use phase increases as the milage increases.

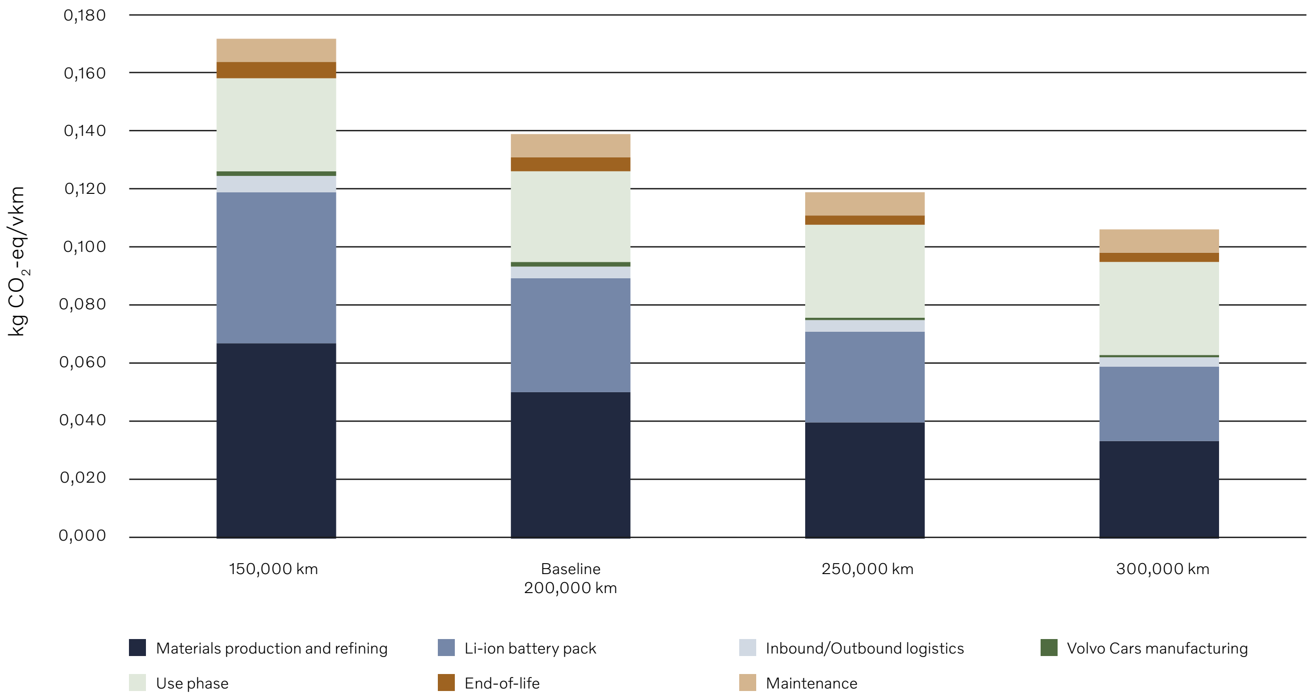

Figure 23 *Changes in impact related to lifetime milage changes for the NMC battery with European electricity.*

Table 11 *Results for lifetime mileages from 200,000 to 300,000 km per functional unit: vehicle-km, in kg* CO_2*-eq.*

	Materials production and refining	Li-ion battery pack	Inbound/ Outbound logistics	Volvo Cars manufacturing	Use phase	End-of-life	Maintanence	Total
150,000 km	0.067	0.052	0.0057	0.0020	0.032	0.0059	0.0078	0.17
Baseline 200,000 km	0.050	0.039	0.0043	0.0015	0.032	0.0044	0.0073	0.14
250,000 km	0.040	0.031	0.0034	0.0012	0.032	0.0036	0.0081	0.12
300,000 km	0.034	0.026	0.0029	0.0010	0.032	0.0030	0.0083	0.11

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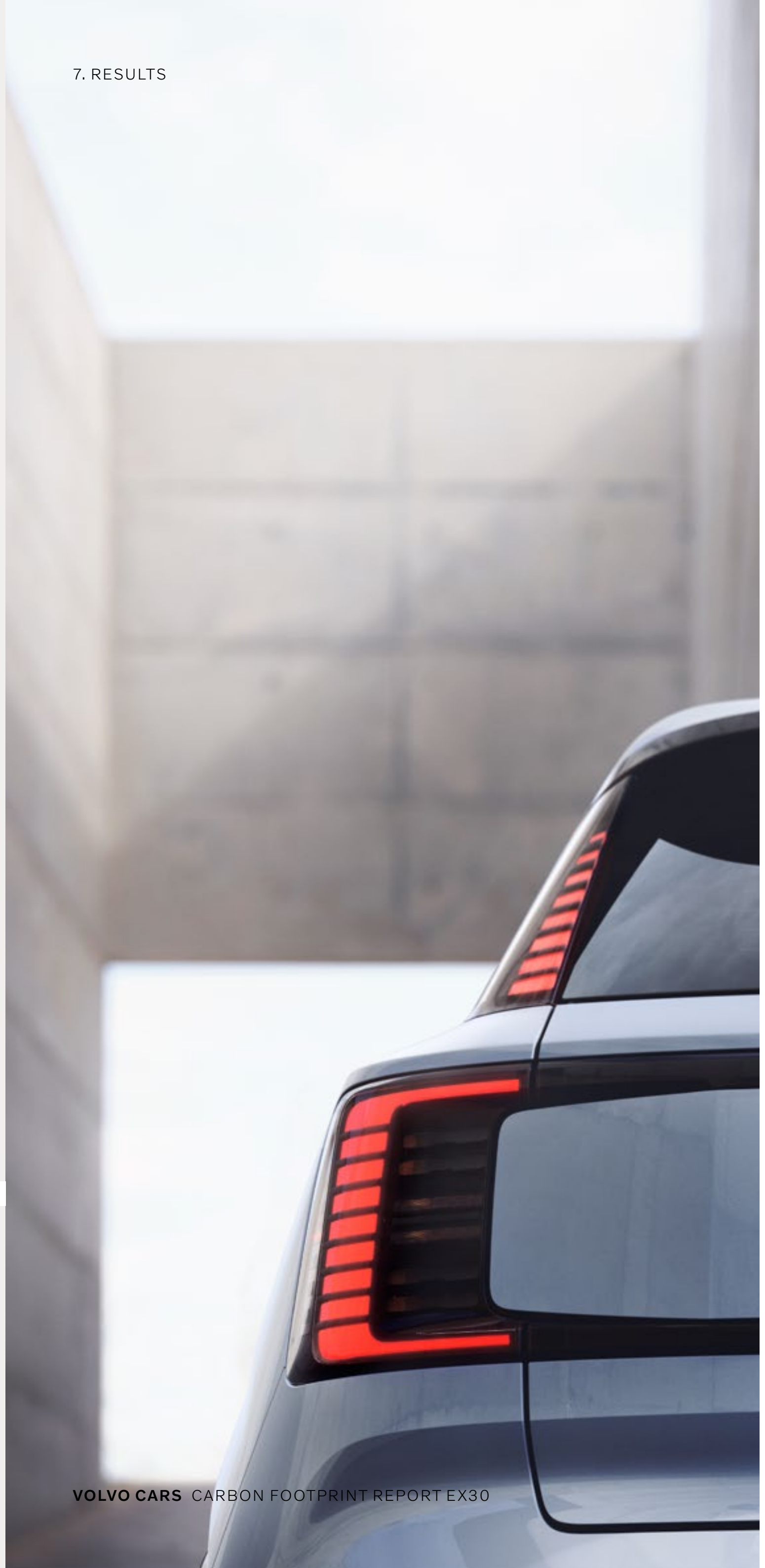
[11] *https://op.europa.eu/en/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1*



7.2.3 Energy use in the use phase

The energy use in the use phase is modelled based on the WLTP test as that is a global standard. WLTP does not, however, take all driving conditions into account. For example, it assumes a driving condition where heating or cooling is not necessary, and infotainment is not used. This could, especially for certain markets, lead to an underestimated energy use figure. For that reason, a sensitivity analysis with 20 per cent and 30 per cent increased energy use was carried out.

In Figure 24 the relative changes in impact per scenario are presented. The NMC battery model is generally more sensitive to changes in use phase emissions, as the WLTP energy consumption results are slightly higher for this model. When the emissions related to a specific electricity mix is high, the relative impact when increasing the energy use during the use phase is also increased. In other words, the increase in impact is higher for the global electricity mix than for the wind power electricity.

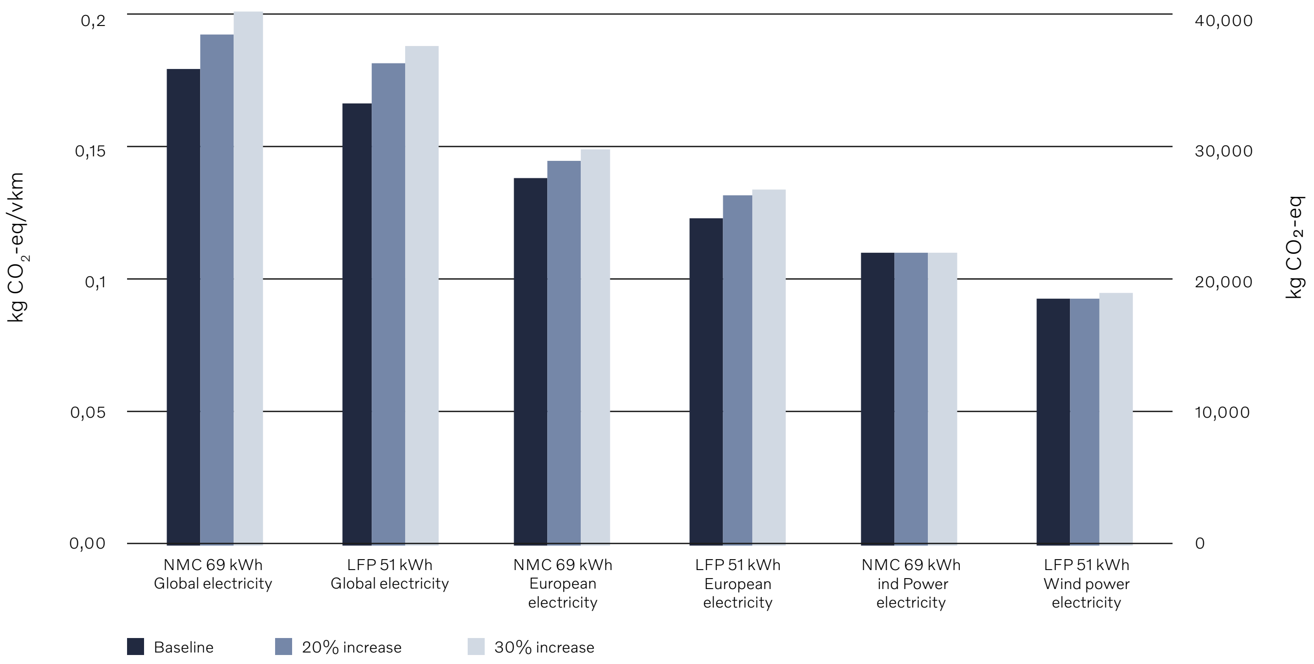


Figure 24 *Effects on the lifecycle impact when WLTP values increase by 20 per cent and 30 per cent.*

Table 12 *Increases in the lifecycle impact when WLTP increases.*

		Base case	**20% increase**	**30% increase**
NMC 69 kWh Global electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	36	39	40
	kg CO_2-eq per vehicle-km	0.18	0.19	0.20
LFP 51 kWh Global electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	31	34	35
	kg CO_2-eq per vehicle-km	0.16	0.17	0.18
NMC 69 kWh European electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	28	29	30
	kg CO_2-eq per vehicle-km	0.14	0.14	0.15
LFP 51 kWh European electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	23	25	25
	kg CO_2-eq per vehicle-km	0.12	0.12	0.13
NMC 69 kWh Wind power electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	22	22	22
	kg CO_2-eq per vehicle-km	0.11	0.11	0.11
LFP 51 kWh Wind power electricity	Tonnes CO_2-eq for the entire lifetime (200,000 km)	18	18	18
	kg CO_2-eq per vehicle-km	0.088	0.088	0.089

7.2.4 Number of passengers

The EX30 in this study is a five-seat vehicle. Depending on the number of passengers, the vehicle life cycle climate impact can be distributed among the vehicle occupants to obtain a person-km functional unit. Such a functional unit would be comparable with the person-km of other transport means. However, considering that the methodology used to assess the impact differs, such a comparison is only possible in theory in this case. Still, a sensitivity analysis exploring the implication of a passenger-km functional unit is interesting as it emphasises the relevance of occupancy. As the average use phase occupancy is unknown, the sensitivity analysis compares a lifetime constant occupancy of one to five persons. In Table 13 the climate change impact per km in kg CO_2-eq are presented for the five different scenarios. As seen previously, the global electricity mix has the greatest impact and wind power the least, with the NMC variant having a greater impact than the LFP variant. When the passenger amount is increasing the impact per person-km is decreased. Scenario entitled "1 passenger" represents one person in the vehicle and "5 passengers" represents one driver and four passengers.

Table 13 *Climate change impact per passenger km (kg CO_2-eq).*

	Unit	1 passenger	2 passengers	3 passengers	4 passengers	5 passengers
NMC 69 kWh Global electricity	Climate impact per vehicle km (kg CO_2e)	0.18	0.18	0.18	0.18	0.18
	Climate impact per passenger km (kg CO_2e)	0.18	0.089	0.060	0.045	0.036
LFP 51 kWh Global electricity	Climate impact per vehicle km (kg CO_2e)	0.16	0.16	0.16	0.16	0.16
	Climate impact per passenger km (kg CO_2e)	0.16	0.078	0.052	0.039	0.031
NMC 69 kWh European electricity	Climate impact per vehicle km (kg CO_2e)	0.14	0.14	0.14	0.14	0.14
	Climate impact per passenger km (kg CO_2e)	0.14	0.069	0.046	0.035	0.028
LFP 51 kWh European electricity	Climate impact per vehicle km (kg CO_2e)	0.12	0.12	0.12	0.12	0.12
	Climate impact per passenger km (kg CO_2e)	0.12	0.058	0.039	0.029	0.023
NMC 69 kWh Wind power electricity	Climate impact per vehicle km (kg CO_2e)	0.11	0.11	0.11	0.11	0.11
	Climate impact per passenger km (kg CO_2e)	0.11	0.055	0.036	0.027	0.022
LFP 51 kWh Wind power electricity	Climate impact per vehicle km (kg CO_2e)	0.088	0.088	0.088	0.088	0.088
	Climate impact per passenger km (kg CO_2e)	0.088	0.044	0.029	0.022	0.018

7.2.1 Battery

Figure 25 shows future scenarios for reduction of carbon dioxide emissions during the manufacturing of two batteries, NMC and LFP. Battery suppliers plan to reduce CO_2-eq emissions by 2025 by replacing 100 per cent of their electricity use with renewable electricity for the manufacturing of the cells, as well as increasing recycling content within their materials. Additionally, they plan to reduce supply chain emissions. The emissions reduction for 51 kWh battery until 2025 is around -20 per cent and for 69 kWh battery the reduction in emissions is around -46 per cent. These improvements are intended to apply to the specifications of these batteries, indicating the use of the same chemistry and materials.

When considering the entire life cycle of the vehicles, a 10 per cent and 2 per cent reduction can be seen for the global electricity mixes for the NMC and LFP battery models, respectively. For the European electricity mix, the NMC and LFP battery models see a reduction during the lifetime of 13 per cent and 3 per cent respectively from 2023 to 2025.

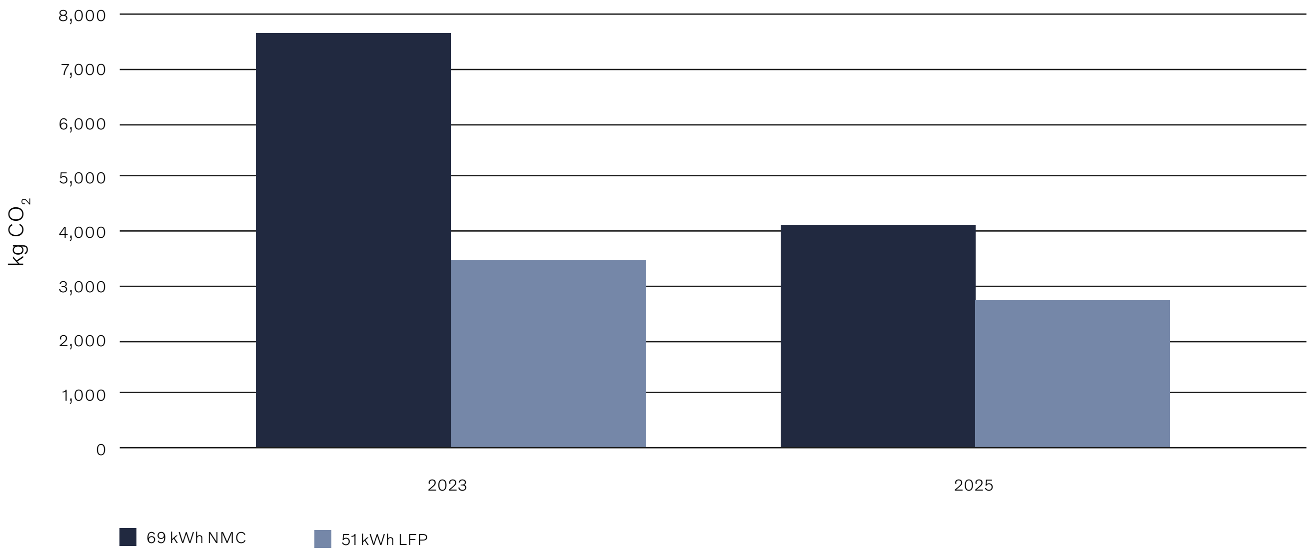


Figure 25 *Future battery manufacturing scenarios per battery unit.*

Table 14 *Batteries manufacturing kg CO_2 eq reduction until 2025.*

	2023	2025
NMC 69 kWh battery model [kg CO_2 eq]	7,800	4,200
LFP 51 kWh battery model [kg CO_2 eq]	3,500	2,800

8. Discussion

The results show that the two variants of the EX30 differ in impact. The disparities primarily stem from the type of battery used in each variant. The manufacturing of the NMC battery incurs a significantly greater environmental impact compared to the LFP variant.

The choice of battery technology and the type of electricity employed during the use phase play a pivotal role in determining the overall carbon footprint. Accounting for the entire life cycle, it becomes apparent that the LFP battery model stands out with the lowest overall impact. The differences in use phase impact becomes insignificant when examining the entire life cycle, and no “break even” point could be found inside the vehicles’ lifetime distances.

The development of battery technologies has been rapid throughout the past several years, with no indication of slowing down. The choices made when developing the battery for EX30 reflects the best knowledge and available technologies at that point in time, while future car models and upgrades will create additional possibilities based on various improvements. Some of these possible options could offer reduced or eliminated use of some high impact materials, such as Li-ion battery cells with cathodes based on solid (or semi-solid) state electrolyte. Additionally, transitioning the energy mix used in battery manufacturing towards renewable sources is another kind of improvement. Different types of battery cells and battery pack designs come with different combinations of strengths and weaknesses, and thus there may be a variety of batteries in different vehicles depending on their intended application and end user.

One key factor affecting the results is the composition of the electricity mix use during the use phase of the vehicle. The emissions associated with the use phase are highly sensitive to variations in electricity source. As seen in the analysis a European electricity mix has a lower impact than a global mix.

The IEA’s Global Energy and Climate (GEC) model offers scenarios of the future trajectory of the development in electricity mixes. The analysis based on the GEC model shows that the impact related to the use phase is anticipated to decrease progressively over time. Depending on which trajectory the electricity mix composition will take, the impact differs. The IEA’s Stated Policies Scenario (STEPS) offers the highest impact during the use phase. If a scenario with less impact would be true, less impact would be seen during the use phase of the vehicle.

It is important to note the potential disparities between the WLTP values used (which are from regulatory type-approval testing) and a possible real-world scenario where the energy consumption seen might be different. The sensitivity analysis showed that the baseline was submitted to a 7 per cent increase in impact during the lifetime if the energy consumption was 20 per cent higher than the official WLTP values, for the NMC variant with global electricity. Factors such as driving, other local conditions and maintenance can influence the emissions and electricity needed. However, the WLTP values provide a standardised benchmark of how impacts during the use phase can differ.

Regarding non-battery materials used, steel, iron, aluminium, polymers, and electronics are the materials that have the largest impacts on the manufacture of the vehicle, largely because of their significant weight share in the vehicle.

Approximately 55 per cent of the vehicle's weight is attributed to the metals aluminum, steel, and iron, while these materials contribute to 58 per cent of the overall climate change impact from the materials, without battery pack. This correlation between weight and impact emphasises the importance of minimising material usage to mitigate the climate change impact. A lower vehicle mass corresponds to reduced energy consumption, emphasising the strategy of material reduction as a key approach. This almost one-to-one ratio is not valid for all materials. For instance, for electronics the environmental impact amounts to 9 per cent of the total impact from the materials but makes up around 2 per cent of the weight. In this case, it becomes important to use the materials sparingly with great precision.

9. Conclussion

In this study, Life Cycle Assessment (LCA) methodology has been used, which is an established approach for assessing the environmental impact of products. The life cycle assessment method is ideal for assessing improvements throughout the life cycle and avoiding suboptimisation, for example reducing the environmental impact in one step while increasing it in another.

This life cycle assessment of the EX30 vehicle with two different battery models provides insight into the vehicle's carbon footprint as well as the underlying causes of emissions. These insights can be used to guide efforts into understanding and reducing emissions.

According to the methodology detailed in this report, the carbon footprint for the EX30 vehicle equipped with NMC and LFP batteries ranges from 0.11 to 0.18 kg CO_2-eq/vkm (22 to 36 tons of CO_2-eq per 200,000 km) and 0.088 to 0.16 kg CO_2-eq/vkm (18 to 31 tons of CO_2-eq per 200,000 km), respectively. On average the model with the LFP battery has a carbon footprint which is 16% lower than the model with the NMC battery. The variations in these results are attributable to the diverse electricity mixes with varying levels of carbon intensity during the use phase examined in this study.

The findings indicate that the selection of the vehicle's battery type and the choice of electricity source during the use phase significantly impact the overall life cycle results and carbon footprint. A choice of wind-based electricity would result in a much lower carbon footprint than global or European electricity mixes. The suppliers' target to reduce the carbon footprint of the batteries in the future can also play a role in lowering the overall carbon footprint of the vehicle.

Materials such as steel, iron and aluminum, and their refining, significantly add to the total carbon footprint, therefore initiatives aimed at diminishing the environmental impact of these materials, such as via increased usage of recycled materials and the incorporation of more renewable energy in production, are crucial steps in reducing the overall carbon footprint.

Further reducing carbon footprints requires more efficient production, greater use of recycled content and increased use of renewable energy.

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10. Appendix

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10 Appendix 1 – List of material library material categories

Material name	Material group
ABS (unfilled)	Polymers
Aluminium (matcat)	Aluminium
Aramid	Polymers
ASA (unfilled)	Polymers
Brake fluid	Fluids and undefined
Cast iron (matcat)	Steel and iron
Catalytic coating	Ceramics and glass
Ceramics	Ceramics and glass
Copper	Copper
Copper alloys	Copper
Cotton	Natural materials
E/P (filled)	Polymers
E/P (unfilled)	Polymers
Elastomer	Polymers
Electrolyte	Fluids and undefined
Electronics	Electronics
EPDM	Polymers
EVAC (filled)	Polymers
EVAC (unfilled)	Polymers
Ferrite magnet	Other metals
Float glass	Ceramics and glass
Friction	Natural materials
GF-Fibre	Ceramics and glass
Glycol	Fluids and undefined
Lead, battery	Other metals
Lubricants (matcat)	Fluids and undefined
Magnesium	Other metals
NdFeB	Other metals
NR	Polymers
PA (filled)	Polymers
PBT (unfilled)	Polymers
PC (filled)	Polymers
PC (unfilled)	Polymers
PC+ABS (filled)	Polymers
PC+ABS (unfilled)	Polymers
PE (filled)	Polymers
PE (unfilled)	Polymers
PET (filled)	Polymers
PET (unfilled)	Polymers
PMMA (unfilled)	Polymers
Polyester	Polymers
Polyurethane (matcat)	Polymers
POM (filled)	Polymers
POM (unfilled)	Polymers
PP (filled)	Polymers
PP (unfilled)	Polymers
PVC (filled)	Polymers
PVC (unfilled)	Polymers
PVC (filled)	Polymers
PVC (unfilled)	Polymers
R-1234yf	Fluids and undefined
SBR	Polymers
Silicone rubber	Polymers
Steel, Sintered	Steel and iron
Steel, Stainless, Austenitic	Steel and iron
Steel, Stainless, Ferritic	Steel and iron
Steel, Unalloyed	Steel and iron
Sulphuric acid	Fluids and undefined
Thermoplastic elastomers (matcat)	Polymers
Thermoplastics (matcat)	Polymers
Tyre	Tyres
Undefined	Fluids and undefined
Washer fluid	Fluids and undefined
Wood (paper, cellulose)	Natural materials

10 Appendix 2 – Summary of data choices and assumptions for component manufacturing

Material	Assumption on component	Comment	Material utilisation change to degree in additional component manufacturing
Cast aluminium	Die-casting process		95%
Wrought aluminium	Rolling + Aluminium sheet deep drawing	Assumed to represent different types of wrought processes	63%
Cast iron	No extra manufacturing processes	The chosen dataset already includes the production of a finished part to be used in automotive applications	
Copper	No extra manufacturing processes	Assumed that processing after manufacturing into copper wire has negligible emissions and waste	
Electrolyte	No extra manufacturing process	Assumed that no processing is required after finished electrolyte production	
Electronics	No extra manufacturing processes	The chosen dataset already includes the production of a finished printed circuit board	
Fluids	No extra manufacturing processes	Assumed that fluids do not need further refining after production of the raw material (the fluid itself)	
Ceramics and glass	No extra manufacturing processes	Assumed that no additional processing is needed after the manufacturing of the glass and ceramic components	
NdFeB magnets	No extra manufacturing processes	The chosen dataset already includes the production of a finished magnet to be used in electric motors for automotive applications	
Polymers	Injection moulding process	Assumed to represent different types of processes	98%
Stainless steel	Steel sheet deep drawing	Sheet is assumed in line with the conservative approach	63%
Steel (in parts, processed at suppliers)	Steel sheet deep drawing	Sheet is assumed in line with the conservative approach	65%
Steel (stamped in a Volvo factory)	Steel scrap generated at Volvo Cars factories	The steel scrap generated at stamping in the Volvo factories, that is the steel in workstream "vehicle structures"	Confidential
Tyres	No extra manufacturing processes	Assumed that the processes after vulcanisation only have minor GHG -emissions	
Other materials	Raw material weight x2	Emissions from raw material production has been multiplied by two, to compensate for further refining and processing	50%

10 Appendix 3 – Chosen datasets

Table 15 *Chosen datasets for material production and refining.*

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
ABS	GLO	Market for acrylonitrile-butadiene-styrene copolymer		agg	Ecoinvent
Aluminium	CN	Aluminium ingot mix IAI 2015		agg	Sphera
Aluminium recycled	RoW	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter (CN) (modified dataset: electricity from CN and thermal energy from China)		u-so	Ecoinvent
Aluminium renewable energy	CN	Aluminium sheet (Renew. electr. LC)		agg	Sphera
Aramid	DE	Aramide fiber (para aramid)		agg	Sphera
ASA	GLO	Market for acrylonitrile-butadiene-styrene copolymer		agg	Ecoinvent
Brake fluid	GLO	Market for diethylene glycol		agg	Ecoinvent
Cast iron	DE	Cast iron part (automotive) - open energy inputs		p-agg	Sphera
Catalytic coating	ZA	Market for platinum group metal concentrate		agg	Ecoinvent
Ceramics	RER	Glass ceramic production		agg	Sphera
Copper	GLO	Copper (99,99%); cathode)		agg	ICA
Copper alloys	GLO	Market for bronze	33%	agg	Ecoinvent
	RoW	Market for brass	49%	agg	Ecoinvent
	GLO	Nickel (Class 1, >99.8% Nickel)	5%	agg	ICA
	GLO	Copper (99.99%; cathode)	14%	agg	Nickel institute
Cotton	GLO	Market for textile, woven cotton		agg	Ecoinvent
E/P	RoW	Polyethylene production, low density, granulate		agg	Ecoinvent
Elastomer	RoW	Market for calcium carbonate, precipitated	30%	agg	Ecoinvent
	CN	Lime (CaO; quicklime lumpy)	20%	agg	Sphera
	GLO	Market for carbon black	7%	agg	Ecoinvent
	GLO	Market for polyethylene terephthalate, granulate, amorphous	5%	agg	Ecoinvent
	GLO	Market for zinc oxide	3%	agg	Ecoinvent
	GLO	Market for synthetic rubber	35%	agg	Ecoinvent

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Electrolyte	GLO	Market for electrolyte, for Li-ion battery		agg	Ecoinvent
Electronics	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing		agg	Ecoinvent
EPDM	DE	Ethylene Propylene Diene Elastomer (EPDM)		agg	Sphera
EVAC	RoW	Market for ethylene vinyl acetate copolymer		agg	Ecoinvent
Ferrite magnet	GLO	Market for ferrite		agg	Ecoinvent
Float glass	RER	Float flat glass		agg	Sphera
Filled termoplastics	RoW	Market for nylon 6		agg	Ecoinvent
Friction	DE	Cast iron part (automotive) - open energy inputs (Modified to CN)	48%	p-agg	Sphera
	GLO	Market for zirconium oxide	12%	agg	Ecoinvent
	GLO	Market for graphite	11%	agg	Ecoinvent
	GLO	Market for barium sulfide	1%	agg	Ecoinvent
	GLO	Market for barite	7%	agg	Ecoinvent
	GLO	Market for aluminium hydroxide	5%	agg	Ecoinvent
	GLO	Market for magnesium oxide	4%	agg	Ecoinvent
	GLO	Market for expanded vermiculite	2%	agg	Ecoinvent
	RER	Calcined petroleum coke	2%	agg	Sphera
GF-Fibre	RoW	Glass fibre production		agg	Ecoinvent
Glycol	CN	Ethylene glycol (MEG) via coal to ethylene glycol process		agg	Sphera
Lead, battery	GLO	Lead, primary		agg	Sphera
Lubricants	CN	Lubricants at refinery		agg	Sphera
Magnesium	CN	Magnesium		agg	Sphera
NdFeB	GLO	Market for permanent magnet, for electric motor		agg	Ecoinvent
NR	DE	Natural rubber (NR) (excl. LUC emissions)		agg	Sphera
PA	RoW	Market for nylon 6		agg	Ecoinvent
PBT	GLO	Polybutylene terephthalate granulate (PBT) mix		agg	Sphera
PC	GLO	Market for polycarbonate		agg	Ecoinvent

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
PC+ABS (filled)	GLO	Market for polycarbonate	52%	agg	Ecoinvent
	GLO	Market for acrylonitrile-butadiene-styrene copolymer	28%	agg	Ecoinvent
PC+ABS (unfilled)	GLO	Market for polycarbonate	51%	agg	Ecoinvent
	GLO	Market for acrylonitrile-butadiene-styrene copolymer	27%	agg	Ecoinvent
	RER	Plastic granulate secondary (low metal contamination)	22%	agg	Sphera
PE	RoW	Polyethylene production, low density, granulate		agg	Ecoinvent
PET (filled)	GLO	Market for polyethylene terephthalate, granulate, amorphous		agg	Ecoinvent
PET (unfilled)	GLO	Market for polyethylene terephthalate, granulate, amorphous	40%	agg	Ecoinvent
	RER	Plastic granulate secondary (low metal contamination)	60%	agg	Sphera
PMMA (unfilled)	GLO	Market for polymethyl methacrylate, sheet		agg	Ecoinvent
Polyester	GLO	Market for fibre, polyester		agg	Ecoinvent
Polyurethane (matcat)	RoW	Market for polyurethane, rigid foam		agg	Ecoinvent
POM	RER	Polyoxymethylene (POM)		agg	PlasticsEurope
PP	GLO	Market for polypropylene, granulate		agg	Ecoinvent
PVC	RoW	Polyvinylchloride production, suspension polymerisation		agg	Ecoinvent
Recycled plastic	RER	Plastic granulate secondary (low metal contamination		agg	Sphera
R-1234yf	DE	R-1234yf production (estimation)		u-so	Sphera
SBR	DE	Styrene-butadiene rubber (S-SBR) mix		agg	Sphera
Silicone rubber	DE	Silicone rubber (RTV-2, condensation)		agg	Sphera
Steel, Sintered	Asia	Steel hot dip galvanised		agg	Worldsteel
Steel, Stainless, Austenitic	GLO	Market for steel, chromium steel 18/8, hot rolled	100%	agg	Ecoinvent
	RoW	Sheet rolling, steel	100%	agg	Ecoinvent
Steel, Stainless, Ferritic	RER	Stainless steel cold rolled coil (430)		p-agg	Eurofer
Steel, Unalloyed	Asia	Steel hot dip galvanised	18%	agg	Worldsteel
	Asia	Steel cold rolled coil	65%	agg	Worldsteel
	CN	EAF Steel billet / slab / bloom	20%	agg	Sphera
	RoW	Hot rolling, steel	18%	agg	Ecoinvent
	RoW	Sheet rolling, steel	18%	agg	Ecoinvent

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Sulphuric acid	RER	Sulphuric acid (96%)		agg	Sphera
Thermoplastic elastomers (matcat)	DE	Polypropylene / ethylene propylene diene elastomer granulate (PP/EPDM, TPO, TPE-O) mix		agg	Sphera
Thermoplastics (matcat)	RoW	Market for nylon 6		agg	Ecoinvent
Tyre	DE	Natural rubber (NR) (incl. LUC emissions)	35%	agg	Sphera
	RoW	Synthetic rubber production	50%	agg	Ecoinvent
	CN	Crude oil mix	6%	agg	Sphera
	GLO	Market for carbon black	5%	agg	Ecoinvent
	GLO	Vulcanisation of synthetic rubber (without additives)	50%	u-so	Sphera
Undefined	RoW	Market for nylon 6		agg	Ecoinvent
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)		agg	Sphera
Wood (paper, cellulose ...)	RER	Laminated veneer lumber (EN15804 A1-A3)		agg	Sphera
Filler for polymers	RER	Talcum powder (filler)		agg	Sphera
	GLO	Market for glass fibre		agg	Ecoinvent

Table 16 *Chosen datasets for material production and refining, manufacturing.*

Material category	Location	Name of LCI dataset	Type	LCI database
Stainless steel manufacturing (DE)	DE	DE: Steel sheet deep drawing (all energy inputs connected)	u-so	Sphera
	CN	Thermal energy from natural gas	agg	Sphera
	CN	Lubricants at refinery	agg	Sphera
Aluminium, manufacturing (DE, EU28)	DE	Aluminium die-cast part	u-so	Sphera
	DE	Aluminium sheet deep drawing	u-so	Sphera
	RER	Aluminium sheet - open input aluminium rolling ingot	p-agg	Sphera
	CN	Thermal energy from natural gas	agg	Sphera
	CN	Lubricants at refinery	agg	Sphera
Polymers (all categories) manufacturing (GLO)	DE	Plastic injection moulding part (unspecific)	u-so	Sphera
	CN	Water (desalinated; deionised)	agg	Sphera
	CN	Thermal energy from natural gas	agg	Sphera
	CN	Lubricants at refinery	agg	Sphera
Steel unalloyed, manufacturing (DE, VCC data)	DE	DE: Steel sheet deep drawing (all energy inputs connected)	u-so	Sphera
	CN	Thermal energy from natural gas	agg	Sphera
	CN	Lubricants at refinery	agg	Sphera

Table 17 *Chosen datasets for electricity.*

Material category	Location	Name of LCI dataset	Type	LCI database
Use phase				
Electricity from solar power	RER	Electricity from photovoltaic	agg	Sphera
Electricity from wind power	RER	Electricity from wind power	agg	Sphera
Electricity from geothermal	RER	Electricity from geothermal	agg	Sphera
Electricity from hydro power	RER	Electricity from hydro power	agg	Sphera
Electricity from bioenergy	RER	Electricity from biomass (solid)	agg	Sphera
Electricity from nuclear power	RER	Electricity from nuclear	agg	Sphera
Electricity from unabated coal	RER	Electricity from lignite	agg	Sphera
Electricity from unabated gas	RER	Electricity from natural gas	agg	Sphera
Electricity from oil	RER	Electricity from heavy fuel oil (HFO)	agg	Sphera
Manufacturing				
Electricity mix for manufacturing	CN	Electricity grid mix 1kV-60kV	agg	Sphera

Table 18 Chosen datasets for End-of-life processing.

Material category	Location	Name of LCI dataset	Type	LCI database
Disassembling	Europe without Switzerland	Treatment of waste mineral oil, hazardous waste incineration	agg	Ecoinvent 3.9.1
	RER	Treatment of scrap lead acid battery, remelting	agg	Ecoinvent 3.9.1
	GLO	Treatment of used tyre	agg	Ecoinvent 3.9.1
Shredded wastes	EU28	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW)	p-agg	ELCD/CEWEP
	EU28	DUPLICA–E - Glass/inert waste on landfill	agg	Sphera
Transport	GLO	Truck, 28-32 t ton weight, MPL 22 t, Euro 5	u-so	Sphera
Diesel	RER	Diesel mix at refinery	agg	Sphera
Electricity from solar power	RER	Electricity from photovoltaic	agg	Sphera
Electricity from wind power	RER	Electricity from wind power	agg	Sphera
Electricity from geothermal	RER	Electricity from geothermal	agg	Sphera
Electricity from hydro power	RER	Electricity from hydro power	agg	Sphera
Electricity from bioenergy	RER	Electricity from biomass (solid)	agg	Sphera
Electricity from nuclear power	RER	Electricity from nuclear	agg	Sphera
Electricity from unabated coal	RER	Electricity from lignite	agg	Sphera
Electricity from unabated gas	RER	Electricity from natural gas	agg	Sphera
Electricity from oil	RER	Electricity from heavy fuel oil (HFO)	agg	Sphera
Electricity from solar power	RER	Electricity from photovoltaic	agg	Sphera

Table 19 Chosen datasets for VCC car factory modelling.

Material category	Location	Name of LCI dataset	Type	LCI database
Electricity	CN	Electricity grid mix 1kV-60kV	agg	Sphera
Water	CN	Tap water from surface water	agg	Sphera
Thermal energy	CN	Thermal energy from natural gas	agg	Sphera
Waste	GLO	Municipal wastewater treatment (sludge incineration, for regionalization)	p-agg	Sphera
	EU28	Waste incineration of municipal solid waste (MSW)	agg	ELCD/CEWEP
	RoW	Treatment of H3PO4 purification residue, residual material landfill	agg	Ecoinvent

Table 20 *Chosen datasets for maintenance modelling.*

Component	Material category	Share	Location	Name of LCI dataset	Type	LCI database
Wiper blade front left	Steel, Unalloyed	48%		Multiple datasets		
	Elastomer	22%		Multiple datasets		
	Thermoplastics (matcat)	7%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	Thermoplastic elastomers (matcat)	10%	DE	Polypropylene / ethylene propylene diene elastomer granulate (PP/EPDM, TPO, TPE-O) mix	agg	Sphera
	POM	4%	RER	Polyoxymethylene (POM)	agg	PlasticsEurope
	PP (filled)	3%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PP (unfilled)	6%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PE	< 1%	RoW	Polyethylene production, low density, granulate	agg	Ecoinvent 3.9.1
Wiper blade front right	Steel, Unalloyed	45%		Multiple datasets		
	Elastomer	21%		Multiple datasets		
	Thermoplastics (matcat)	11%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	Thermoplastic elastomers (matcat)	9%	DE	Polypropylene / ethylene propylene diene elastomer granulate (PP/EPDM, TPO, TPE-O) mix	agg	Sphera
	PP (unfilled)	5%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	POM (unfilled)	5%	RER	Polyoxymethylene (POM)	agg	PlasticsEurope
	PP (filled)	4%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PE (unfilled)	< 1%	RoW	Polyethylene production, low density, granulate	agg	Ecoinvent 3.9.1
Wiper blade rubber plug	EPDM	100%	DE	Ethylene Propylene Diene Elastomer (EPDM)	agg	Sphera
Wiper blade rear	PBT (filled)	57%	GLO	Polybutylene terephthalate granulate (PBT) mix	agg	Sphera
	Aluminium (matcat)	17%	CN	Aluminium ingot mix IAI 2015	agg	Sphera
	Steel, Unalloyed	15%		Multiple datasets		
	Elastomer	6%		Multiple datasets		
	PA (filled)	2%	RoW	market for nylon 6	agg	Ecoinvent 3.9.1
	POM (unfilled)	< 1%	RER	Polyoxymethylene (POM)	agg	PlasticsEurope
	Steel, Stainless, Ferritic	< 1%	RER	Stainless steel cold rolled coil (430)	p-agg	Eurofer
	Undefined	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	PET (unfilled)	< 1%		Multiple datasets		

Component	Material category	Share	Location	Name of LCI dataset	Type	LCI database
Tyre	Tyre	82%		Multiple datasets		
	Steel, Unalloyed	12%		Multiple datasets		
	PA (unfilled)	6%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
Brake discs	Cast iron	100%	DE	Cast iron part (automotive) – open energy inputs	p-agg	Sphera
Condenser	Aluminium	79%	CN	Aluminium ingot mix IAI 2015	agg	Sphera
	PA (filled)	17%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	Steel, Unalloyed	2%		Multiple datasets		
	EPDM	1%	DE	Ethylene Propylene Diene Elastomer (EPDM)	agg	Sphera
	Polyurethane (matcat)	< 1%	RoW	Market for polyurethane, rigid foam	agg	Ecoinvent 3.9.1
	Undefined	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
Battery 12 V	Sulphuric acid	30%	RER	Sulphuric acid (96%)	agg	Sphera
	Lead, battery	62%	GLO	Lead, primary	agg	Sphera
	PP (unfilled)	6%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PE (unfilled)	1%	RoW	Polyethylene production, low density, granulate	agg	Ecoinvent 3.9.1
	PP (unfilled)	< 1%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
Brake fluid	Brake fluid	100%	GLO	Market for diethylene glycol	agg	Ecoinvent 3.9.1
AC fluid	R-1234yf	100%	DE	R-1234yf production (estimation)	u-so	Sphera
Cabin filter	PET (unfilled)	15%		Multiple datasets		
	PP (unfilled)	12%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PP (filled)	24%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	PA (unfilled)	24%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	PE (unfilled)	24%	RoW	Polyethylene production, low density, granulate	agg	Ecoinvent 3.9.1
Steering joint	Cast iron	100%	DE	Cast iron part (automotive) – open energy inputs	p-agg	Sphera

Component	Material category	Share	Location	Name of LCI dataset	Type	LCI database
Lower link arm rh, cpl	Aluminium	82%	CN	Aluminium ingot mix IAI 2015	agg	Sphera
	Steel, Unalloyed	13%		Multiple datasets		
	NR	3%	DE	Natural rubber (NR) (excl. LUC emissions)	agg	Sphera
	Glycol	< 1%	CN	Ethylene glycol (MEG) via coal to ethylene glycol process	agg	Sphera
	PA (filled)	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	Elastomer	< 1%		Multiple datasets		
	PP (unfilled)	< 1%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	Undefined	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	POM (unfilled)	< 1%	RER	Polyoxymethylene (POM)	agg	PlasticsEurope
	Lubricants	< 1%	CN	Lubricants at refinery	agg	Sphera
Lower link arm lh, cpl	Aluminium	82%	CN	Aluminium ingot mix IAI 2015	agg	Sphera
	Steel, Unalloyed	13%		Multiple datasets		
	NR	3%	DE	Natural rubber (NR) (excl. LUC emissions)	agg	Sphera
	Glycol	< 1%	CN	Ethylene glycol (MEG) via coal to ethylene glycol process	agg	Sphera
	PA (filled)	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	Elastomer	< 1%		Multiple datasets		
	PP (unfilled)	< 1%	GLO	Market for polypropylene, granulate	agg	Ecoinvent 3.9.1
	Undefined	< 1%	RoW	Market for nylon 6	agg	Ecoinvent 3.9.1
	POM (unfilled)	< 1%	RER	Polyoxymethylene (POM)	agg	PlasticsEurope
	Lubricants	< 1%	CN	Lubricants at refinery	agg	Sphera
Brake pads	Cast iron	61%	DE	Cast iron part (automotive) – open energy inputs	p-agg	Sphera
	Steel, Unalloyed	4%		Multiple datasets		
	Friction	36%		Multiple datasets		

10 Appendix 4 – Data quality assessment

From Table 22 to Table 26, the data quality assessments are listed per life cycle phase. Each datapoint has received a score from 1 (best) to 5 (worst) according to five different correlation aspects. Table 21 lists the data quality indicators used to assess the data used in this study. Table 27 summarizes the findings.

Table 21 *Data quality indicator matrix used to assess the data used in the study.*

Aspect	1	2	3	4	5
Temporal correlation (time related coverage)	Less than three years before year of study	Less than six years before year of study	Less than 10 years before year of study	Less than 15 years before year of study	Age of data unknown or more than 15 years before year of study
Geographical correlation	Data from area of process origin	Average data from larger area in which area of process origin is included	Data from area with similar production conditions	Data from specified area used for process in unknown area	Data from area with very different production conditions
Technological correlation	Data from enterprises, processes, and materials under study	Data from processes and materials under study but from different enterprise or group of enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology (e.g. using data for ceramic glass to represent production of MICA)	Data on related processes or materials but different or unknown technology
Representative	Representative data from sufficient sample over an adequate period to even out normal fluctuations (this includes future projection if necessary)	Representative data from a small sample but for adequate periods	Representative data from sufficient sample but from shorter periods	Representative data but from a small sample and shorter periods or incomplete data from sufficient sample and periods	Representativeness unknown or incomplete data from a small sample and/or shorter periods
Precision		Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate

A.4.1 Temporal correlation

Most of the datasets are less than three years old (58 per cent), together with datasets that scored 2 and are less than 6 years old (87 per cent). One dataset (Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) (ELCD/CEWEP)) is more than 15 years old. The datasets used in the end-of-life (EoL) modelling only have a small impact considering the entire life cycle. Overall, the temporal correlation adequately fulfils the data quality requirements.

A.4.2 Geographical correlation

Most of the datasets derive from areas with similar production conditions as the study. 68 per cent of all datasets used have scored 3. Some processes could be related to specific countries, but for the most part, Global and Rest-of-world datasets were used instead. Such as, when datasets for China were not available, regionalised datasets were instead used. Due to the unavailability of some datasets, 23 datasets representing European conditions were used rather than Chinese and scored 5 in the geographical assessment.

A.4.3 Technological correlation

Most of the datasets represent processes and materials from different enterprises. Two thirds of the datasets scored 2. Together with the datasets that scored 1, they make up 90 per cent of the datasets. One dataset (Market for nylon 6 (Ecoinvent)) scored 5, as this dataset is used as a proxy to model an undefined material group. In general, the technological correlation is assessed to be good and in line with the data quality requirements.

A.4.4 Representative

All the datasets have scored 1 or 2 in the representative aspect with 94 per cent of the datasets being representative data from a sufficient sample over an adequate period to even out normal fluctuations (i.e. scoring a 1).

A.4.5 Precision

In the precision aspect almost all (84 per cent) datasets consist of verified data based on measurements. 15 per cent of the datasets consist of verified data partly based on assumptions or non-verified data based on measurements. One dataset (Talcum powder (filler) (Sphera)) scored 3 based on the assumption that all fillers are talcum.

Car manufacturing and logistics receive overall good scores as the data is collected from Volvo Cars' own production facilities and controlled processes. The use phase also scores well, as electricity consumption data is based on vehicle specific measurements, and impact calculations are based on new emission factors from the Ecoinvent database and current and forecasted electricity mix data from IEA.

Table 22 *Data quality assessment for material production and refining.*

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
ABS (unfilled)	Polymers	Market for acrylonitrile-butadiene-styrene copolymer(GLO)	1	3	2	1	1
Aluminium (matcat)	Aluminium	Aluminium ingot mix IAI 2015	3	1	1	1	1
	Aluminium (recycled)	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter (CN) (modified data from Petroleum from CN and thermal energy from China)	3	2	2	1	1
	Renewable aluminium	Aluminium sheet (Renew. electr. LC)	1	1	2	1	1
Aramid	Polymers	Aramide fiber (para aramid)	1	5	2	1	1
ASA (unfilled)	Polymers	Market for acrylonitrile-butadiene-styrene copolymer	1	3	3	1	1
Brake fluid	Fluids and undefined	Market for diethylene glycol	4	3	2	1	1
Cast iron (matcat)	Cast iron	Cast iron part (automotive) – open energy inputs	1	5	2	1	1
		Electricity grid mix 1kV-60kV	2	1	1	1	1
		Thermal energy from natural gas	2	1	1	1	1
Catalytic coating	Glass	Market for platinum group metal concentrate	3	3	2	2	1
Ceramics	Ceramics	Glass ceramic production	1	5	2	1	1
Copper	Copper	Copper (99,99%); cathode)	3	3	2	1	1
Copper alloys		Market for bronze	1	3	1	1	1
		Market for brass	1	3	1	1	1
		Nickel (Class 1, >99.8% Nickel)	3	3	1	1	1
		Copper (99.99%; cathode)	2	3	1	1	1
Cotton	Natural materials	Market for textile, woven cotton	4	3	2	1	1
E/P (filled)	Polymers	Polyethylene production, low density, granulate	2	3	3	1	1
E/P (unfilled)	Polymers	Polyethylene production, low density, granulate	2	3	3	1	1

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Elastomer	Calcium carbonate	Market for calcium carbonate, precipitated	2	3	2	1	1
	Lime	Lime (CaO; quicklime lumpy)	1	1	2	1	1
	Carbon black	Market for carbon black	4	3	2	1	1
	PET	Market for polyethylene terephthalate, granulate, amorphous	1	3	2	1	1
	Zinc oxide	Market for zinc oxide	4	3	2	1	1
	Rubber	Market for synthetic rubber	1	3	3	1	1
Electrolyte	Electrolyte	Market for electrolyte, for Li-ion battery	2	3	2	1	1
Electronics	Electronics	Market for printed wiring board, surface mounted, unspecified, Pb containing	1	3	4	1	1
EPDM	Polymers	Ethylene Propylene Diene Elastomer (EPDM)	1	5	2	1	1
EVAC (filled)	Polymers	Market for ethylene vinyl acetate copolymer	1	3	2	1	1
EVAC (unfilled)	Polymers	Market for ethylene vinyl acetate copolymer	1	3	2	1	1
Ferrite magnet	Other metals	Market for ferrite	1	3	2	1	1
Float glass	Glass	Float flat glass	1	5	2	1	1
Filled thermoplastics	Polymers	Market for nylon 6	1	3	2	1	1
Friction	Cast iron	Cast iron part (automotive) – open energy inputs	1	5	2	1	1
	Zirconium oxide	Market for zirconium oxide	4	3	2	1	1
	Graphite	Market for graphite	4	3	2	1	1
	Barium sulfide		2	3	2	1	1
	Barite	Market for barite	4	3	2	1	1
	Aluminium hydroxide	Market for aluminium hydroxide	2	3	2	1	1
	Magnesium oxide	Market for magnesium oxide	4	3	2	1	1
	Vermiculite	Market for expanded vermiculite	4	3	2	1	1
	Calcined Petroleumium Coke	Calcined petroleum coke	1	5	2	1	1

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
GF-Fibre	Glass	Glass fibre production	1	3	2	1	1
Glycol	Fluids and undefined	Ethylene glycol (MEG) via coal to ethylene glycol process	1	1	2	1	1
Lead, battery	Other metals	Lead, primary	1	3	2	1	1
Lubricants (matcat)	Fluids and undefined	Lubricants at refinery	2	1	2	1	1
Magnesium	Other metals	Magnesium	1	1	2	1	1
NdFeB	Other metals	Market for permanent magnet, for electric motor	4	3	2	1	1
NR	Polymers	Natural rubber (NR) (excl. LUC emissions)	1	5	2	1	1
PA (filled)	Polymers	Market for nylon 6	1	3	2	1	1
PA (unfilled)	Polymers	Market for nylon 6	1	3	2	1	1
PBT (filled)	Polymers	Polybutylene terephthalate granulate (PBT) mix	1	3	2	1	1
PBT (unfilled)	Polymers	Polybutylene terephthalate granulate (PBT) mix	1	3	2	1	1
PC (filled)	Polymers	Market for polycarbonate	1	3	2	1	1
PC (unfilled)	Polymers	Market for polycarbonate	1	3	2	1	1
PC+ABS (filled)	PC	Market for polycarbonate	1	3	2	1	1
	ABS	Market for acrylonitrile-butadiene-styrene copolymer	1	3	2	1	1
PC+ABS (unfilled)	PC	Market for polycarbonate	1	3	2	1	1
	ABS	Market for acrylonitrile-butadiene-styrene copolymer	1	3	2	1	1
	Secondary polymers	Plastic granulate secondary (low metal contamination)	1	5	3	1	1
PE (filled)	Polymers	Polyethylene production, low density, granulate	2	3	2	1	1
PE (unfilled)	Polymers	Polyethylene production, low density, granulate	2	3	2	1	1
PET (filled)	Polymers	Market for polyethylene terephthalate, granulate, amorphous	1	3	2	1	1

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
PET (unfilled)	Polymers	Market for polyethylene terephthalate, granulate, amorphous	1	3	2	1	1
	Secondary polymers	Plastic granulate secondary (low metal contamination)	1	5	3	1	1
PMMA (unfilled)	Polymers	Market for polymethyl methacrylate, sheet	1	3	2	1	1
Polyester	Polymers	Market for fibre, polyester	2	3	3	1	1
Polyurethane (matcat)	Polymers	Market for polyurethane, rigid foam	1	3	2	1	1
POM (filled)	Polymers	Polyoxymethylene (POM)	4	5	2	1	1
POM (unfilled)	Polymers	Polyoxymethylene (POM)	4	5	2	1	1
PP (filled)	Polymers	Market for polypropylene, granulate	1	3	2	1	1
PP (unfilled)	Polymers	Market for polypropylene, granulate	1	3	2	1	1
PVC	Polymers	Polyvinylchloride production, suspension polymerisation	1	3	2	1	1
R-1234yf	Fluids and undefined	R-1234yf production (estimation)	2	5	2	1	1
SBR	Polymers	Styrene-butadiene rubber (S-SBR) mix	1	5	2	1	1
Silicone rubber	Polymers	Silicone rubber (RTV-2, condensation)	1	5	2	1	1
Steel, Sintered	Steel and Iron	Steel hot dip galvanised	1	2	2	1	1
Steel, Stainless, Austenitic	Steel and Iron	Market for steel, chromium steel 18/8, hot rolled	1	3	2	1	1
	Sheet rolling	Sheet rolling, steel	1	3	2	1	1
Steel, Stainless, Ferritic	Steel and Iron	Stainless steel cold rolled coil (430)	3	5	2	1	1
Steel, Unalloyed	Hot-dip galvanised steel	Steel hot dip galvanised	1	2	2	1	1
	Cold rolled steel	Steel cold rolled coil	1	2	2	1	1
	Recycled steel	EAF Steel billet / slab / bloom	1	1	3	1	1
		Hot rolling, steel	1	3	2	1	1
		Sheet rolling, steel	1	3	2	1	1
Sulphuric acid	Fluids and undefined	Sulphuric acid (96%)	1	5	2	1	1

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Thermoplastic elastomers (matcat)	Polymers	Polypropylene / ethylene propylene diene elastomer granulate (PP/EPDM, TPO, TPE-O) mix	1	5	3	1	1
Thermoplastics (matcat)	Polymers	Market for nylon 6	1	3	3	1	1
Tyre		Natural rubber (NR) (incl. LUC emissions)	1	5	1	1	1
		Synthetic rubber production	1	3	2	1	1
		Crude oil mix	2	1	2	1	1
		Market for carbon black	4	3	1	1	1
Undefined	Fluids and undefined	Market for nylon 6	1	3	5	2	2
Washer fluid	Fluids and undefined	Ethanol (96%) (hydrogenation with nitric acid)	1	5	2	1	1
Wood (paper, cellulose ...)	Natural materials	Laminated veneer lumber (EN15804 A1-A3)	1	5	3	1	1
Filler for polymers	Talc	Talcum powder (filler)	1	5	2	1	3
	Glass fibre	Market for glass fibre	4	3	2	1	1
Manufacturing							
Stainless steel manufacturing (DE) <LC>		DE: Steel sheet deep drawing (all energy inputs connected)	1	5	2	1	1
		Thermal energy from natural gas	2	1	2	1	1
		Lubricants at refinery	2	1	2	1	1
Aluminium, manufacturing (DE, EU28) <LC>		Aluminium die-cast part	1	5	2	1	1
		Aluminium sheet deep drawing	1	5	2	1	1
		Aluminium she–t – open input aluminium rolling ingot	1	5	2	1	1
Polymers (all categories) manufacturing (GLO) <LC>		Plastic injection moulding part (unspecific)	2	5	2	1	1
		Water (desalinated; deionised)	1	5	2	1	1
Steel unalloyed, manufacturing (DE, VCC data) <LC>		DE: Steel sheet deep drawing (all energy inputs connected)	1	5	2	1	1

Material name	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Electricity							
Electricity mix for manufacturing		Electricity grid mix 1kV-60kV	2	1	2	2	2

Table 23 *Data quality assessment for vehicle use.*

Electricity type	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Electricity from solar power	Electricity from photovoltaic	2	3	1	1	2
Electricity from wind power	Electricity from wind power	2	3	1	1	2
Electricity from geothermal	Electricity from geothermal	2	3	1	1	2
Electricity from hydro power	Electricity from hydro power	2	3	1	1	2
Electricity from bioenergy	Electricity from biomass (solid)	2	3	1	1	2
Electricity from nuclear power	Electricity from nuclear	2	3	1	1	2
Electricity from unabated coal	Electricity from lignite	3	3	1	1	2
Electricity from unabated gas	Electricity from natural gas	3	3	1	1	2
Electricity from oil	Electricity from heavy fuel oil (HFO)	2	3	1	1	2
Electricity from solar power	Electricity from photovoltaic	2	3	1	1	2

Table 24 *Data quality assessment for maintenance.*

Material category	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Tyre	Tyre	Natural rubber (NR) (incl. LUC emissions)	1	5	1	1	1
Cast iron (matcat)	Cast iron	Cast iron part (automotive) – open energy inputs	1	5	2	1	1
Steel, Unalloyed	Hot-dip galvanised steel	Steel hot dip galvanised	1	2	2	1	1
Lead, battery	Other metals	Lead, primary	1	3	2	1	1
Sulphuric acid	Fluids and undefined	Sulphuric acid (96%)	1	5	2	1	1
Float glass	Glass	Float flat glass	1	5	2	1	1
PA (unfilled)	Polymers	Market for nylon 6	1	3	2	1	1
Electronics	Electronics	Market for printed wiring board, surface mounted, unspecified, Pb containing	1	3	4	1	1
Aluminium (matcat)	Aluminium	Aluminium ingot mix IAI 2015	3	1	1	1	1
PP (unfilled)	Polymers	Market for polypropylene, granulate	1	3	2	1	1
Friction	Cast iron	Cast iron part (automotive) – open energy inputs	1	5	2	1	1
Brake fluid	Fluids and undefined	Market for diethylene glycol	4	3	2	1	1
E/P (filled)	Polymers	Polyethylene production, low density, granulate	2	3	3	1	1
PP (filled)	Polymers	Market for polypropylene, granulate	1	3	2	1	1
Thermoplastics (matcat)	Polymers	Market for nylon 6	1	3	3	1	1
PE (unfilled)	Polymers	Polyethylene production, low density, granulate	2	3	2	1	1
PC (unfilled)	Polymers	Market for polycarbonate	1	3	2	1	1
R-1234yf	Fluids and undefined	R-1234yf production (estimation)	2	5	2	1	1
PBT (filled)	Polymers	Polybutylene terephthalate granulate (PBT) mix	1	3	2	1	1
PA (filled)	Polymers	Market for nylon 6	1	3	2	1	1
Elastomer	Calcium carbonate	Market for calcium carbonate, precipitated	2	3	2	1	1

Material category	Materials	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
PET (unfilled)	Polymers	Market for polyethylene terephthalate, granulate, amorphous	1	3	2	1	1
Thermoplastic elastomers (matcat)	Polymers	Polypropylene / ethylene propylene diene elastomer granulate (PP/ EPDM, TPO, TPE-O) mix	1	5	3	1	1
EPDM	Polymers	Ethylene Propylene Diene Elastomer (EPDM)	1	5	2	1	1
NR	Polymers	Natural rubber (NR) (excl. LUC emissions)	1	5	2	1	1
POM (unfilled)	Polymers	Polyoxymethylene (POM)	4	5	2	1	1
Undefined	Fluids and undefined	Market for nylon 6	1	3	5	2	2
E/P (unfilled)	Polymers	Polyethylene production, low density, granulate	2	3	3	1	1
Copper	Copper	Copper (99,99%); cathode)	3	3	2	1	1
Glycol	Fluids and undefined	Ethylene glycol (MEG) via coal to ethylene glycol process	1	1	2	1	1
PBT (unfilled)	Polymers	Polybutylene terephthalate granulate (PBT) mix	1	3	2	1	1
Copper alloys	0	Market for bronze	1	3	1	1	1
Polyurethane (matcat)	Polymers	Market for polyurethane, rigid foam	1	3	2	1	1
Steel, Stainless, Ferritic	Steel and iron	Stainless steel cold rolled coil (430)	3	5	2	1	1
Lubricants (matcat)	Fluids and undefined	Lubricants at refinery	2	1	2	1	1
Silicone rubber	Polymers	Silicone rubber (RTV-2, condensation)	1	5	2	1	1
PE (filled)	Polymers	Polyethylene production, low density, granulate	2	3	2	1	1
Steel, Stainless, Austenitic	Steel and iron	Market for steel, chromium steel 18/8, hot rolled	1	3	2	1	1
PVC	Polymers	Polyvinylchloride production, suspension polymerisation	1	3	2	1	1

Table 25 *Data quality assessment for end-of-life treatment.*

Process name	Name of generic dataset used	Temporal correlation	Geographical correlation	Technological correlation	Representative	Precision
Disassembling	Treatment of waste mineral oil, hazardous waste incineration	1	3	2	2	2
	Treatment of scrap lead acid battery, remelting	3	3	2	2	2
	Treatment of used tyre	3	1	2	2	2
Shredding VDA Original <u-so>	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW)	5	3	2	1	1
	DUPLICA–E - Glass/inert waste on landfill	1	3	2	1	1
Transport	Truck, 28-32 t ton weight, MPL 22 t, Euro 5	1	1	1	1	1
Diesel	Diesel mix at refinery Sphera	1	3	1	1	1
Electricity	Electricity from photovoltaic	2	3	2	1	2
	Electricity from wind power	2	3	2	1	2
	Electricity from geothermal	2	3	2	1	2
	Electricity from waste	2	3	2	1	2
	Electricity from heavy fuel oil (HFO)	2	3	2	1	2
	Electricity from nuclear	2	3	2	1	2
	Electricity from hydro power	2	3	2	1	2
	Electricity from natural gas	2	3	2	1	2
	Electricity from lignite	2	3	2	1	2

Table 26 *Data quality assessment for VCC car factory.*

Process	Name of generic dataset used	Temporal correlation (time related coverage)	Geographical correlation	Technological correlation	Representative	Precision
Electricity	Electricity grid mix 1kV-60kV	2	1	1	1	1
Water	Tap water from surface water	1	1	1		
Thermal energy	Thermal energy from natural gas	2	1	1	1	2
Waste	Municipal wastewater treatment (sludge incineration, for regionalization)	1	3	1	1	2
	Waste incineration of municipal solid waste (MSW)	2	5	1	1	2
	treatment of H3PO4 purification residue, residual material landfill	1	3	1	1	1

Table 27 *Quality assessment of data used in the study.*

Data points	Material production and refining	Car manufacturing, inbound and outbound logistics	Use of vehicle	Maintenance	End-of-life treatment
Temporal correlation (time related coverage)	1–4	1	2–3	1–4	1–5
Geographical correlation	1–5	1	3	1–5	1–3
Technological correlation	1–5	1	1	1–5	1–2
Representative	1–2	1–2	1	1–2	1–2
Precision	1–3	2	2	1–2	1–2

10 Appendix 5 – End-of-life assumptions and method

A5.1 Transport

Transportation of materials sent to material recycling is included and it is assumed the material is transported 500 km by truck. According to the European Commission's recommendation on the use of Environmental Footprint methods[12], waste from manufacturing/construction sites can be assumed to be transported 100 km. As the waste from the vehicle end-of-life could be considered more specific, greater distances for end-of-life-related transport could be assumed. Therefore, a conservative estimation of 500 km is used.

A5.2 Disassembly

The disassembly stage is globally still, mostly a manual process. The energy consumption of this stage is therefore disregarded in this study. As the weight of the disassembled parts is low, potential additional transport of these components was disregarded.

A5.3 Pre-treatment

Pre-treatment was included for the following disassembled components:

- Lead acid battery
- Tyres
- Li-ion batteries

For the lead acid batteries, catalytic converter, and tyres, Ecoinvent datasets are used for the pre-treatment stage in this study. The Li-ion battery is assumed to be transported 500 km by truck to the recycling facility.

For the remaining disassembled parts, no inventory is made since their disassembly is done as a safety precaution and they will later be handled similarly to the rest of the vehicle. The fluids and oils that are incinerated likewise do not go through any pre-treatment.

A5.4 Shredding

In the shredding process the vehicles are milled to smaller fractions. This process uses electricity. In order to estimate the amount of energy needed, the energy consumption per kg in the dataset Treatment of used glider from Ecoinvent 3.9.1 is used. The electricity used in this process is modelled as global average electricity grid mix in 2038 as presented by the IEA's STEPS data.

The entire vehicle (except the parts sent for specific pre-treatment) is sent through the shredding process. No additional transport is included as shredding is modelled to occur at the same site as dismantling.

A5.5 Material recycling

Metals are separated and recycled after shredding, as well as materials in the pre-treated components. Based on the choice of cut-off approach for end-of-life modelling, this stage is outside the boundaries of the life cycle and is not included in the inventory, except for the transportation to the material recycling as mentioned above.

A5.6 Final disposal – incineration and landfill

The disassembled fluids and oils, as well as the combustible part of the shredder light fraction are modelled to be incinerated without energy recovery. The choice to not include energy recovery relates to the global scope of the LCA. To model the incineration of the waste oils, an ecoinvent dataset for treatment of waste oil was used.

To model the emissions from the combustion of material from the shredder, a dataset for incineration of mixed plastics is used, based on the main content of the flow going to this stage. The main part of the weight will be from the plastics in the vehicle. The dataset chosen was a LCA for experts dataset of EU-28 incineration of mixed plastic.

Non-combustible materials, like ceramics and glass, make up a small part of the vehicle but is the part of the shredder light fraction that cannot be combusted. This flow is either landfilled or recycled as filler material, in both cases modelled with a dataset for landfilling of glass/inert matter, from Sphera.

Transportation of materials which are separated in the shredding processes and which are assumed to be recycled is estimated to 500 km by truck.

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[12] *European Comission, COMMISSION RECOMMENDATION: on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. ANNEXES 1 to 2 (2021).*

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A5.7 Data collection

This section provides an overview of the data collection activities relating to each life cycle stage. For a full list of datasets, see Appendix 3 – Chosen datasets. According to the cut-off methodology, the processes presented in Table 28 are included in the data collection effort.

Table 28 *Processes included in the data collection effort for end-of-life.*

Disassembly stage	Pre-processing stage	Final disposal
Batteries	Separate handling. Lead recovery from lead acid and designated Li-ion battery dismantling	According to material category*
Tyres	Pre-treatment for tyre recycling	None (sent to material recycling)
Liquids (coolants, brake fluids etc)		Incineration
Oils (engine, gearbox, etc)		Incineration
Oil filters		Incineration
Airbags and seat belt pretensioners	Disarming of explosive, Shredding	None (sent to material recycling)
Rest of vehicle	Shredding	According to material category*

** Metals to material recycling, combustible material to incineration (mainly plastics) and residue to landfill.*

10 Appendix 6 – Specific data used in modelling

Table 29 *Share of each steel type in model.*

Type of steel modelled	Share
Hot-Dip galvanised	17.91%
Cold rolled steel coils	64.57%
Recycled steel	17.52%

Table 30 *Recycled content in plastics.*

Plastic type	Recycled content
PP (filled)	15.5%
PET	59.7%
PC+ABS	22%

Table 31 *Shares of aluminium types in the car (excluding the battery).*

Aluminium type	Share
Recycled	31%
Produced with renewable electricity	32%
Unrecycled aluminium	37%

Table 32 *Difference in vehicle parts changes for maintenance for the scenarios.*

VEHICLE PART	Unit	Baseline 200,000 km	150,000 km	250,000 km	300,000 km
Wiper blade	Number of sets	13	13	13	13
Tire	Number of items	16	12	24	28
Brake fluid	Litres	4.2	3.2	6.3	7.4
Brake pads	Number of items (8 items each exchange)	8	8	16	16
Brake discs	Number of items (4 items each exchange)	0	0	0	0
Battery 12 V	Number of items	3	3	3	3
Steering joint	Number of items	1	1	1	2
Link arm	Number of items	2	2	2	4
Condenser	Number of items	1	1	1	2
AC fluid	Number of AC container volume	2	2	3	3
Cabin filter	Number of items	12	9	15	18

10 Appendix 7

Table 33 *Characterisations factors used in the study, according to IPCC Intergovernmental Panel on Climate Change by the United Nations*[13]

Substance	GWP-100	Unit
1,1,1-Trichloroethane	161	CO_2-eq
1,2-Dibromoethane	1.02	CO_2-eq
Bromoform	0.25	CO_2-eq
Butane (n-butane)	0.006	CO_2-eq
Carbon dioxide	1	CO_2-eq
Carbon dioxide, fossil	1	CO_2-eq
Carbon tetrachloride (tetrachloromethane)	2,200	CO_2-eq
Chloroform	20.6	CO_2-eq
Chloromethane (methyl chloride)	5.54	CO_2-eq
Dichloroethane (ethylene dichloride)	1.3	CO_2-eq
Dichloromethane (methylene chloride)	11.2	CO_2-eq
Dinitrogen monoxide	273	CO_2-eq
Ethane	0.437	CO_2-eq
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	6,520	CO_2-eq
Ethane, 1,2-dichloro-	1.3	CO_2-eq
Ethyl chloride	0.481	CO_2-eq
Halon (1211)	1,930	CO_2-eq
Halon (1301)	7,200	CO_2-eq
Methane	29.8	CO_2-eq
Methane, bromo-, Halon 1001	2.43	CO_2-eq
Methane, dichloro-, HCC-30	11.2	CO_2-eq
Methane, monochloro-, R-40	5.54	CO_2-eq
Methyl bromide	2.43	CO_2-eq
Nitrogentriflouride	17,400	CO_2-eq
Nitrous oxide (laughing gas)	273	CO_2-eq
Perfluoropentane	9,220	CO_2-eq
Propane	0.02	CO_2-eq
R 11 (trichlorofluoromethane)	5,560	CO_2-eq
R 113 (trichlorotrifluoroethane)	6,520	CO_2-eq
R 114 (dichlorotetrafluoroethane)	9,430	CO_2-eq
R 116 (hexafluoroethane)	12,400	CO_2-eq
R 12 (dichlorodifluoromethane)	11,200	CO_2-eq
R 124 (chlorotetrafluoroethane)	597	CO_2-eq
R 125 (pentafluoroethane)	3,740	CO_2-eq
R 13 (chlorotrifluoromethane)	16,200	CO_2-eq
R 134a (tetrafluoroethane)	1,530	CO_2-eq
R 141b (dichloro-1-fluoroethane)	860	CO_2-eq
R 142b (chlorodifluoroethane)	2,300	CO_2-eq
R 143 (trifluoroethane)	364	CO_2-eq
R 143a (trifluoroethane)	5,810	CO_2-eq
R 152a (difluoroethane)	164	CO_2-eq
R 21 (Dichlorofluoromethane)	160	CO_2-eq
R 22 (chlorodifluoromethane)	1,960	CO_2-eq
R 23 (trifluoromethane)	14,600	CO_2-eq
R 245fa (1,1,1,3,3-Pentafluoropropane)	962	CO_2-eq
R 32 (difluoromethane)	771	CO_2-eq
R E245fa2 (2-(Difluoromethoxy)-1,1,1-trifluoroethane)	878	CO_2-eq
Sulphur hexafluoride	25,200	CO_2-eq
Tetrachloroethene (perchloroethylene)	6.34	CO_2-eq
Tetrafluoromethane	7,380	CO_2-eq
Trichloroethene (isomers)	0.044	CO_2-eq
Trichloromethane (chloroform)	20.6	CO_2-eq

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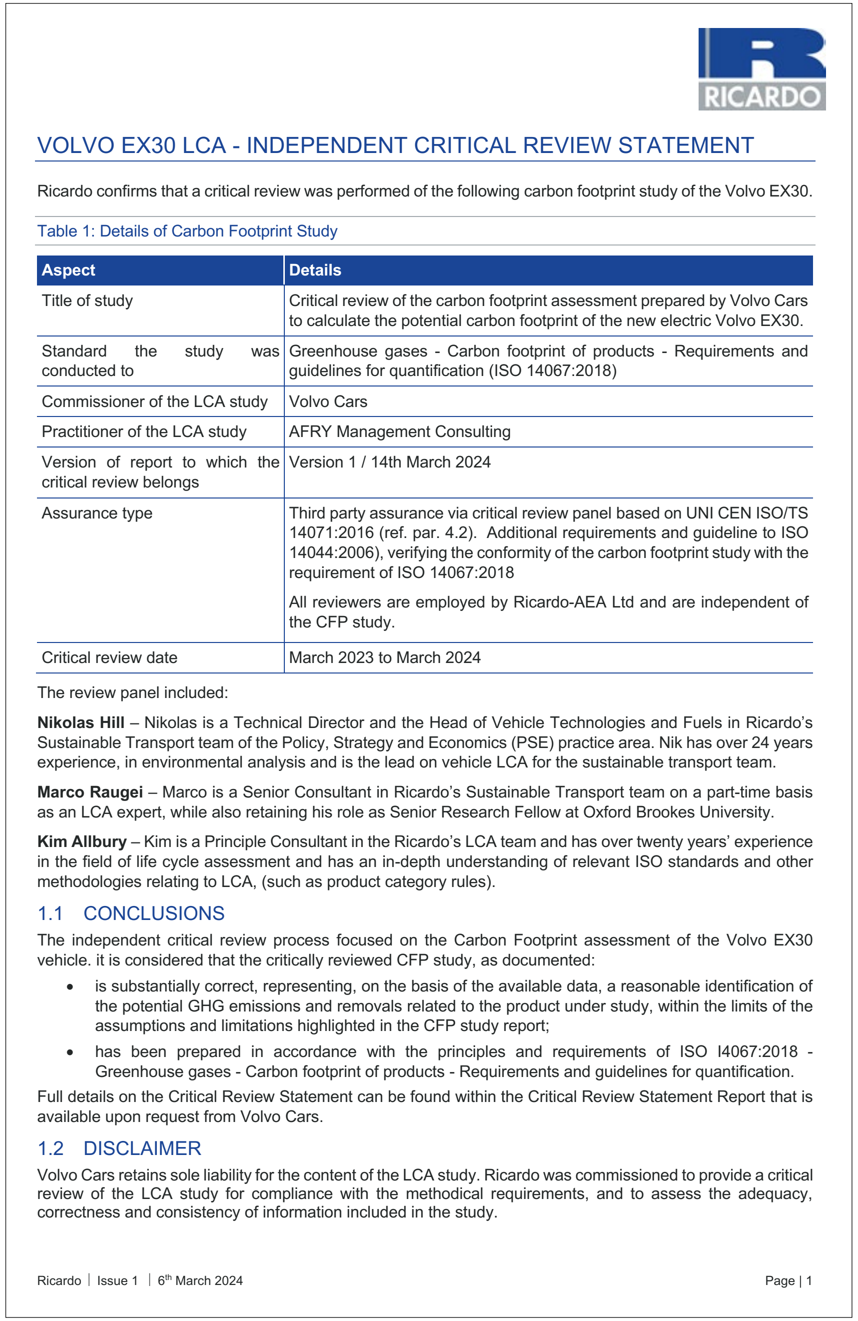
[13] *https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf*

10 Appendix 8 – Critical review



VOLVO EX30 LCA - INDEPENDENT CRITICAL REVIEW STATEMENT

Ricardo confirms that a critical review was performed of the following carbon footprint study of the Volvo EX30.

Table 1: Details of Carbon Footprint Study

Aspect	Details
Title of study	Critical review of the carbon footprint assessment prepared by Volvo Cars to calculate the potential carbon footprint of the new electric Volvo EX30.
Standard the study was conducted to	Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification (ISO 14067:2018)
Commissioner of the LCA study	Volvo Cars
Practitioner of the LCA study	AFRY Management Consulting
Version of report to which the critical review belongs	Version 1 / 14th March 2024
Assurance type	Third party assurance via critical review panel based on UNI CEN ISO/TS 14071:2016 (ref. par. 4.2). Additional requirements and guideline to ISO 14044:2006), verifying the conformity of the carbon footprint study with the requirement of ISO 14067:2018 All reviewers are employed by Ricardo-AEA Ltd and are independent of the CFP study.
Critical review date	March 2023 to March 2024

The review panel included:

Nikolas Hill – Nikolas is a Technical Director and the Head of Vehicle Technologies and Fuels in Ricardo's Sustainable Transport team of the Policy, Strategy and Economics (PSE) practice area. Nik has over 24 years experience, in environmental analysis and is the lead on vehicle LCA for the sustainable transport team.

Marco Raugei – Marco is a Senior Consultant in Ricardo's Sustainable Transport team on a part-time basis as an LCA expert, while also retaining his role as Senior Research Fellow at Oxford Brookes University.

Kim Allbury – Kim is a Principle Consultant in the Ricardo's LCA team and has over twenty years' experience in the field of life cycle assessment and has an in-depth understanding of relevant ISO standards and other methodologies relating to LCA, (such as product category rules).

1.1 CONCLUSIONS

The independent critical review process focused on the Carbon Footprint assessment of the Volvo EX30 vehicle. it is considered that the critically reviewed CFP study, as documented:

- is substantially correct, representing, on the basis of the available data, a reasonable identification of the potential GHG emissions and removals related to the product under study, within the limits of the assumptions and limitations highlighted in the CFP study report;
- has been prepared in accordance with the principles and requirements of ISO I4067:2018 - Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification.

Full details on the Critical Review Statement can be found within the Critical Review Statement Report that is available upon request from Volvo Cars.

1.2 DISCLAIMER

Volvo Cars retains sole liability for the content of the LCA study. Ricardo was commissioned to provide a critical review of the LCA study for compliance with the methodical requirements, and to assess the adequacy, correctness and consistency of information included in the study.

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10 Appendix 9 – Certificate of wind power usage during manufacturing

Contract Name
Annual Green Power Trading in North Hebei Region Changqing Wind Power Plant from January – December 2023 – Between Changqing Wind Power Plant and Zhangjiakou Zhonghe New Energy Group Co.,Ltd - 2023 Green Power Trading Contract 112.

Contract Volume
January 1, 2023 – December 31, 2023

Settlement Price
See contract for details

Consumptive Party
Kaiyue Automotive Large Parts Manufacturing (Zhangjiakou) Co., Ltd

Consumptive Site
Hebei province

Electricity Party
Hebei Huadian Kangbao Wind Energy Co., Ltd.

Electricity Site
Hebei province

Agent Of Consuming Party
Zhangjiakou Zhonghe New Energy Group Co., Ltd.

Transmission Party
State Grid Hebei Electric Power Co., Ltd

Consumptive Cycle
January 1, 2023 - January 31, 2023

Electricity Type
Wind power

Green Electricity Certificate No.
'The certificate is true and valid after verification this NO. on the website. You can double check it after register through the link: https://www.greenenergy.org.cn. As presented on next page.

BPX 北京电力交易中心
BEIJING POWER EXCHANGE CENTER

绿色电力消费凭证
区块链溯源
Green Electricity Consumption Certificate
Blockchain Traceability

绿色电力消费结算凭证存证详情
(Details Of Green Power Consumption Certificate)

证书编号（Certificate No.):	12231000030685
合同编号（Contract No.):	00f326d0-32d4-4aba-9ebb-451a250751a3
合同名称（Contract Name):	2023年1-12月冀北地区年度绿色电力交易长青风电场-长青风电场与张家口中合新能源集团有限公司-2023年绿色电力交易合同112
合同周期（Contract Volume):	2023年01月01日-2023年12月31日
合同电量（Electricity Contract):	82760.000MWh
结算编号（Settlement No.):	b401d385-3344-4ddb-ba49-3e240d07b2b2
结算电价（Settlement Price):	详见合同
消纳方（Consumptive Party):	凯悦汽车大部件制造（张家口）有限公司
消纳方所在地（Consumptive Site):	河北
供电方（Electricity Party):	河北华电康保风电有限公司
供电方所在地（Electricity Site):	河北
消纳方代理（Agent Of Consuming Party):	张家口中合新能源集团有限公司
输电方（Transmission Party):	国网冀北电力有限公司
消纳周期（Consumptive Cycle):	2023年01月01日-2023年01月31日
消纳电量（Electricity Consumption):	2324.000MWh
电量类型（Electricity Type):	风电
合同存证编号（Contract Deposit No.):	d9d729c44a89961dd8175400ed7c38e197b99a5cfde66d236de5e970a140df2b
合同存证时间（Contract Deposit Time):	2023-02-03 01:00:01
结算存证编号（Settlemen Deposit No.):	b251cf8e4fd9ed695243974819b3c687bff33bd2d7545846167f34ae335b6fa2
结算存证时间（Settlemen Deposit Time):	2023-03-21 14:44:28
绿证编号（Green Electricity Certificate No.):	01223012202515486

10 Appendix 9 – Certificate of wind power usage during manufacturing

证书信息明细表

CERTIFICATE INFORMATION LIST

真实有效

国家可再生能源信息管理中心 证书编号：01223012202515486

买家信息

买家名称	所在地	所属人姓名	绿证权益所属地	绿电交易量（kwh）
凯悦汽车大部件制造（张…	/	凯悦汽车大部…		2324000

卖家信息

项目名称	所在地	卖家名称
康保处长地风电场一期49.5兆瓦工程	/	河北华电康保…

绿证号段：PWC09091307230014202301000001-002324

绿电生产 2023-01 → 绿证核发 2023-03-01 → 绿证交易 2023-03-01

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