VOLVO

Carbon Footprint Report

Carbon footprint of Volvo EX90

1. Contents

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2. Abbreviations

ABS:
Acrylonitrile Butadiene Styrene

APS:
Announced Pledges Scenario

AWD:
All Wheel Drive

BEV:
Battery Electric Vehicle

BOM:
Bill Of Materials

ECU:
Electronic Control Unit

E/P:
Ethylene Propylene

EPD:
Environmental Product Declaration

GHG:
Greenhouse Gas

GWP:
Global Warming Potential

IC:
Integrated Circuit

IEA:
International Energy Agency

IMDS:
International Material Data System

LCA:
Life Cycle Assessment

LCI:
Life Cycle Inventory

LCIA:
Life Cycle Impact Assessment

LCA FE:
LCA For Experts

LFP:
Lithium Iron Phosphate

MHEV:
Mild Hybrid Electric Vehicle

NMC:
Nickel Manganese Cobalt

NZE:
Net Zero Emissions by 2050 scenario

PA:
Polyamide

PBT:
Polybutylene

PC:
Polycarbonate

PCB:
Printed Circuit Board

PET:
Polyethylene Terephthalate

PE:
Polyethylene

PHEV:
Plug-in Hybrid Electric Vehicle

PP:
Polypropylene

STEPS:
Stated Policies Scenario

WLTP:
Worldwide Harmonized Light Vehicle Test Procedure

WLTC:
Worldwide Harmonised Light Vehicle Test Cycle

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3. Executive summary

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At Volvo Cars, sustainability is as important as safety. We aim to lead the way 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.

Our long-term aim is to become a fully electric car company and we are committed to accompanying the release of each battery electric vehicle (BEV) with a comprehensive lifecycle assessment (LCA) of its carbon footprint. In so doing, we intend to improve transparency for our customers, employees, investors and other stakeholders interested in our environmental performance.

This report presents the carbon footprint of the fully-electric EX90, which goes into production in 2024. It also contains comparisons with the XC90 plug-in hybrid (PHEV) and mild hybrid (MHEV), vehicles of similar size with different propulsion technologies. The assessment examines the global warming potential (GWP) according to ISO 14067 guidelines using characterisation factors determined by the Intergovernmental Panel on Climate Change (IPCC) and has been third-party reviewed. The scope includes the complete vehicle life cycle from cradle-to-grave, from extracting and refining of raw materials to end-of-life treatment. The study takes a conservative approach that avoids underestimating the carbon footprint. Its findings are not directly comparable with those of other studies, except where the same methodology and assumptions have been applied.

The EX90 is manufactured in the USA and equipped with a 111 kWh battery. The XC90 PHEV and MHEV are manufactured in Sweden and have 18.8 kWh and 0.37 kWh capacity batteries respectively.

The study assumes a lifetime driving distance of 200,000 kilometres and energy use according to Worldwide Harmonised Light Vehicle Test Procedure (WLTP) results. Carbon footprints are assessed for charging with European and global electricity mixes, as well as wind-generated electricity. For internal combustion engines, calculations are based on consumption of petrol blended with 5 per cent ethanol (E5 petrol). Potential changes in electricity supply over the vehicles' lifetime are evaluated according to the International Energy Agency's Stated Policies Scenario (STEPS).

Figure i illustrates that the lifecycle carbon footprint of the EX90 is approximately 50 per cent lower than the XC90 MHEV and 20 per cent lower than the XC90 PHEV, when the European electricity mix is used for charging. Although GHG emissions from production of the EX90's Li-ion battery modules are a significant contributor, its total carbon footprint is still considerably smaller than the XC90 models. If charged with wind-generated electricity, the EX90's carbon footprint is further reduced in comparison with charging with European electricity mix.

Figure ii shows accumulated use phase emissions when the European electricity mix is used for charging. It illustrates the distances beyond which the EX90's cumulative GHG emissions become lower than the XC90 PHEV and XC90 MHEV.

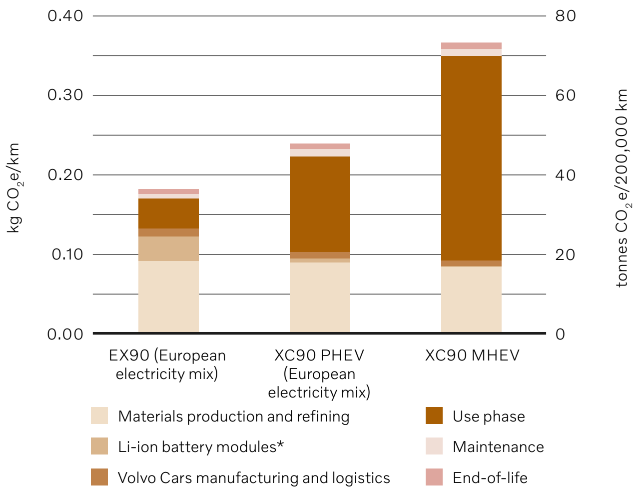

Figure i. *Carbon footprint when charging with European electricity mix.*

** Includes the complete battery for XC90 MHEV.*

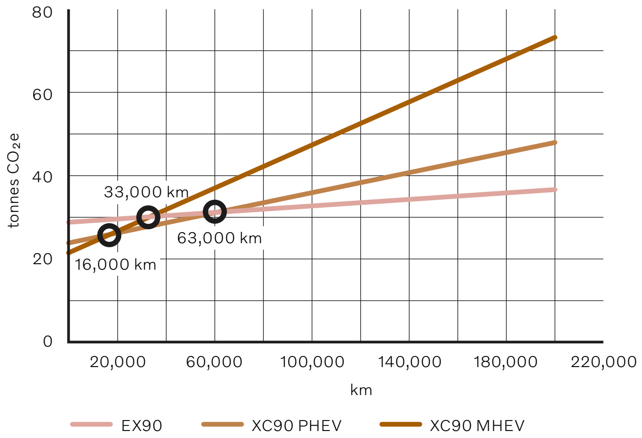

Figure ii. *Accumulated emissions when charging with European electricity mix. All non-use-phase emissions are summarised at 0 kilometres distance driven.*

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In the sensitivity analysis, different future energy scenarios, adjusted lifetime distance, increased vehicle energy use and average passenger numbers are evaluated. Energy scenarios that reflect faster decarbonisation are beneficial for the EX90's carbon footprint. Lifetime distances in excess of 200,000 kilometres also reduce the EX90's carbon footprint in comparison with the XC90 models. Increased energy use causes a greater impact in the XC90 PHEV, as comparatively less distance is driven in electric mode.

The conclusions in this carbon footprint study, as well as those on our other battery electric vehicles, support our strategy to become a fully electric car company. We will continue to mitigate GHG emissions throughout our value chains and advocate for emission reductions in electricity generation.

Key findings

- The total carbon footprint of the EX90 is approximately 50 per cent lower than the XC90 MHEV and 20 per cent lower than XC90 PHEV, when charged with the European electricity mix.
- The total carbon footprint of the EX90 is lower than XC90 PHEV and XC90 MHEV when charged with any of the electricity sources evaluated in this study.
- Consumption of wind-generated electricity significantly reduces the carbon footprint in comparison with global and European electricity mixes.
- Production of Li-ion battery modules accounts for a significant proportion of the EX90's carbon footprint.
- Production of iron, steel and aluminium have a significant impact on the carbon footprint of all vehicles in this study.
- The carbon footprint of the XC90 PHEV is significantly affected by increased energy use, as less of the distance driven is in electric mode.

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4. Methodology

This section describes the goal and scope, system boundary and various assumptions.

4.1 The products

This study assesses the carbon footprint of the EX90 battery electric vehicle (BEV) in comparison with two models of similar size; the XC90 long-range plug-in hybrid vehicle (PHEV) and the XC90 mild hybrid electric vehicle (MHEV)[1], see Table 1 for details.

All three vehicles are offered in different configurations. This study assesses a common equipment level for each vehicle:

- EX90, Twin Motor, electric, Plus, 7-seat
- XC90, T8 AWD plug-in hybrid, electric/petrol, Plus, 7-seat
- XC90, B6 AWD mild hybrid, petrol, Plus, 7-seat

The EX90 is manufactured in the USA and the XC90 models in Sweden. The lithium-ion (Li-ion) battery modules for EX90 and XC90 PHEV are manufactured in China.

Table 1 *Sample vehicles used in the study.*

Vehicle	Total mass (kg)	Li-ion battery capacity (kWh)	Cathode
EX90	2,748	111	NMC811
XC90 PHEV	2,328	18.8	NMC811
XC90 MHEV	2,143	0.37	NMC523

The foundation for the methodology used in this study was developed by Volvo Cars and Polestar for the carbon footprint studies of the EX40 and Polestar 2 in 2020. Further developments of the methodology and significant changes are explained in the sections below.

[1] A mild hybrid is a vehicle that has an electric motor to assist its internal combustion engine but does not have an electric-only mode of propulsion, whereas a plug-in hybrid does have an electric-only mode. The plug-in hybrid can be charged with electricity from external sources.

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4.2 Goal of the study

Volvo Cars has the ambition to reach net zero greenhouse gas emissions[2] by 2040 and to improve transparency in our environmental reporting. The goal of this study is to determine the carbon footprint of the EX90 in comparison with two hybrid models of a similar size. This comparison is valid as the same methodology and assumptions have been applied consistently in all vehicle assessments.
The purpose of all three vehicles is to transport passengers and their belongings. This report is aimed at our customers, employees, investors and other stakeholders interested in the environmental performance of our vehicles. The study was carried out to gain increased knowledge of the EX90's carbon footprint and determine which materials and processes have the greatest impact. The information in this report will assist efforts to reduce the carbon footprint of our future vehicles.

4.3 Scope of the study

The performed study is a Life Cycle Assessment (LCA), but it only considers greenhouse gas emissions, a so-called carbon footprint study.
The study has been carried out according to ISO 14067 standard and explores the global warming potential (GWP), using characterization factors for 100-year global warming potential from the latest assessment report (Sixth Assessment Report[3]) by the Intergovernmental Panel on Climate Change (IPCC). The following components of the carbon footprint 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

No carbon offsetting is accounted for.

This study covers the cradle-to-grave vehicle life cycle, from extracting and refining raw materials to end-of-life treatment, see Figure 1. The use phase includes routine maintenance, such as replacing tyres and windscreen wipers, as specified in the Life cycle inventory analysis.

No cut-off criteria have been applied for the mass of materials in parts or energy use, with the intention to ensure that the complete inventory is considered when quantifying the carbon footprint. Material content not specified by our part suppliers is included and modelled as a polymer. For more information, see the Life cycle inventory analysis.

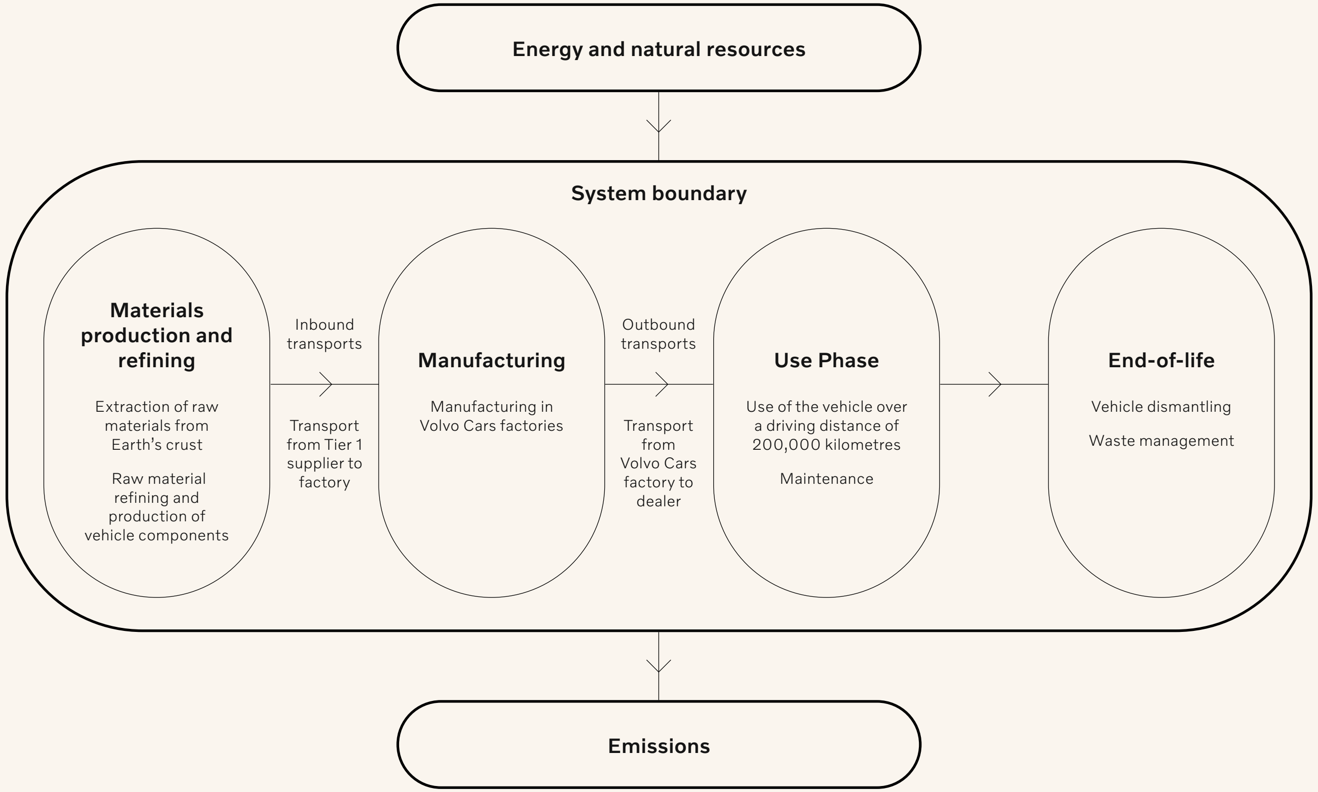

Figure 1 *System boundary of the study.*

[2] https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf
[3] https://www.ipcc.ch/assessment-report/ar6/

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The time boundary of the study relates to manufacturing in 2024 and a vehicle lifespan of 15 years, after which end-of-life handling is carried out. 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 greenhouse gases. The end-of-life handling aims to reflect global conditions in 2040, based on current conditions in 2023 in Sweden. This approach is conservative, as the vehicles are expected to be scrapped around 2040, by which time end-of-life handling is expected to have improved. However, the end-of-life handling varies between countries, which is not captured in the modelling and therefore underestimation of the impact is possible. Overall, this is assumed to be a reasonable approach.

The study follows an attributional approach, i.e., it is not aimed at capturing systemic changes.

The geographic boundary of the study relates to vehicle manufacturing in the USA for the EX90 and Sweden for the XC90 models. The vehicles are sold globally and, therefore, use phase charging with European and global electricity mixes, as well as wind-generated electricity, is assessed. Generic datasets are used for upstream processes, such as raw material production and refining, specific to the country or region in which they are conducted when the location is known or can be reasonably assumed, and when available. This is one step towards better data quality compared to the previous carbon footprint studies on EX40 and EC40 which used global datasets for upstream processes as first option.

The use of recycled aluminium, steel and polymers is also considered, unlike the EX40 and EC40 carbon footprint studies. Use of biobased material is considered for the natural rubber in tyres but not for other polymers. This is a conservative assumption that tends to overestimate impacts from the use of polymers, although the effect on overall results is minimal.

Generic data has been used for most upstream processes. The modelling of component production is based on material compositions, where generic datasets for material production and generic datasets for manufacturing processes have been combined for each material. Where no appropriate dataset is available to represent the manufacturing process for a certain material, resource use and emissions from raw material production have been multiplied by two as a compensatory measure. Although some stages in component value chains might not have been included, such as assembly processes, their contribution to the total carbon footprint are likely minimal.

4.3.1 Function and functional unit

The function of vehicles in this study is to transport persons and their belongings. The functional unit is vehicle-kilometre (vkm), whereas vehicle lifetime distance was used in previous carbon footprint studies for EX40 and EC40. Vehicle-kilometre more accurately reflects the function of the vehicle – its mobility – whereby longer lifetime distances lead to lower life cycle impact per vkm. In practice, carbon footprint is calculated for the total life cycle and divided by the distance driven during its lifespan. Carbon footprint results are also presented for the vehicle's total lifespan.

As the vehicles studied are of similar size, they are assumed to have the same occupancy rate.

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The effect of including number of passengers in the functional unit is explored in a sensitivity analysis. Inclusion of number of passengers in the functional unit enables comparison with other vehicles and modes of transport, provided that similar scope and methodology as in this study are applied. Due to lack of data of average passenger numbers, corresponding results have not been calculated, but the sensitivity analysis presents the outcome for different occupancy rates.

The reference flow in the study is the vehicle mass divided by the lifetime distance of 200,000 kilometres. The mass of vehicles in this study can be found in Table 1.

4.3.2 Allocation

This study uses the simple cut-off approach, also called the recycled content approach, which is the recommended allocation method in the EPD[4] system. This method follows the *polluter pays principle* which imply that if there are several product systems that share the same material, the environmental burden is assigned to the one that causes the waste. Reflecting this, the system boundary between the life cycles occurs at lowest market value of the materials. If waste material is not recycled or reused in new product systems, final disposal is included in the life cycle of the vehicle.

This means that a product made with recycled material carries the burden of the recycling process, and that no credit is given to a product system that generates material that is sent to recycling. This is applied both for the waste material that is sent to recycling from manufacturing processes as well as from end-of-life treatment. No system expansion has been applied in this study, thus no credits are given for materials being recycled and potentially avoiding other material production, or for energy recovered during waste incineration potentially avoiding other energy production.

Material waste from production processes is also accounted for by including the GHG emissions associated with the production of that material. This is especially relevant for steel and iron, and aluminium, for which production processes result in a significant amount of scrap material, which is sent for recycling. The total amounts of steel and iron, and aluminium considered are thus larger than the amount ending up in the vehicle.

Total number of vehicles produced at a manufacturing facility is used as the allocation basis, irrespective of the models or variants manufactured. Annual resource use and waste generation at facilities is divided by the total production volume when calculating impact per vehicle.

4.3.3 Primary assumptions, limitations and exclusions

Assumptions made in this study generally follow the precautionary principle in order to avoid underestimating the impact of uncertainties.

The use phase considers a vehicle lifetime of 15 years. Potential changes in European and global electricity mixes during this period are based on the International Energy Agency's (IEA) Stated Policies Scenario (STEPS). STEPS is a conservative benchmark that does not assume governments will achieve their announced environmental goals, commitments to the Paris Agreement or other climate targets and only considers the projected effect of policies that are in place, as well as those that have been announced. The effect of changes to electricity mixes in other IEA scenarios is evaluated in a sensitivity analysis.

The vehicles' lifetime distance is assumed to be 200,000 kilometres. The relative impact of longer lifetime distances is evaluated in a sensitivity analysis. Part replacements related to maintenance are considered, which does not include a vehicle's Li-ion battery as it is assumed to not reach EOL before vehicle EOL.

Vehicle energy use is calculated according to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) which uses the Worldwide Harmonised Light Vehicle Test Cycle (WLTC). Calculations include losses during charging and driving, but excludes use of non-essential auxiliary such as infotainment and air conditioning.

WLTC is based on analysis of a range of real-world driving conditions around the world. However, WLTP is a laboratory test and does not consider individual driver's driving style, traffic conditions, weather conditions, road inclination or load on the car (passengers and luggage), all of which can have a significant impact on actual energy usage. Detailed test procedures differ between different types of vehicles and drivetrains.

The shortened Type 1 test procedure is performed for BEVs. It consists of two dynamic segments, DS1 and DS2, combined with two constant speed segments (CSSM and CSSE). Dynamic segments are used to determine the energy consumption for the applicable WLTP test cycle. The constant speed

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

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segments are intended to reduce test duration by depleting the battery more rapidly than in the consecutive cycle Type 1 test procedure. Testing is carried out at an ambient temperature of 23 °C.

Exhaust emission compounds, CO_2 emissions and fuel consumption for PHEVs are determined in two test conditions; charge-depleting operating condition and charge-sustaining operating condition. Overall results are determined by the weighted combination of these test results based on the WLTP utility factor. The utility factor for a vehicle is established based on the range achieved in charge-depleting condition; longer electric range results in higher utility factor. Tests are carried out at an ambient temperature of 23 °C and are correlated to 14 °C (charge-sustaining operating condition only).

Proposed regulations for new vehicles sold in Europe from January 2025 will adjust parameters used to derive the utility factor to better reflect real-world driving (EURO6E-BIS)[5,6]. These draft regulations are considered for calculations in this study.

Vehicle occupancy rates are assumed to be the same for all vehicles in this study. The effect of including passenger numbers in the functional unit is explored in a sensitivity analysis.

This study does not include GHG emissions derived from:

- Our non-manufacturing operations, such as from business travels, research and development or other indirect activities.
- Our infrastructure, including construction and maintenance of buildings and production equipment.
- Construction and maintenance of roads and charging infrastructure.

[5] https://ec.europa.eu/transparency/comitology-register/screen/documents/082562/1/consult?lang=en (see Annexes 4-15, p27-28)
[6] https://theicct.org/wp-content/uploads/2022/12/euro6e-type-approval-dec22.pdf

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4.3.4 Data quality requirements

Data quality is assessed against requirements on several aspects to manage uncertainty. Table 2 provides an overview of the different aspects and corresponding requirements.

Table 2 *Data quality requirements.*

Aspect	Description	Requirements in this study
Time-related coverage	The age of data and the minimum length of time over which it is collected.	Generic data should be as recent as possible and no more than ten years old.
Geographical coverage	The region in which data for unit processes should be collected.	Material production and refining data should be representative of the region in which materials or components are produced, when known. Vehicle manufacturing data should be representative of its location. Use phase data should be representative of European and global averages. End-of-life data should be representative of global averages.
Technology coverage	The type of technology used (specific or average).	Data should be representative of the technology used in production processes.
Representativeness	The degree to which dataset modelling reflects actuality.	Primary data should be used that is representative of processes under our financial control. Secondary data may be used for upstream and downstream processes but should fulfil the above requirements for time-related, geographical and technology coverage.
Precision	The degree of variability in data values.	Data should be as representative as possible and obtained from reliable sources, with references provided.
Completeness	Ensuring all relevant input and output data is included for each dataset.	Generic data should be obtained from credible sources, such as recognised LCI databases. Internal data should cover all relevant inputs and outputs. Primary data collected from our direct suppliers should be jointly verified.
Reproducibility	Assessment of methodology and data. Ensuring independent parties can reproduce equivalent results.	Information about methodology and data (reference sources) should be provided.
Data sources	Assessment of the data sources used.	Data should be obtained from reliable sources, with references provided.
Information uncertainty	Inclusion of all data, models and assumptions.	Data should be obtained from credible sources, with references provided.

Data quality assessment is summarised below and explained in more detail in Appendix 3.

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Data quality varies significantly for temporal and geographic correlations. Datasets from ecoinvent LCI database were, in many cases, created more than 10 years ago, whereas Sphera's Managed LCA Content (MLC) datasets tend to be less than three years old. Datasets from both companies are updated every year, in response to for example changes in energy mixes. Geographic correlation varies, primarily due to the origin of many materials being unknown. However, battery modules and some aluminium, both associated with high impacts, are modelled with datasets with good geographic coverage. Electronics is also a high-impact category and scores poorly in terms of both time-related and geographic correlation, which should be considered when interpreting the results.

Overall, technological correlation has a large spread, although most of the data represents the technology well. Vehicle manufacturing and logistics data is of good quality and comes from our facilities and monitored processes. The use phase is also modelled with good quality data since electricity and fuel usage data are based on vehicle specific measurements and impact calculations are based on relatively recent emission factors from Sphera MLC and electricity mix data from IEA. End-of-life treatment receives less good scores, as current data is used and there is considerable uncertainty how it will change over the vehicle's lifespan. Similarly, waste handling varies significantly in different markets and changes in are difficult to predict.

Overall, data quality is considered sufficient concerning our operations and the vehicles' use phase. Data quality for materials production and refining, and end-of-life treatment varies widely, but is considered better for materials sourced directly by us, Li-ion battery modules and tyres.

In addition to quality rating, data has been verified by comparing the mass of the materials in the bill of materials (BOM) with the total vehicle mass, to ensure that the full mass of the vehicle has been captured in the model.

4.4 Report and critical review

This study has been conducted by Volvo Cars and will be published on its website in 2024. It contains the complete study, and there is no additional separate documentation. Compliance with ISO 14067 standard has been reviewed by a third party, see Appendix 8.

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4.5 Way of working summary

Figure 2 shows a high-level overview of how Volvo Cars works to derive the carbon footprint of vehicles.

This study uses LCA for Experts (LCA FE) modelling software developed by Sphera. Data is imported with a mapping tool called LCA BOM Import, in which each material is connected to a specific LCI and/or manufacturing process dataset. The primary data sources are:

- IMDS (International Material Data System) datasheets, containing information on the material composition of components.
- LCI databases from ecoinvent (version 3.9.1) and Sphera (Sphera MLC version 2023.2).
- Data from our operations, including manufacturing and logistics.
- LCA results from suppliers of Li-ion battery modules and tyres.

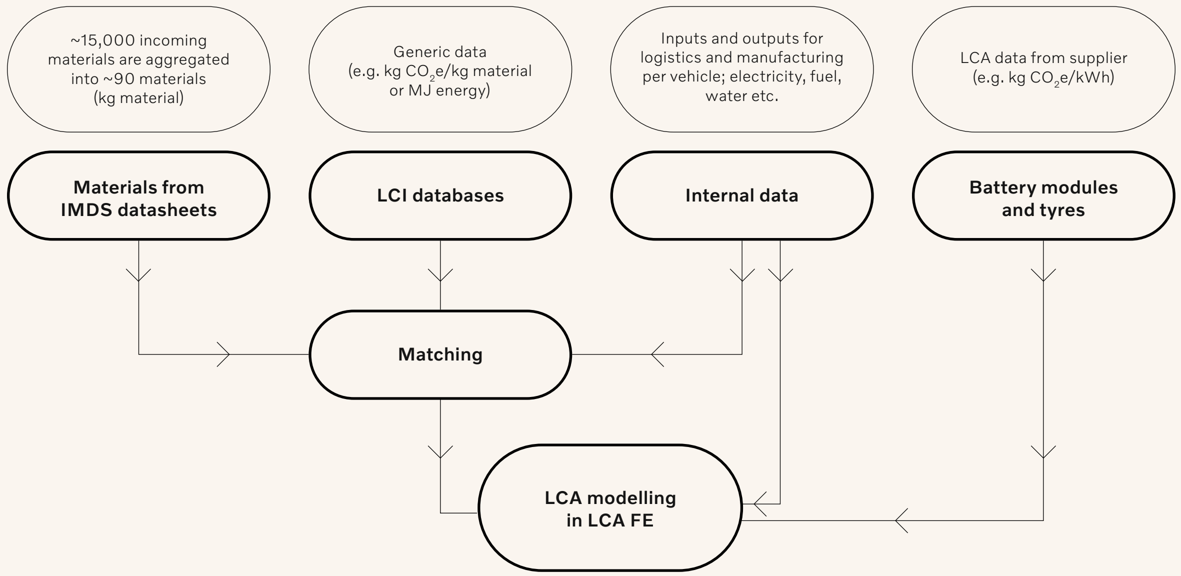

Figure 2 *Overview of way of working.*

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4.6 Methodology for defining material composition

The primary data sources for material composition are datasheets from IMDS for each vehicle component. For each vehicle a specific configuration has been chosen, corresponding to a certain combination of parts. By combining datasheets for each of these configurations, the total amount of material in each vehicle can be derived.

As the number of declared materials in IMDS datasheets for a vehicle may exceed 15,000, an aggregation tool converts the IMDS materials into approximately 90 material categories, which are imported to LCA FE. Material categories are further aggregated into material types when presenting the results, see Figure 3 and Table 3. The complete list of material categories can be found in Appendix 1.

Table 3 *Material types and categories.*

Material type	Number of material categories
Steel	5
Aluminium	1
Magnesium	1
Copper	2
Zinc	1
Lead, 12 V battery	1
Neodymium magnets	1
Polymers	Approx. 40 (incl. filled and unfilled)
Natural materials	3
Ceramics and glass	3
Electronics	15
Fluids	10
Undefined	1

IMDS datasheets provide reliable material composition data, although other relevant information such as recycled content or country of origin may be missing. Therefore, complementary data is gathered for many components. In some cases, material composition and carbon footprint data are provided by the supplier.

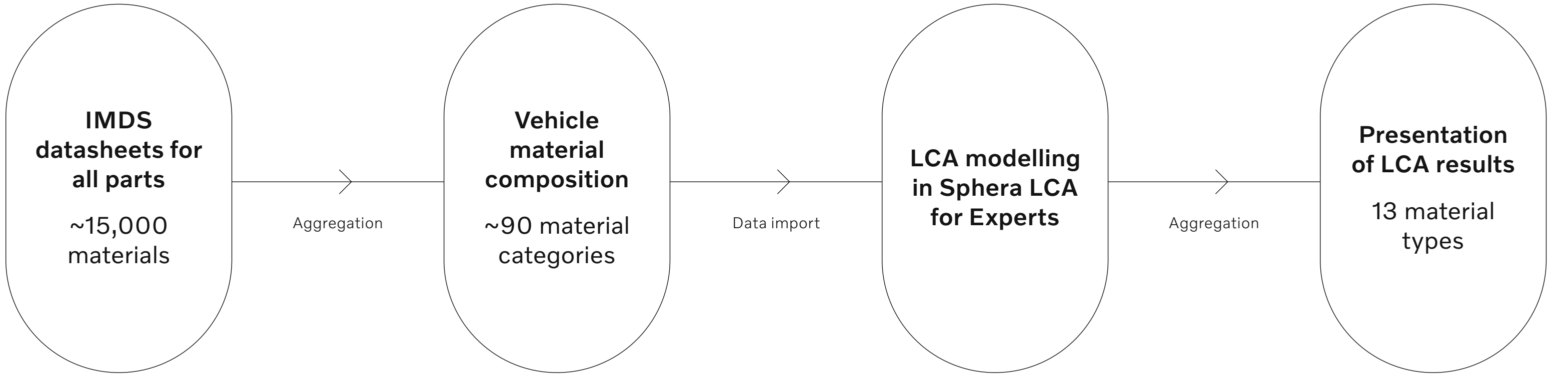

Figure 3 *Material aggregation steps.*

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5. Life cycle inventory analysis

This section outlines the various inputs and outputs considered in the study.

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5.1 Overview of life cycle and data

Figures 4, 5 and 6 display life cycle flowcharts for the EX90 and the two XC90 models. They show the type of data used in the study for different materials and life cycle stages, and Volvo Cars related production[7].

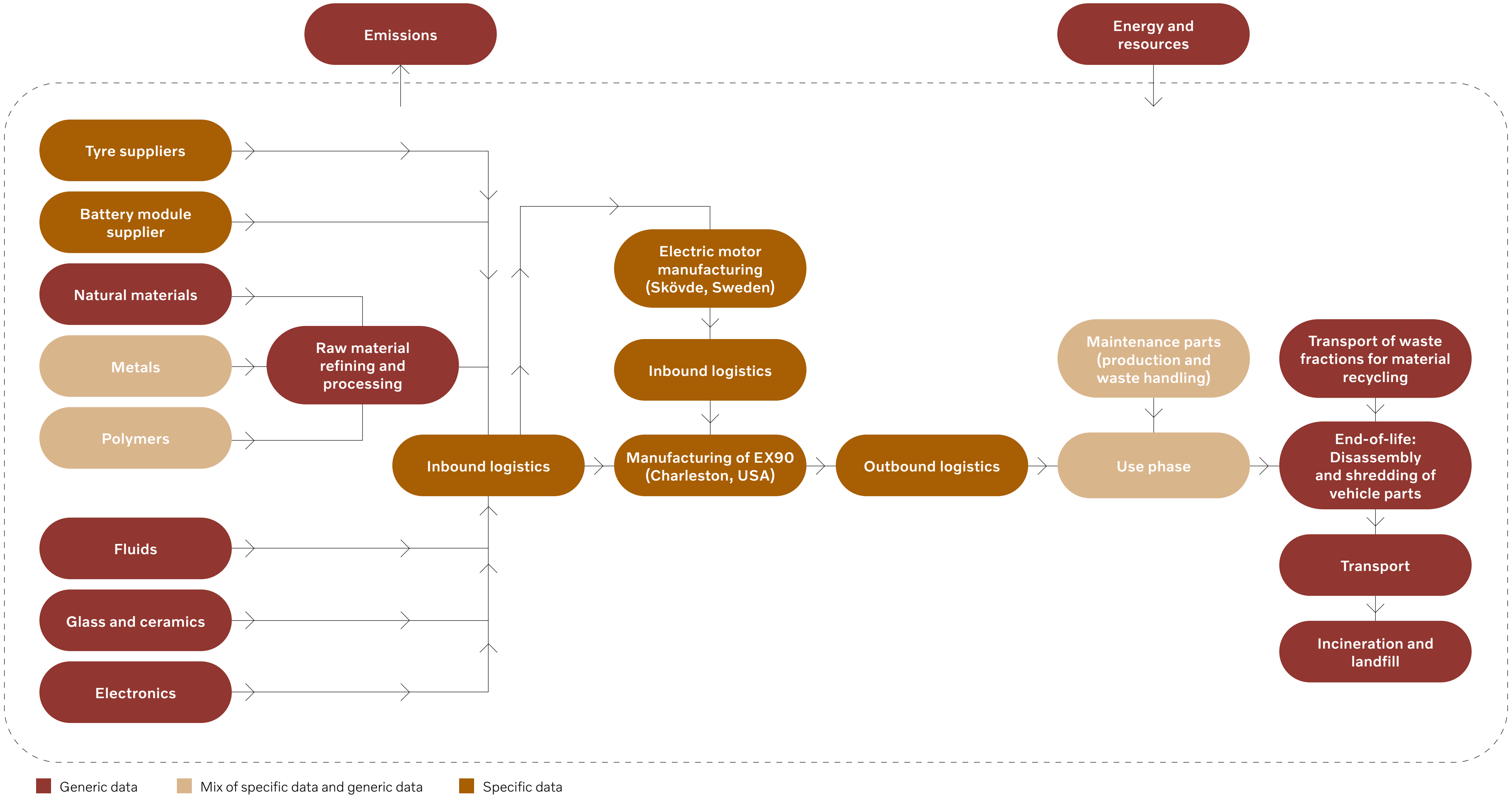

Figure 4 *Life cycle of the EX90.*

[7] *The Skövde plant was part of Volvo Cars until 2021 when it was transferred to Aurobay, a joint venture company owned by Volvo Cars and Geely Holding, and by end of 2022 Volvo Cars divested its holding in Aurobay. In parallel electric motor manufacturing was introduced on a separate production line, owned and operated by Volvo Cars, at the Skövde plant for Volvo vehicles. In this report, all impacts from engine and motor manufacturing have been included in "Volvo Cars manufacturing," despite some of the operations no longer being controlled by Volvo Cars.*

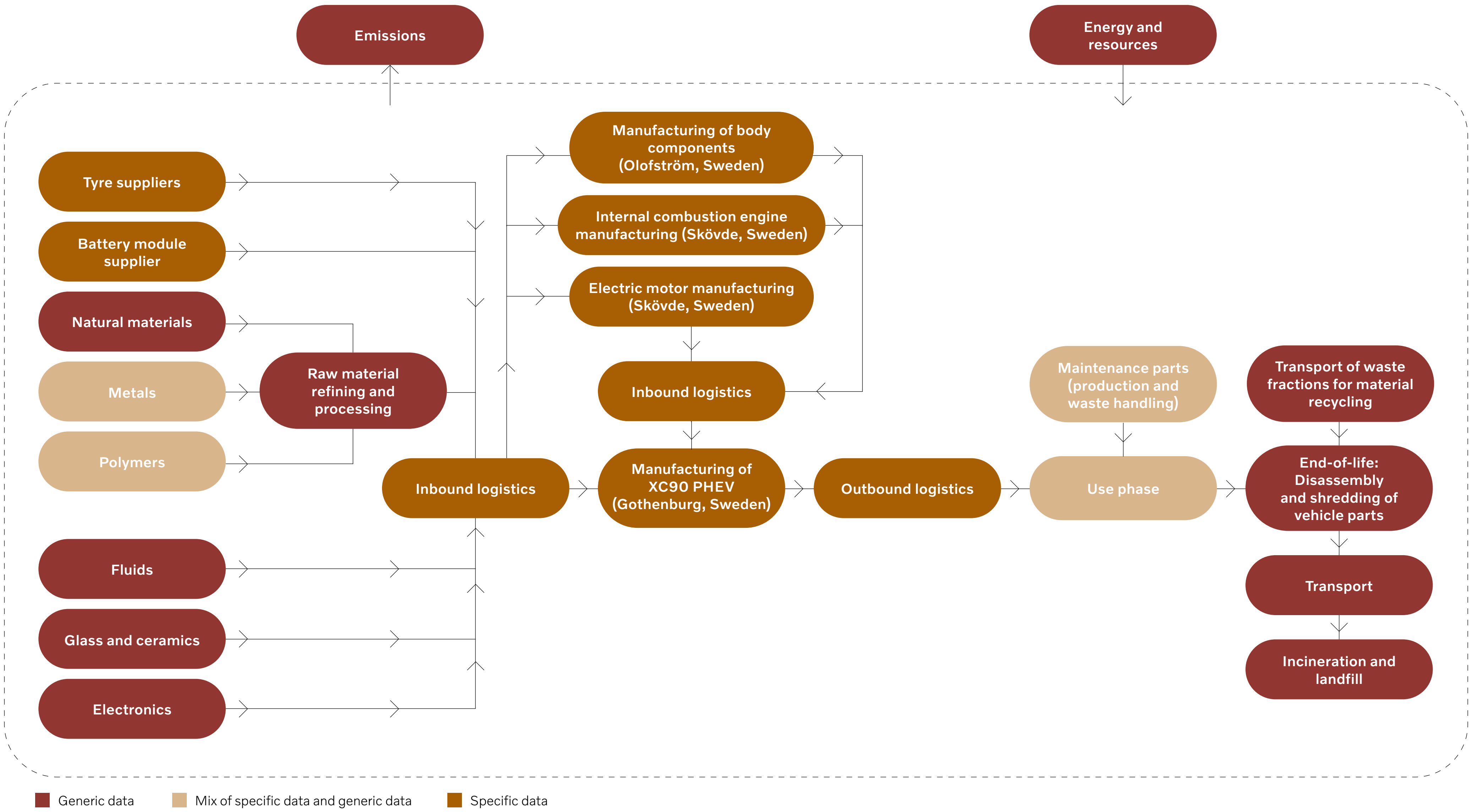

Figure 5 *Life cycle of the XC90 PHEV.*

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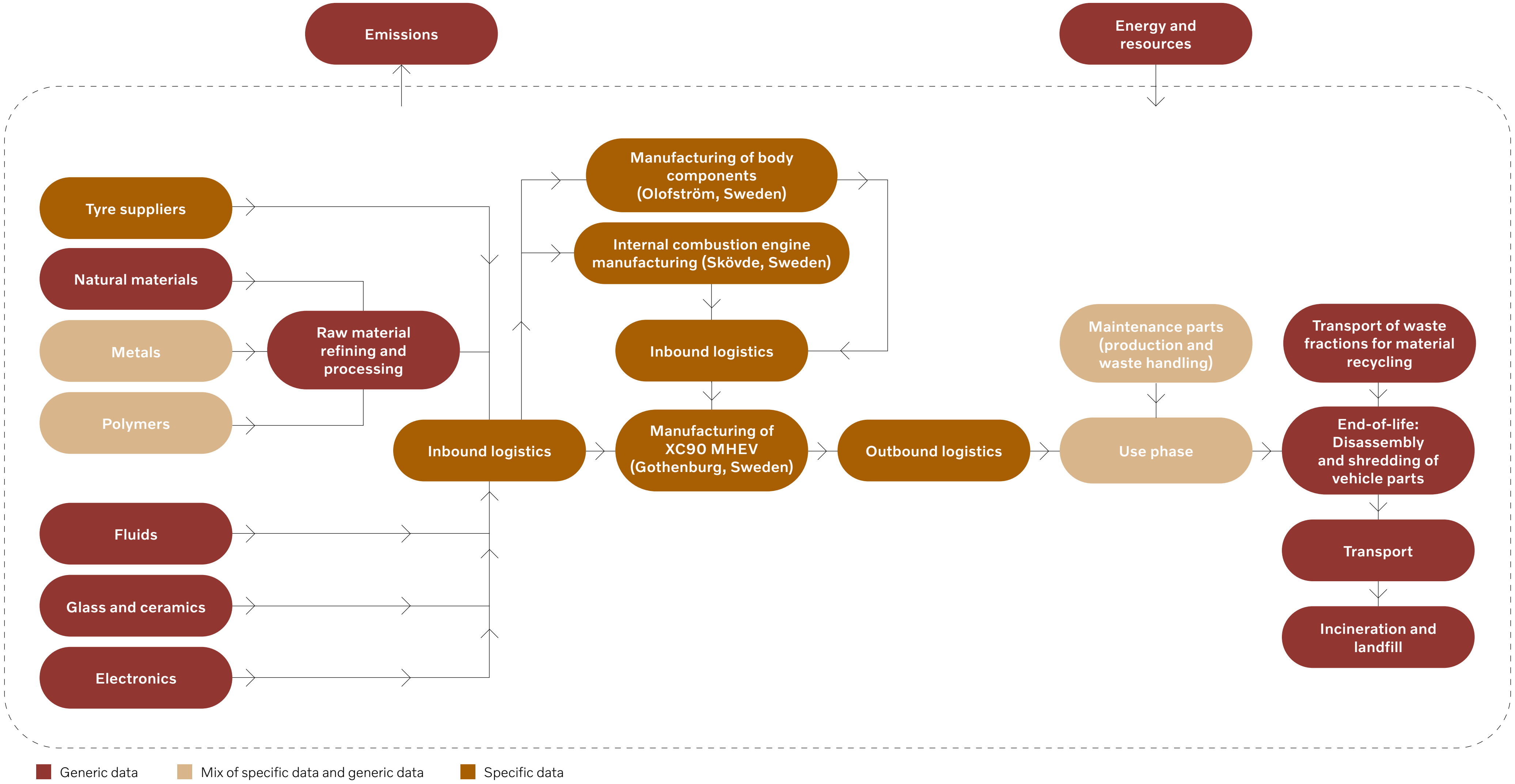

Figure 6 *Life cycle of the XC90 MHEV.*

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5.2 Material production and refining

Our modelling in LCA For Experts includes a division of the material composition into approximately 90 material categories, see section 4.6. The vehicle's total mass is divided into these material categories.

Each material is coupled with one or more LCI datasets, which represent production and refining in each material category. These are modelled with datasets from Sphera MLC and ecoinvent 3.9.1., see Appendix 2.

The material content corresponding to the total mass of a vehicle is included in the study, with a small amount categorised as "undefined material" in the material aggregation step. The share of undefined material is 1 per cent of the total vehicle mass. As this material category contains many undefined polymers, a dataset for polyamide (nylon 6) is used as an approximation, since it has the highest carbon footprint of the polymers included in this study.

Several datasets are used to represent the refining and production of components, see Appendix 2. Some of these datasets include both raw material production and component manufacturing. In these cases, no additional datasets are added.

The material composition of the vehicles is shown below in Figure 7 and Table 4.

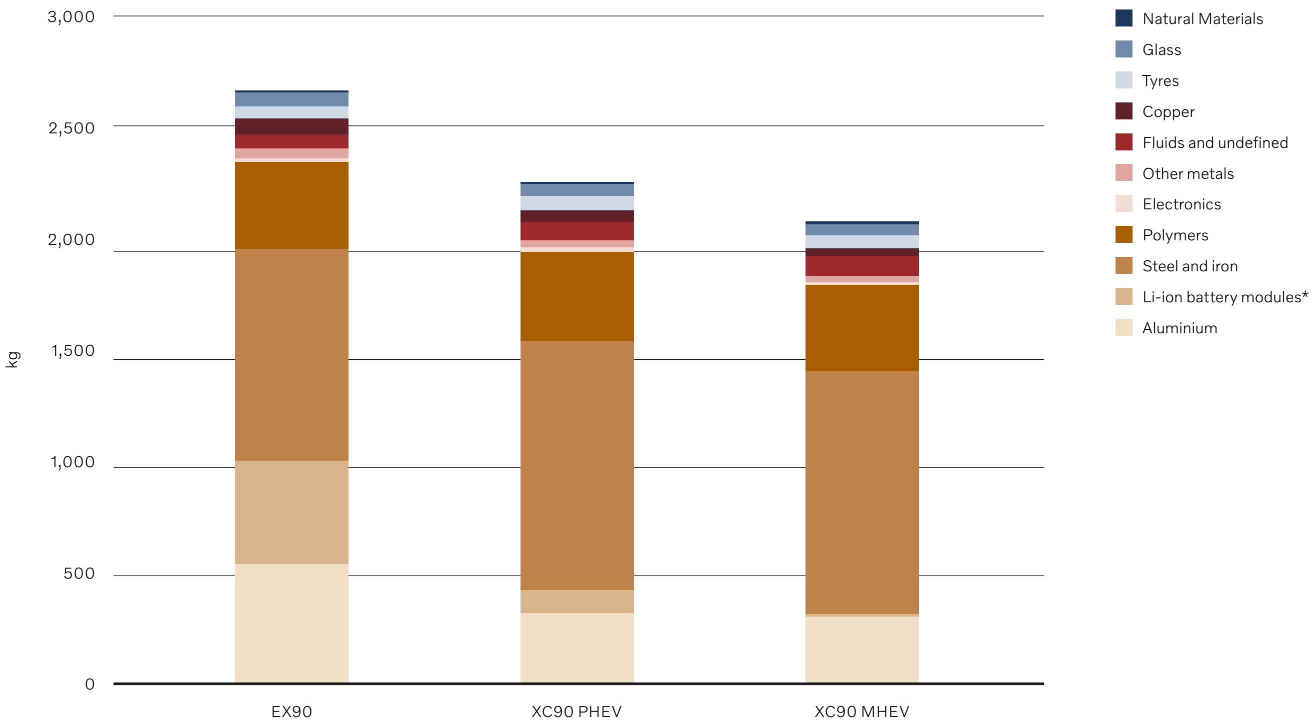

Figure 7 *Material compositions.*

** Includes the complete battery for XC90 MHEV.*

Table 4 *Material composition in mass percentage.*

** Includes the complete battery for XC90 MHEV.*

Vehicle	Aluminium	Li-ion battery modules*	Steel and iron	Polymers	Electronics	Other metals	Fluids and undefined	Copper	Tyres	Glass	Natural materials
EX90	20%	17%	36%	15%	0.50%	1.9%	2.3%	2.6%	2.2%	2.3%	0.16%
XC90 PHEV	14%	4.4%	50%	18%	0.39%	1.7%	3.9%	2.3%	2.7%	2.5%	0.31%
XC90 MHEV	15%	0.38%	53%	19%	0.34%	1.7%	4.0%	1.6%	2.9%	2.6%	0.32%

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5.2.1 Aluminium production and refining

Aluminium content is assumed to be 65 per cent cast and 35 per cent wrought, based on a report published by the European Aluminium Association[8]. In keeping with our conservative approach, an assumption is made that all wrought aluminium is processed into sheets, as sheet production has a lower material utilisation rate than other forms of wrought aluminium processing. Cast aluminium is modelled with a die-casting process.

Production waste from aluminium component manufacturing is included in impact calculations for each vehicle in this study, despite it being recycled and used in other products. The material utilisation rate for manufacturing cast and wrought aluminium can be found in Appendix 4.

The aluminium content of the EX90 is:

- 11 per cent primary, modelled with specific data from suppliers.
- 2 percent primary, produced in Canada.
- 4 per cent primary, produced in in China.
- 22 per cent recycled.
- 61 per cent from unknown primary sources, modelled on a global average.

The aluminium content of the XC90 models is assumed to come from primary sources exclusively, as data on recycled content was not available at the time this study was conducted.

5.2.2 Steel production and refining

The raw material dataset used for the unalloyed steel material category is cold rolled and hot dip galvanised. This is divided into two flows, with a process step added to both:

1. Steel sourced by Volvo Cars that is processed and stamped under the company's control, with a material utilisation rate from internal data.
2. Steel sourced and processed by suppliers, with a material utilisation rate from the corresponding generic dataset.

Production waste from steel component manufacturing is included in impact calculations for each vehicle in this study, despite it being recycled and used in other products. The material utilisation rates for steel components can be found in Appendix 4.

In conventional steel production, approximately 15 to 25 per cent steel scrap is added in order to enhance processing performance, according to the World Steel Association[9].

Half of the EX90's total steel content is sourced by Volvo Cars, of which:

- 70 per cent is produced in USA, with an average recycled content of 32 per cent.
- 30 per cent is produced in Europe, with an average recycled content of 20 per cent.

The remainder is sourced by the company's suppliers, of which:

- 9 per cent has an average recycled content of 28 per cent, based on supplier information.
- For the remaining percentage, the global average has been assumed, which implies a recycled content of 15 per cent recycled content (based on LCI dataset).

Thereby, the overall recycled content of steel in the EX90 is 23 per cent.

Production of steel in the XC90 models is modelled as global steel production. Based on information from suppliers, LCI dataset background data and Volvo Cars' steel specialists estimate, the overall recycled content is assumed to be 16 per cent.

5.2.3 Electronics production and refining

Electronics includes printed circuit boards (PCBs) and components mounted on them. It does not include chassis, cables or other components in electronic control units (ECUs), which are sorted into other material categories.

In many cases, ecoinvent's generic dataset for electronics has been used. This represents the production of lead-free, surface-mounted PCBs with typical electronic components mounted on them.

In order to improve accuracy, some electronic components have been identified in the vehicle list of parts on a more detailed level (capacitors, resistors etc.) and modelled by matching them to generic datasets from ecoinvent and Sphera MLC. Extra care has been taken for integrated circuits (ICs), since these are an environmental hotspot for electronics. The components of one ECU with a high number of ICs were matched manually with selected datasets from Extension database XI: Electronics from Sphera. The ecoinvent datasets used to model all other electronic components can be found in Appendix 2.

[8] https://european-aluminium.eu/wp-content/uploads/2022/10/aluminum-content-in-european-cars_european-aluminium_public-summary_101019-1.pdf
[9] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

5.2.4 Polymer production and refining

This material category regards polymer materials such as plastics, excluding rubber in tyres and polymers in natural materials. A dataset for injection moulding has been used to represent the processing of plastic parts from a polymer raw material. The material utilisation rate for plastic manufacturing processes can be found in Appendix 4.

13 per cent of polymers (including elastomers in the tyres) in the EX90 are recycled or biobased, in comparison with 6 per cent in the XC90 models. Recycled plastic is modelled with a dataset for mechanically recycled plastics.

Filled polymers contain talc and/or glass fibres, as detailed below in Table 5.

Table 5 *Content of fillers in polymers in the LCI model.*

Polymer	Talc content [%]	Glass fibre content [%]
E/P (filled)	20	
PA (filled)		20
PBT (filled)		30
PP (filled)	10	15

5.2.5 Material categories with no processing data

Raw materials processing data for approximately 6 per cent of total vehicle mass was unavailable in the LCI databases. In those cases, the material mass was doubled as a proxy for the processing. This means that the processing is assumed to have the same carbon footprint as the production of the raw material itself.

5.2.6 Electricity use in material production and refining

In most LCI datasets for material production and refining processes, it is not possible to modify the electricity source. For LCI datasets that allow modification, the global electricity mix has been used, see Appendix 2.

5.2.7 Battery modules

The EX90 battery comprises 17 battery modules that contain Li-ion battery cells. The cathode active material is an oxide containing nickel, manganese and cobalt while the anode active material consists of graphite.

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The battery module supplier for EX90 and XC90 PHEV carried out cradle-to-gate carbon footprint assessments for the battery modules, which were subject to our guidelines and review. For cell manufacturing and module assembly the supplier uses natural gas for heating, and hydropower electricity. Through an agreement between Volvo Cars and the battery module supplier, the suppliers of anode and cathode material are required to secure renewable electricity at their facilities by summer 2024 by acquiring International Renewable Energy Certificates (I-RECs), the effect of which is included in this study. The carbon footprint of the materials in the battery modules and energy used in anode, cathode, cell and module production processes have been assessed using datasets from Sphera MLC and ecoinvent.

The total mass of battery modules in the EX90 is 474 kilograms and 102 kilograms in the XC90 PHEV.

The materials and complex processes in battery manufacturing cause significant climate impact[10]. The diversity and accuracy of generic datasets for Li-ion batteries is limited, although inaccuracies are minimised by the provision of specific supplier information. Primary activities and system boundaries for the assessment of battery modules are illustrated in Figure 8.

The remaining parts of the EX90 and XC90 PHEV batteries have been modelled based on IMDS data and their mass and carbon footprint are included within corresponding material types in figures and tables. This includes for example the tray/carrier, battery and thermal management system, switch box, busbars, thermal barriers, and lid.

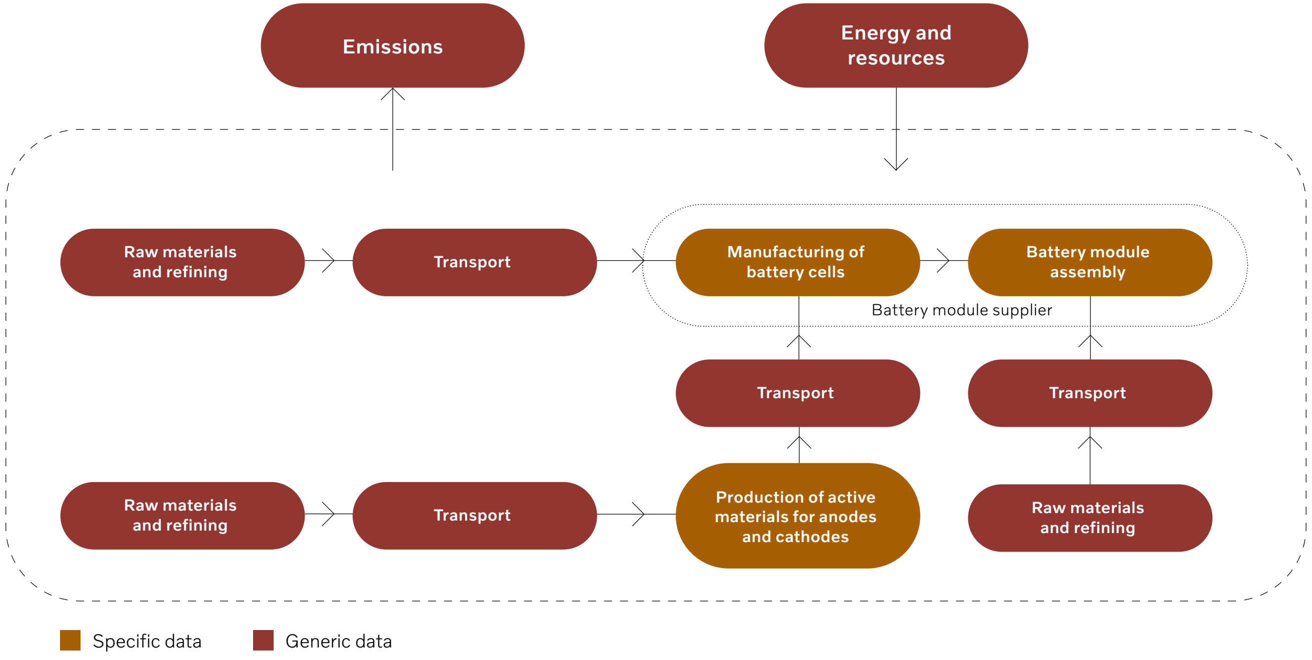
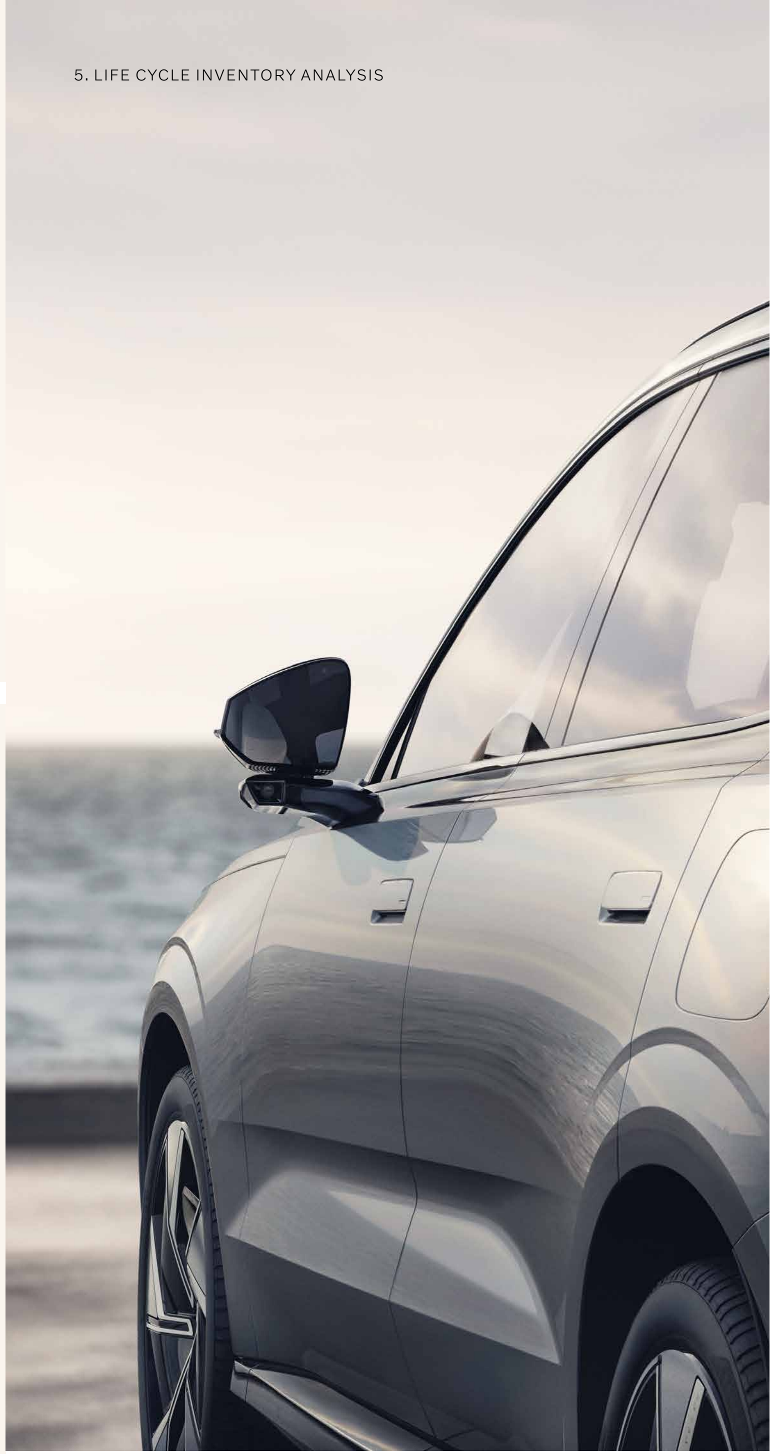


Figure 8 *Battery module manufacturing, cradle-to-gate.*

For XC90 MHEV the complete battery is sourced from a supplier and has in this study been modelled based on IMDS data, with a total mass of 8 kilograms. In figures and tables in this report where mass and carbon footprint are presented for EX90 and XC90 PHEV battery modules, corresponding information for the complete XC90 MHEV battery is provided to enable a reasonable comparison.

In the EU, a new battery regulation was adopted in summer 2023 which requires among other things 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 (some not decided at time of writing), and it's important to be aware that those are not the same as what has been used in this LCA study, since the purposes differ. We will follow the EU battery regulation and calculate the battery carbon footprints according to related rules and disclose the results according to related requirements, once finalised, however those have not been used in this study and are not presented in this report.

[10] *https://www.mdpi.com/2313-0105/5/2/48*



5.2.8 Tyre production

The climate impact of tyres fitted to the EX90 and XC90 models has been calculated from assessments made by their supplier in accord with our guidelines. IMDS data was used to represent the material composition of tyres exchanged during the life cycle of vehicles and assessed by Volvo Cars.

The supplier used LCA For Experts software to model carbon footprint, using Sphera MLC materials datasets. The all-season tyres, fitted to all models, have a combined mass of 59.6 kilograms on the EX90 and 62.4 kilograms on the XC90 models. The primary activities and system boundaries for the assessment of tyre manufacturing are illustrated in Figure 9.

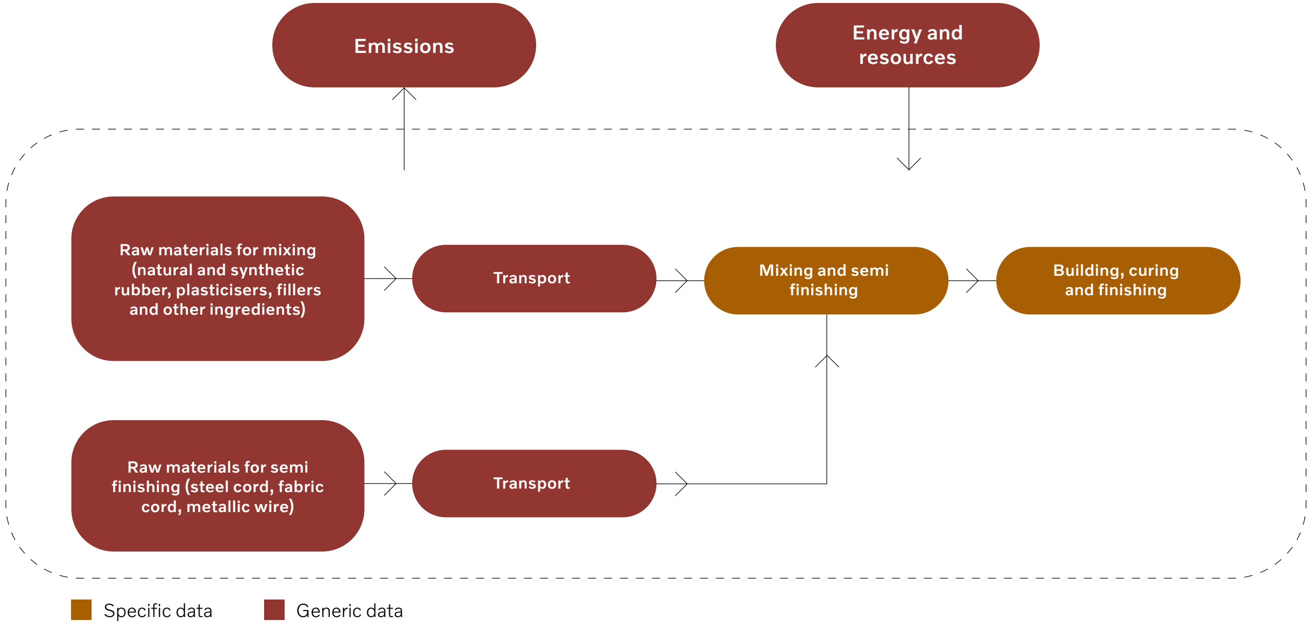


Figure 9 *Tyre manufacturing, cradle-to-gate.*

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5.3 Manufacturing and logistics

5.3.1 Logistics

Company data is used to calculate the impact of inbound transport (component transportation from direct suppliers to our manufacturing facilities). Total emissions from inbound transportation are divided by the total number of vehicles produced. Company data is also used to calculate the impact of outbound transport (transportation of products from our facilities to our dealers). Total emissions from outbound transport are divided by the total number of vehicles sold. Sphera MLC datasets were used to model the impact of sea, rail, road and air transportation, see Appendix 2.

5.3.2 Vehicle manufacturing

Although the EX90 is manufactured in the USA, its electric motor is made in Sweden. Both XC90 models are entirely manufactured in Sweden. Data on water use, energy consumption and waste generation is collected from all manufacturing facilities, with allocation based on total output of vehicles, components and motors. In some cases, forecasts based on historic data were used. The datasets used to model manufacturing impact are listed in Appendix 2.

By applying this data to the production of electric motors, internal combustion engines and body components, there is a slight double-counting of the impacts since in the generic modelling of the materials production and refining, the processing for making the components in the vehicles is already included. This approach was taken due to the difficulty of accurately separating out the related individual components, but the overlap is estimated to be small with minimal effect on overall result.

5.4 Use phase

5.4.1 Driving

The climate impact of driving is calculated by combining energy use per kilometre with the impact of electricity generation, fuel production and combustion. Energy use is based on WLTP results and includes losses from charging and driving, as well as the use of essential auxiliary systems. Table 6 shows the energy use for each vehicle.

Table 6 *Energy use in driving.*

	Electricity use (kWh/100 km)	E5 petrol use (l/100 km)*	Total energy use (kWh/100 km)
EX90	20.9		20.9
XC90 PHEV**	13.6	3.5	45.2
XC90 MHEV		9.1	82.1

** The energy content in E5 petrol is 9.02 kWh/l[11]*

*** The weighted WLTP driving cycle corresponds to 63.5 per cent of total distance driven in electric mode, in accord with EURO6E-BIS[12] regulations.*

The vehicles' use phase is estimated to be 15 years. Over an estimated lifetime distance of 200,000 kilometres, 50 per cent is allocated to the first five years, 30 per cent to the subsequent five years and 20 per cent to the last five years, as illustrated in Figure 10. These estimates are based on the ED11344 European Commission report, issue number 3[13], and warranty data.

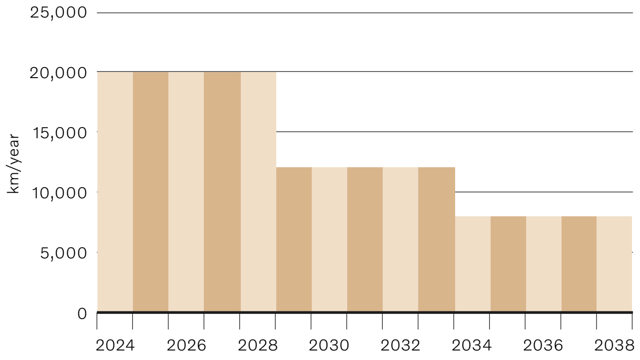

Figure 10 *Annual driving distance in the use phase.*

The impact of electricity generation is modelled on European and global electricity mixes, as well as wind-generated electricity. Electricity generation mixes are based on the IEA's World Energy Outlook 2022 Extended Data. Electricity generated from different sources is paired with Sphera LCI datasets (see Appendix 2) to calculate both direct and upstream impact.

[11] https://www.preem.se/contentassets/287803866adc43f1b9b68dceb8c07aff/bensin-95-bensin-98.pdf
[12] https://ec.europa.eu/transparency/comitology-register/screen/documents/082562/1/consult?lang=en (see Annexes 4–15, p 27–28)
[13] https://climate.ec.europa.eu/system/files/2020-09/2020_study_main_report_en.pdf

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The IEA uses the Global Energy and Climate Model to explore possible future energy related scenarios, based on a number of assumptions. In this study, the Stated Policies Scenario (STEPS) was used to determine the changes over time of electricity sources used for vehicle charging, as shown in Figure 11 and Figure 12. STEPS reflects current and potential future policy in a range of sectors and countries. Two other IEA scenarios are evaluated in the sensitivity analysis.

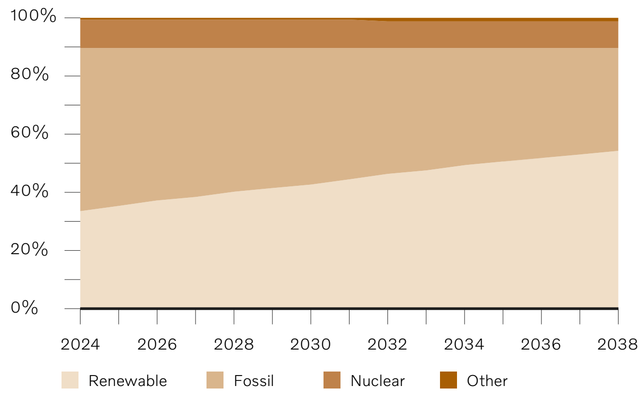

Figure 11 *Changes in the global electricity generation mix for STEPS.*

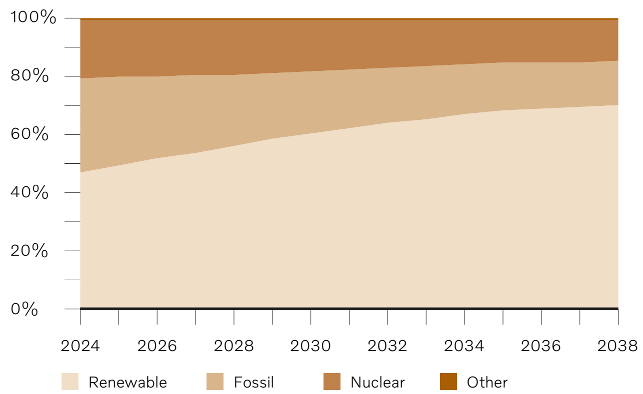

Figure 12 *Changes in the European electricity generation mix for STEPS.*

Average use phase emissions, based on the annual driving distances and according to the STEPS projection, are 0.45 kg CO_2e/kWh for the global electricity mix and 0.18 kg CO_2e/kWh for the European electricity mix.

The XC90 models are assumed to be fuelled with petrol blended with 5 per cent ethanol (E5 petrol).

5.4.2 Maintenance

The quantity of components replaced in routine vehicle maintenance are detailed in Appendix 5, based on sales data, service book recommendations and input from our aftermarket sales specialists. Modelling of production and end-of-life handling applies the same methodology used for all other components.

5.5 End-of-life

It is assumed that all vehicles will receive appropriate end-of-life treatment, which was modelled to represent global average situations as far as possible.

As described in the Allocation section, the simple cut-off approach is applied to end-of-life treatment. Consequentially, for recycled material the impact of dismantling and pre-treatment (such as shredding) is included but not material separation, refining or credit for reuse in other products.

End-of-life treatment begins with a disassembly step to remove hazardous components and parts that are candidates for specific recycling efforts. The disassembled parts are treated and the remaining vehicle is shredded, with the resulting fractions used for material recycling, incineration or landfill deposition.

In the disassembly stage, the following hazardous and valuable components are removed:

- Batteries, wheels and tyres
- Coolant, antifreeze, brake, shock absorber and windscreen washer fluids
- Refrigerant
- Airbags and seat belt pretensioners

Coolants are primarily incinerated. An assumption is made that 55 per cent of tyres are recycled and 45 per cent incinerated. Airbags and seat belt pretensioners, removed for safety reasons, are incinerated. 12-volt batteries are sent for lead recovery and the Li-ion battery is assumed to be recycled. Recycling legislation is assumed to be more stringent at the end of the estimated use phase.

Shredded material is separated into fractions including:

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

The metal fractions can be sent for further refining and material recycling. Shredder light fraction can be incinerated for energy generation or sent to landfill sites. For the purposes of this study, it is assumed that combustible materials are incinerated and non-combustible materials sent for landfill.

Energy recovery is not included in this study, due to an absence of comprehensive data. Material losses in shredding and refining are outside the system boundaries determined by the simple cut-off approach.

An overview is provided in Figure 13 and more information about modelling end-of-life treatment can be found in Appendix 6.

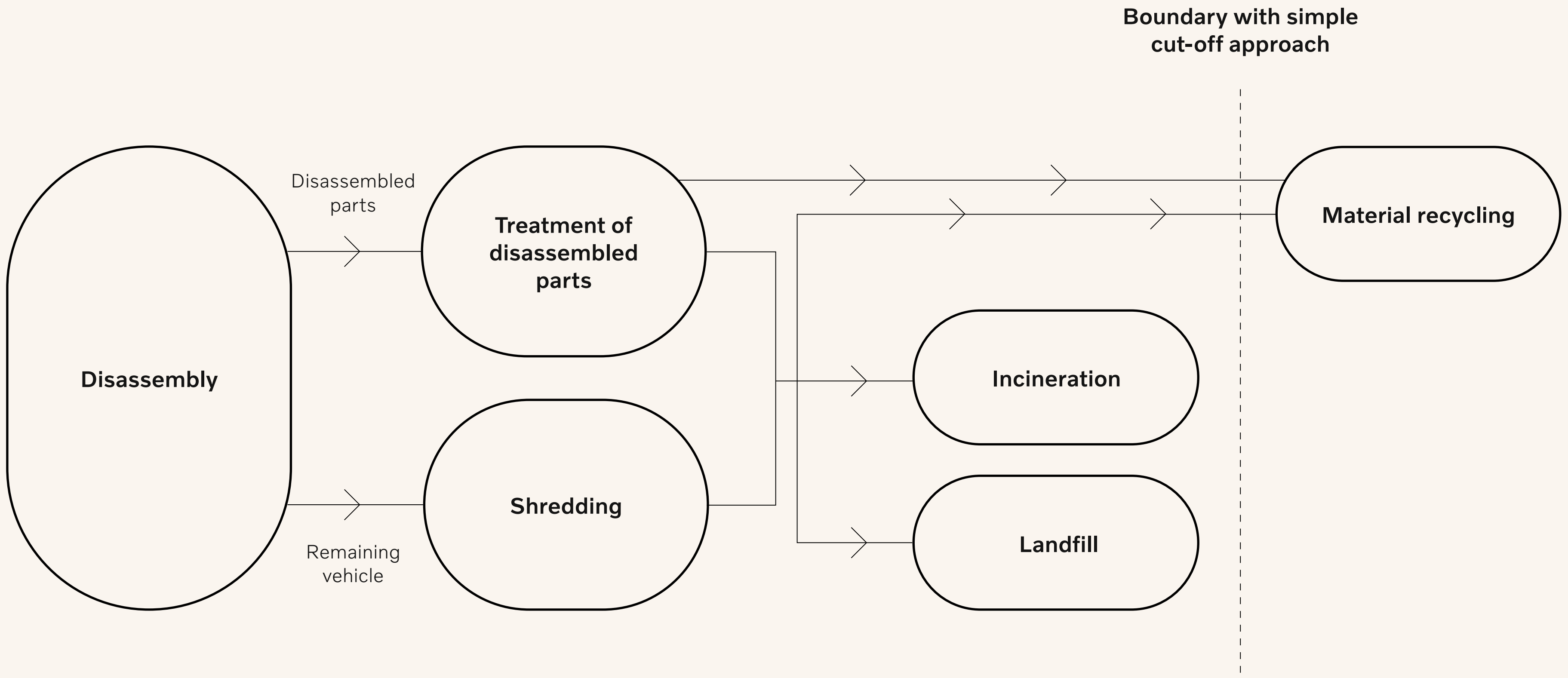

Figure 13 *System boundary at end-of-life.*

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6. Life cycle impact assessment

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For the life cycle impact assessment phase, the life cycle inventory data are interpreted in terms of potential contribution to climate impact. Results are based on available data at the time of the study and are regarded to be representative for 15 years after publication, i.e. until 2039. The quantified results in this report have been rounded to two significant digits in order to improve clarity and consistency in report, as well as to acknowledge inherent uncertainties.

The life cycle carbon footprints of EX90 driven with three different electricity mixes are shown in Figure 14, while Figure 15 shows the results for the three different vehicles with European electricity mix for charging. Table 7 and Table 8 provides the values represented in the figures.

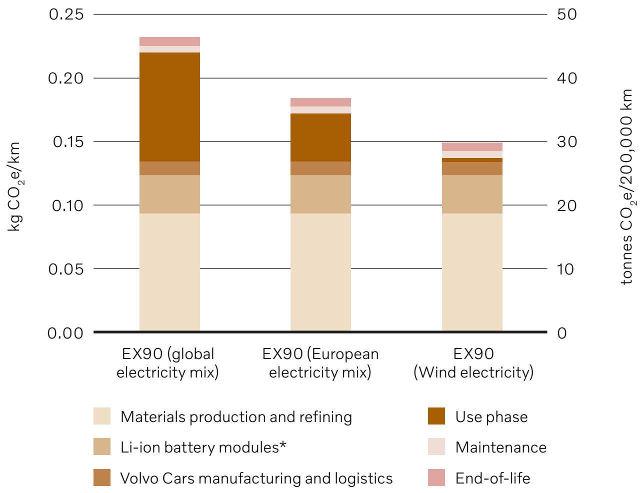

Figure 14 *The EX90's carbon footprint when charging with different electricity mixes.*

** Includes the complete battery for XC90 MHEV.*

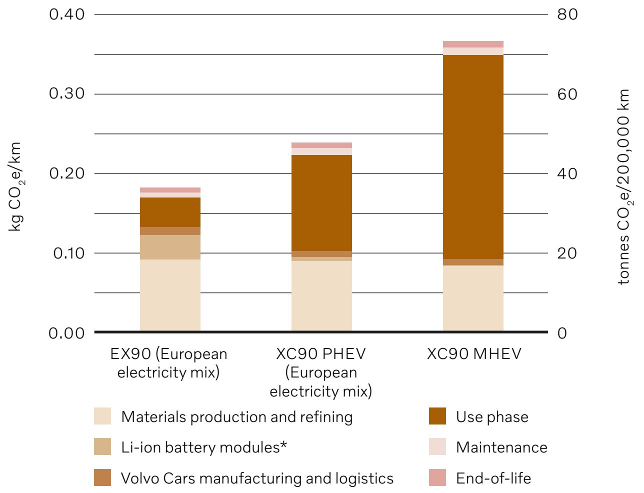

Figure 15 *Carbon footprint when charging with European electricity mix.*

** Includes the complete battery for XC90 MHEV.*

Table 7 *Total carbon footprint, per vehicle km and lifetime distance.*

	EX90 (Global electricity mix)	EX90 (European electricity mix)	EX90 (Wind electricity)	XC90 PHEV (European electricity mix)	XC90 MHEV
Carbon footprint (kg CO_2e/vehicle km)	0.23	0.18	0.15	0.24	0.37
Carbon footprint (tonnes CO_2e/200,000 km)	46	37	30	48	73

Table 8 *Total carbon footprint in kg CO_2e per vehicle km of different life cycle stages.*

** Includes the complete battery for XC90 MHEV.*

	Materials production and refining	Li-ion battery modules*	Volvo cars manufacturing and logistics	Use phase	Maintenance	End-of-life
EX90 (global electricity mix)	0.094	0.031	0.010	0.086	0.0055	0.0067
EX90 (European electricity mix)	0.094	0.031	0.010	0.038	0.0055	0.0067
EX90 (wind electricity)	0.094	0.031	0.010	0.0029	0.0055	0.0067
XC90 PHEV (global electricity mix)	0.092	0.0052	0.0073	0.15	0.0089	0.0070
XC90 PHEV (European electricity mix)	0.092	0.0052	0.0073	0.12	0.0089	0.0070
XC90 PHEV (wind electricity)	0.092	0.0052	0.0073	0.097	0.0089	0.0070
XC90 MHEV	0.086	0.00063	0.0073	0.26	0.0089	0.0068

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When charged with wind-generated electricity, the EX90 causes the lowest climate impact, according to this study. The results show that the climate impact of material production and refining, manufacturing and logistics are greater for the EX90 than the XC90 models, primarily due to emissions caused by Li-ion battery production. The EX90, when charged with the European electricity mix, causes less emissions over its full lifetime than the XC90 PHEV and significantly less emissions than the XC90 MHEV, which consumes more E5 petrol than the PHEV variant.

In Figure 16, accumulated use phase emissions (with European electricity mix for charging) is displayed for each vehicle, with all non-use-phase emissions summarised at 0 km distance driven, illustrating the distances at which emission amounts intersect.

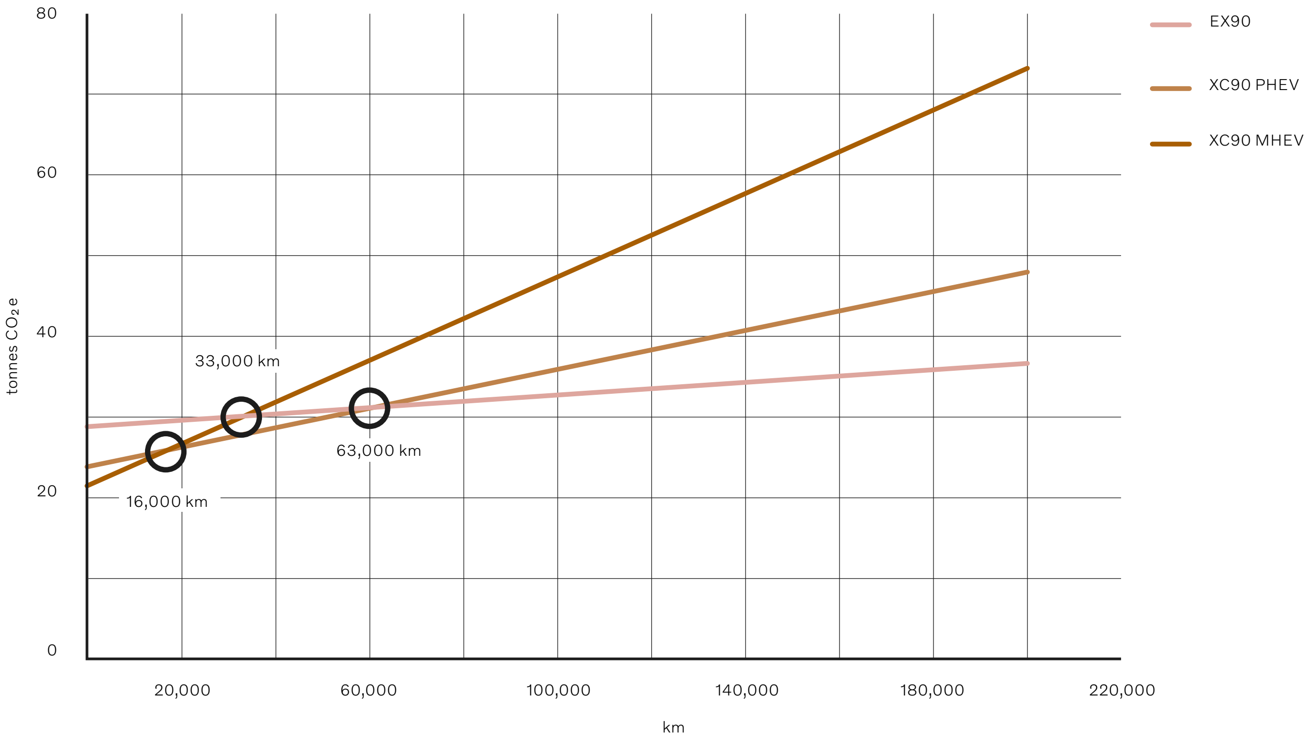

Figure 16 *Accumulated emissions, when charging with European electricity mix. All non-use-phase emissions are summarised at 0 kilometres distance driven.*

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Figure 17 and Table 9 illustrate the climate impact of material production and refining for the vehicle models in this study.

Aluminium is the major contributor to material production and refining emissions for all three vehicles, primarily due to electricity consumption in smelting.

Emissions from the production of Li-ion batteries are 25 per cent of total for the EX90, due to high energy consumption for cell production from mining to the actual cell production.

Steel and iron is the third largest contributor to production and refining emissions for the EX90 (17 per cent), and the second largest contributor for the XC90 PHEV (28 per cent) and the XC90 MHEV (31 per cent). This is primarily due to the use of the blast furnace-basic oxygen furnace route in steel production.

Polymers account for 15 per cent of production and refining emissions for the XC90 MHEV and 14 per cent for the XC90 PHEV, the third largest emissions-contributing material category for both vehicles.

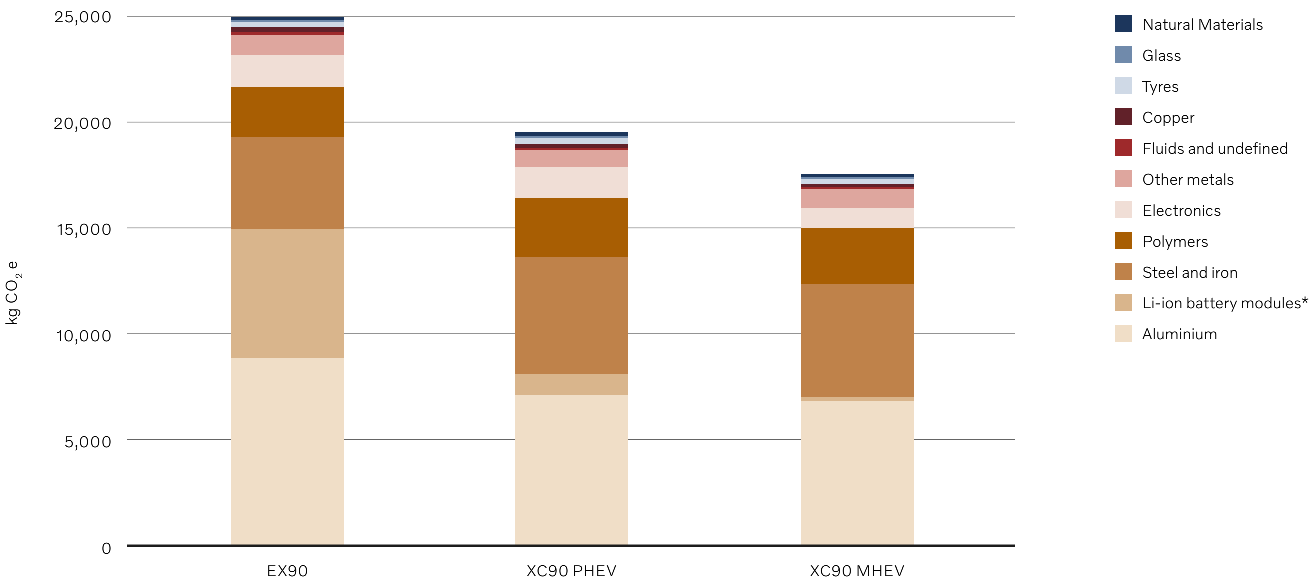

Figure 17 *Carbon footprint from materials production and refining.*

** Includes the complete battery for XC90 MHEV.*

Table 9 *Carbon footprint from materials production and refining in percentages.*

** Includes the complete battery for XC90 MHEV.*

Vehicle	Aluminium	Li-ion battery modules*	Steel and iron	Polymers	Electronics	Other metals	Fluids and undefined	Copper	Tyres	Glass	Natural materials
EX90	36%	25%	17%	10%	5.8%	4.0%	0.25%	1.3%	0.83%	0.57%	0.13%
XC90 PHEV	36%	5.3%	28%	14%	7.5%	4.1%	0.49%	1.3%	1.2%	0.77%	0.48%
XC90 MHEV	39%	0.72%	31%	15%	5.3%	4.9%	0.49%	0.93%	1.3%	0.79%	0.53%

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6.1 Life cycle impact assessment by components

As described in the scope of the study, the carbon footprint consists of several components, for which the results are shown in Figures 18–20 and Tables 10–12 (with European electricity mix for charging). Not all inventory data for material production contain separated values for aircraft emissions or emissions from land use. In those cases, such emissions are assumed to be included in the fossil GHG emissions component.

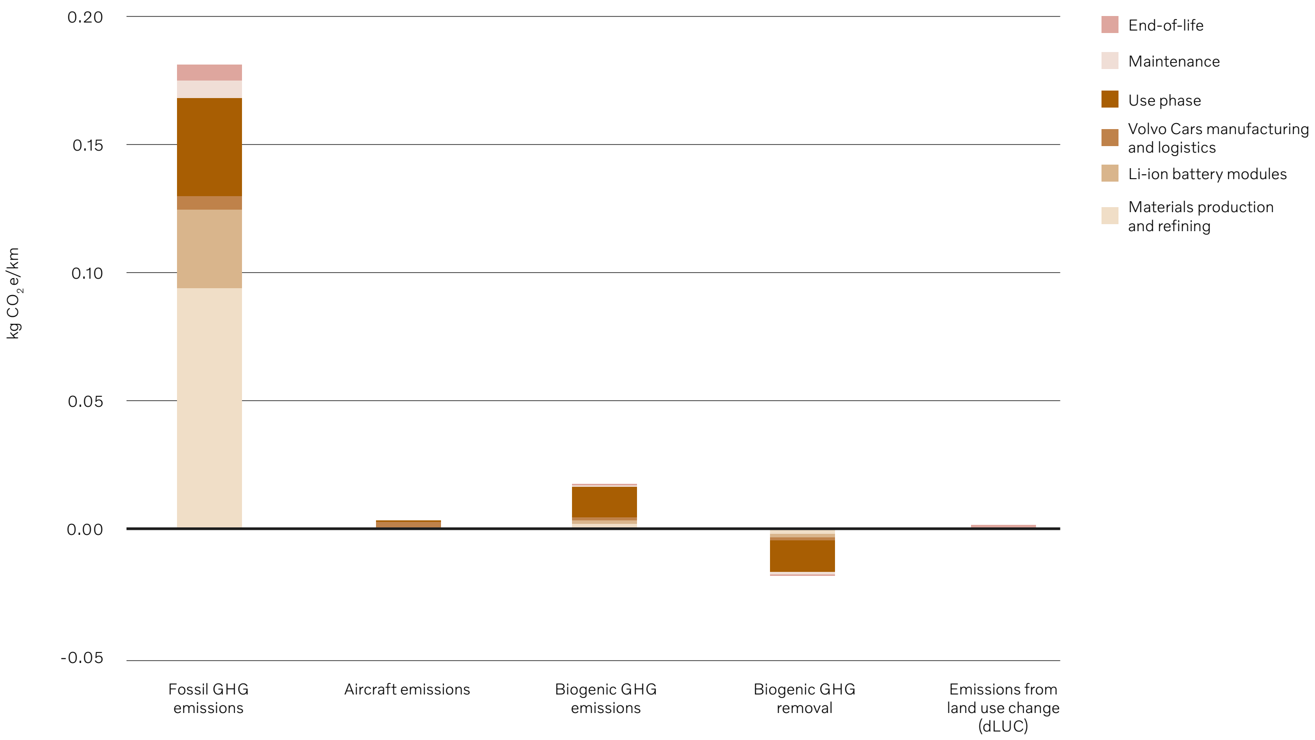

Figure 18 *Results for the five components according to ISO 14067 for EX90 when charging with European electricity mix.*

Table 10 *Results for five components according to ISO 14067 for EX90 when charging with European electricity mix.*

EX90 European electricity

kg CO_2e per vehicle km	Materials production and refining	Li-ion battery modules	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
Fossil GHG emissions	9.4E-02	3.0E-02	5.5E-03	3.8E-02	6.4E-03	6.6E-03
Aircraft emissions	1.8E-07	7.9E-06	1.9E-03	1.5E-07	1.2E-09	2.9E-10
Biogenic GHG emissions	1.6E-03	1.1E-03	1.2E-03	1.2E-02	1.8E-04	1.8E-04
Biogenic GHG removal	-1.8E-03	-1.1E-03	-1.1E-03	-1.2E-02	-1.1E-03	-6.9E-05
Emissions from land use change (dLUC)	1.2E-04	7.6E-06	2.1E-05	3.7E-06	2.8E-06	5.5E-06

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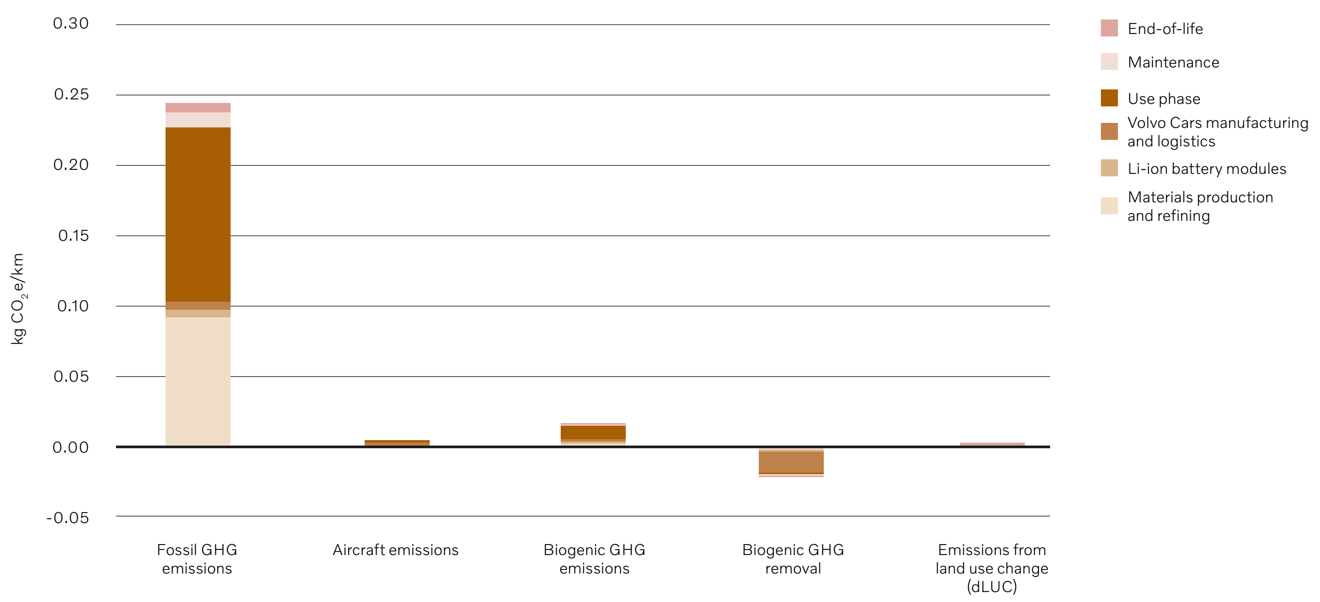
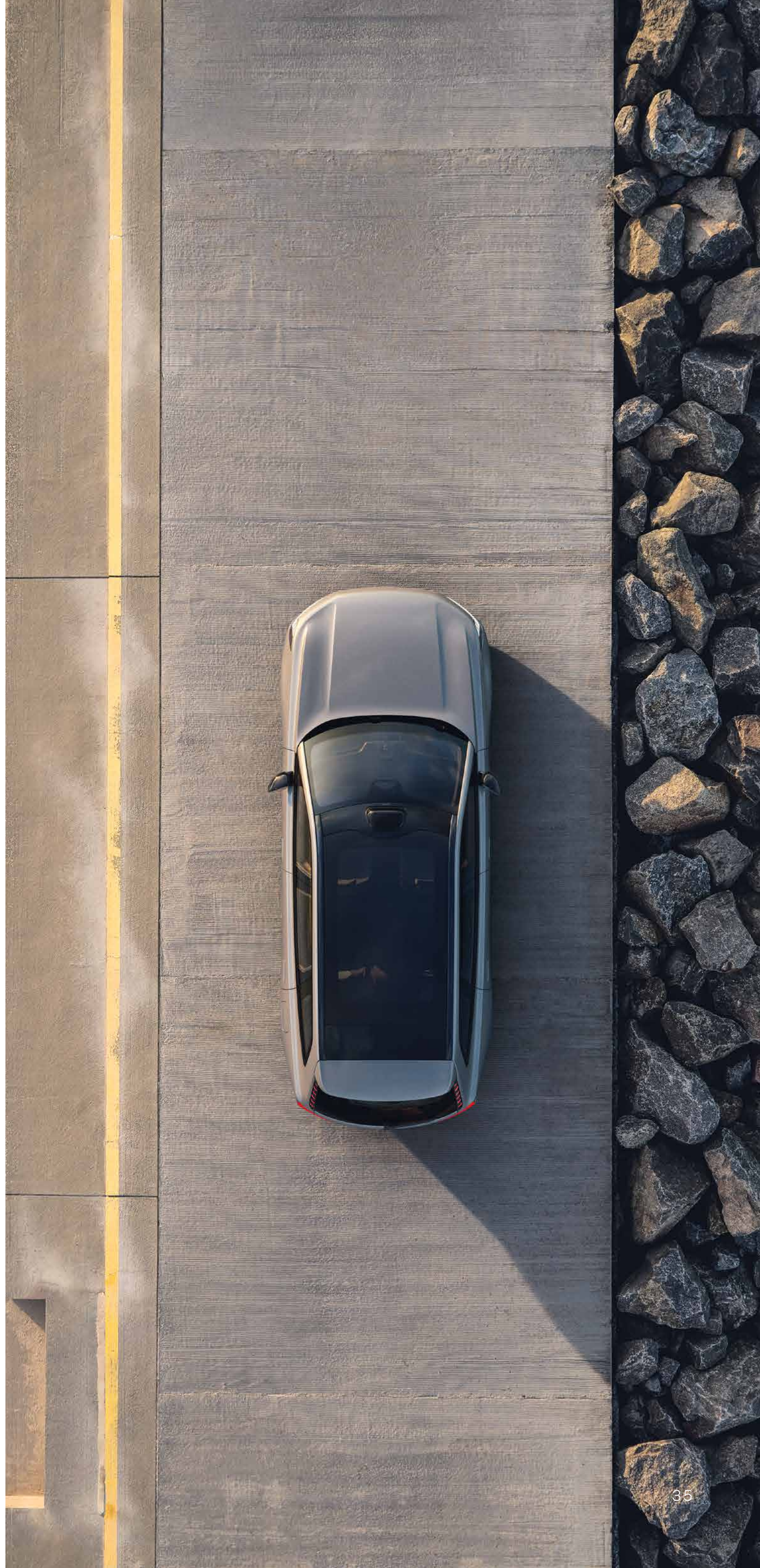


Figure 19 *Results for the five components according to ISO 14067 for XC90 PHEV when charging with European electricity mix.*

Table 11 *Results for the five components according to ISO 14067 for XC90 PHEV when charging with European electricity mix.*

XC90 PHEV European electricity

kg CO_2e per vehicle km	Materials production and refining	Li-ion battery modules	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
Fossil GHG emissions	9.1E-02	5.2E-03	5.4E-03	1.2E-01	9.9E-03	6.9E-03
Aircraft emissions	2.0E-08	1.3E-06	1.9E-03	1.0E-07	1.5E-09	2.4E-10
Biogenic GHG emissions	2.8E-03	1.9E-04	1.2E-03	1.0E-02	2.6E-04	1.8E-04
Biogenic GHG removal	-1.8E-03	-1.8E-04	-1.1E-03	-1.5E-02	-1.2E-03	-5.8E-05
Emissions from land use change (dLUC)	1.2E-04	1.3E-06	2.1E-05	5.5E-04	3.9E-06	4.6E-06



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Nearly all GHG emissions have fossil origin, with biogenic GHG emissions being the second largest still ending up at significantly lower levels. The other components contribute less than 1 per cent to the total.

For the fossil and biogenic components the use phase contributes the most, with bioenergy electricity being the largest source. For the land use change component, the highest impact is related to maintenance, caused by replacements of tyres (containing natural rubber). 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.

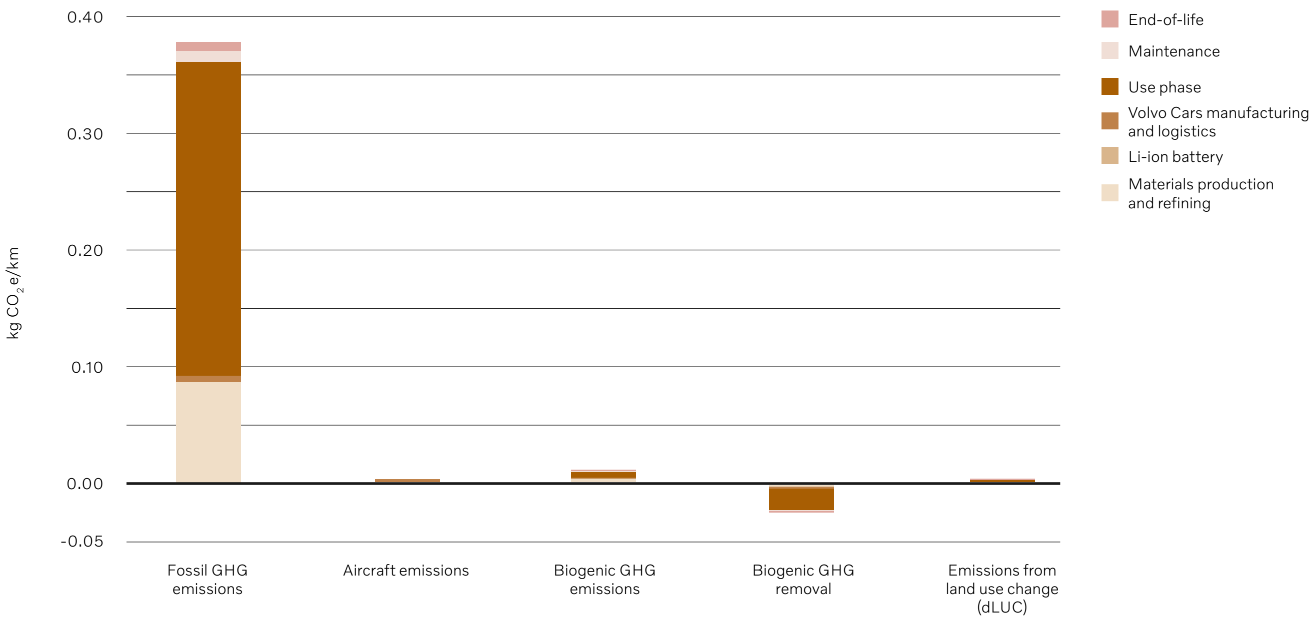

Figure 20 *Results for the five components according to ISO 14067 for XC90 MHEV.*

Table 12 *Results for the five components according to ISO 14067 for XC90 MHEV.*

XC90 MHEV						
kg CO_2e per vehicle km	**Materials production and refining**	**Li-ion battery**	**Volvo Cars manufacturing and logistics**	**Use phase**	**Maintenance**	**End-of-life**
Fossil GHG emissions	8.5E-02	6.3E-04	5.4E-03	2.7E-01	9.9E-03	6.6E-03
Aircraft emissions	2.0E-08	5.5E-11	1.9E-03	4.7E-09	1.5E-09	2.2E-10
Biogenic GHG emissions	2.6E-03	1.3E-05	1.2E-03	5.2E-03	2.6E-04	1.7E-04
Biogenic GHG removal	-1.7E-03	-1.1E-05	-1.1E-03	-1.9E-02	-1.2E-03	-5.3E-05
Emissions from land use change (dLUC)	1.1E-04	8.2E-07	2.1E-05	1.4E-03	3.9E-06	4.2E-06

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7. Sensitivity analysis

In this section, the effect of variable factors is evaluated.

7.1 Changes in electricity generation

As predicting changes in electricity generation is uncertain, we examine the effect on the carbon footprint of two additional IEA scenarios. All scenarios are described in Table 13.

The IEA only provides NZE scenarios for World and Advanced economies (OECD, Bulgaria, Croatia, Cyprus, Malta and Romania), not for individual countries or regions. Therefore, only charging with the global electricity, and not European, mix is evaluated and presented in Figure 21.

Table 13 *Definitions and objectives of IEA scenarios*[14]*.*

	Stated Policies Scenario (STEPS)	Announced Pledges Scenario (APS)	Net Zero Emissions by 2050 Scenario (NZE)
Definitions	This reflects current policy, based on sector by sector and country by country assessment of current policies, as well as those announced by national governments.	This assumes that all governmental climate commitments, including Nationally Determined Contributions (NDCs), longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met.	A path for the global energy sector to reach net zero CO_2 emissions by 2050, without relying on emission reductions by other parties, and universal access to electricity and clean cooking by 2030.
Objectives	To provide a benchmark in assessing the potential achievements and limitations of recent energy and climate policies.	To highlight the gap between current pledges and reaching the goals of the 2015 Paris Agreement. To reveal the gap between current targets and achieving universal energy access.	To advocate action in achieving net zero CO_2 emissions from industrial processes by 2050 and meeting other energy-related sustainable development goals.

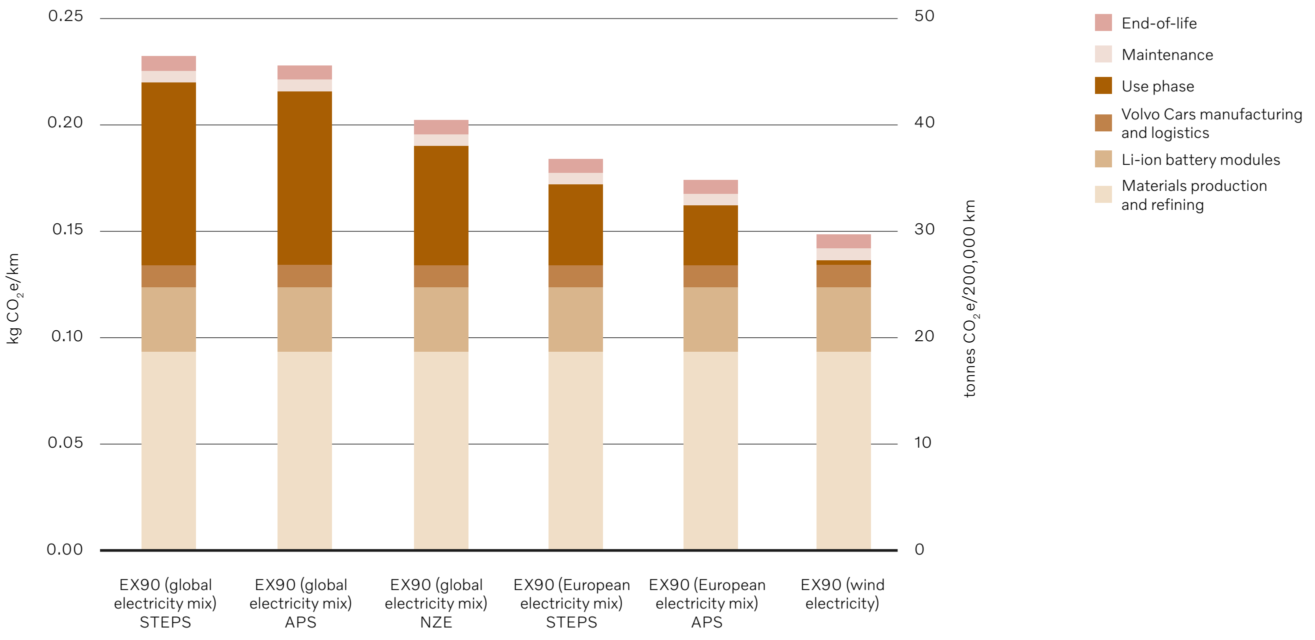

Figure 21 *The effect of changes in electricity generation on the climate impact of the EX90.*

[14] https://www.iea.org/reports/global-energy-and-climate-model

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7.2 Lifetime distance

A lifetime distance of 200,000 kilometres is assumed for the purposes of this study, in line with many other passenger vehicle LCAs. As the EX90 and XC90 may exceed this estimate[15], we evaluate the effect of 250,000 and 300,000 kilometre lifetime distances on climate impact. We also evaluate the effect of a lifetime distance of 150,000 kilometres. The number of components replaced in routine maintenance are estimated in Appendix 5. Results are given in Figure 22 and Table 14.

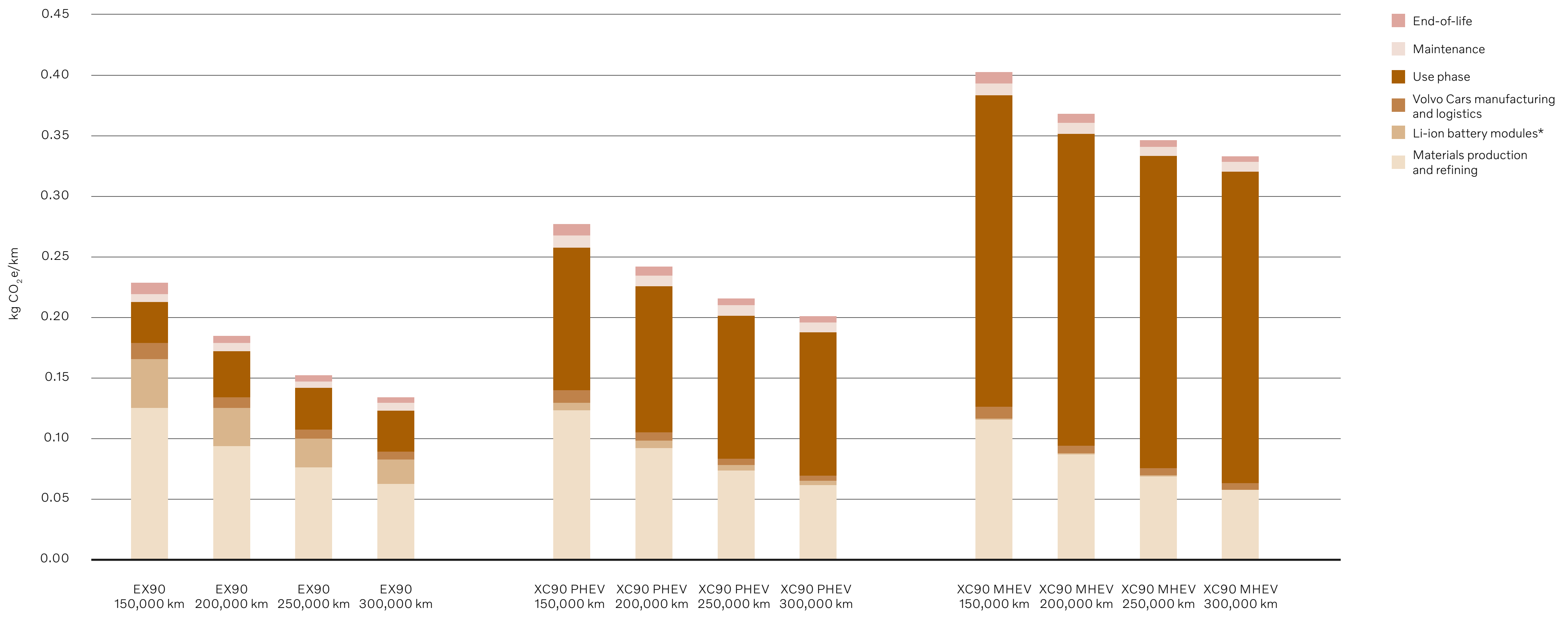

Figure 22 *The effect of lifetime distance on the carbon footprint when charging with European electricity mix.*
** Includes the complete battery for XC90 MHEV.*

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

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Table 14 *The effect of lifetime distance on the carbon footprint when charging with European electricity mix.*

		150,000 km		200,000 km		250,000 km		300,000 km	
		per km (kg CO_2e)	Total (tonnes CO_2e)	per km (kg CO_2e)	Total (tonnes CO_2e)	per km (kg CO_2e)	Total (tonnes CO_2e)	per km (kg CO_2e)	Total (tonnes CO_2e)
EX90	Use phase	0.034	5.0	0.038	7.6	0.034	8.4	0.034	10
	Maintenance	0.0063	0.94	0.0055	1.1	0.0057	1.4	0.0061	1.8
	Other lifecycle stages	0.19	28	0.14	28	0.11	28	0.094	28
XC90 PHEV	Use phase	0.12	23	0.12	24	0.12	29	0.12	35
	Maintenance	0.010	2.0	0.0089	1.8	0.0081	2.0	0.0082	2.5
	Other lifecycle stages	0.15	30	0.11	22	0.09	22	0.074	22
XC90 MHEV	Use phase	0.26	51	0.26	51	0.26	64	0.26	77
	Maintenance	0.010	2.0	0.0089	1.8	0.0081	2.0	0.0082	2.5
	Other lifecycle stages	0.13	27	0.10	20	0.081	20	0.067	20

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7.3 Changes in use phase energy consumption

Energy use is calculated according to the WLTP. This method does not consider individual driving styles, traffic and weather conditions, road inclination or load mass, which have a significant impact on energy use. As this may lead to underestimation in some markets, we have evaluated the effect of 20 and 30 per cent increases in energy use.

Higher energy use leads to a shorter electric range for the XC90 PHEV, which in turn impacts the utility factor, leading to a lower share of distance driven in electric mode. Since internal combustion powertrains are less efficient than electric alternatives, their relative increase in energy input is higher than for the electric powertrains. These effects are reflected in the results given in Figure 23 and Table 15.

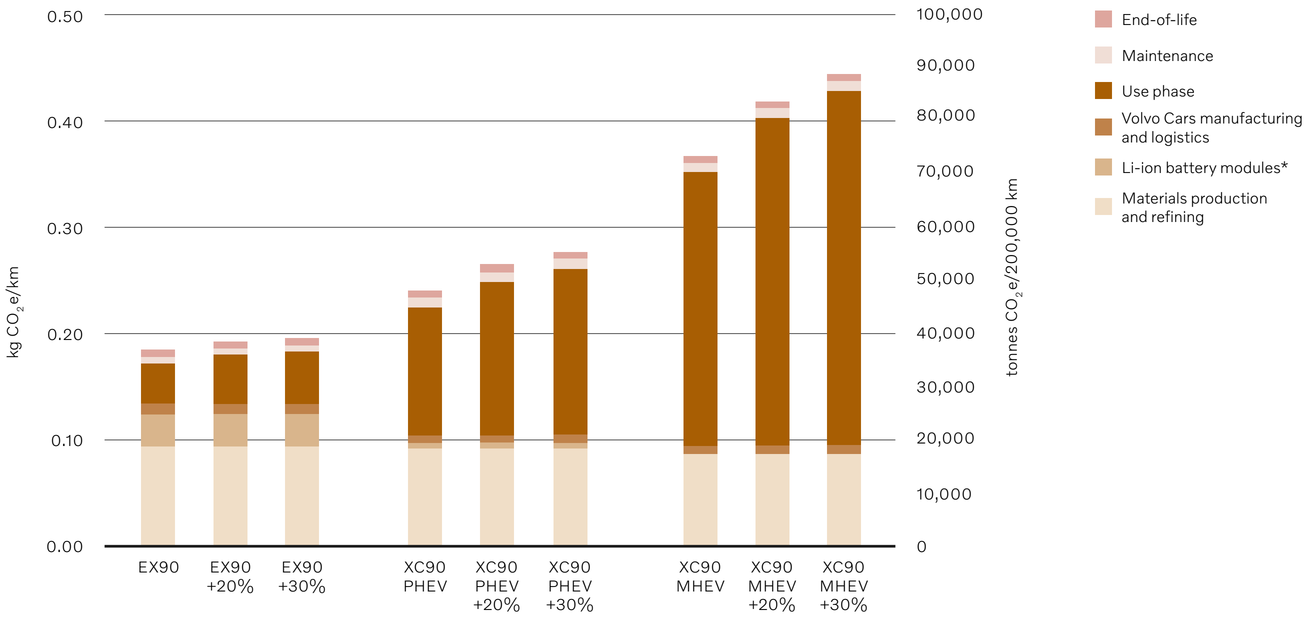

Figure 23 *Carbon footprint when applying different scenarios for energy use in use phase, when charging with European electricity mix.*

** Includes the complete battery for XC90 MHEV.*

Table 15 *Carbon footprint when applying different scenarios for energy use in use phase, when charging with European electricity mix.*

			Increased energy use	
	Functional unit	**Baseline level**	**Increase by 20%**	**Increase by 30%**
EX90	Carbon footprint per vehicle km (kg CO_2e)	0.18	0.19	0.20
	Carbon footprint per lifetime distance (tonnes CO_2e)	37	38	39
XC90 PHEV	Carbon footprint per vehicle km (kg CO_2e)	0.24	0.26	0.28
	Carbon footprint per lifetime distance (tonnes CO_2e)	48	53	55
XC90 MHEV	Carbon footprint per vehicle km (kg CO_2e)	0.37	0.42	0.44
	Carbon footprint per lifetime distance (tonnes CO_2e)	73	84	89

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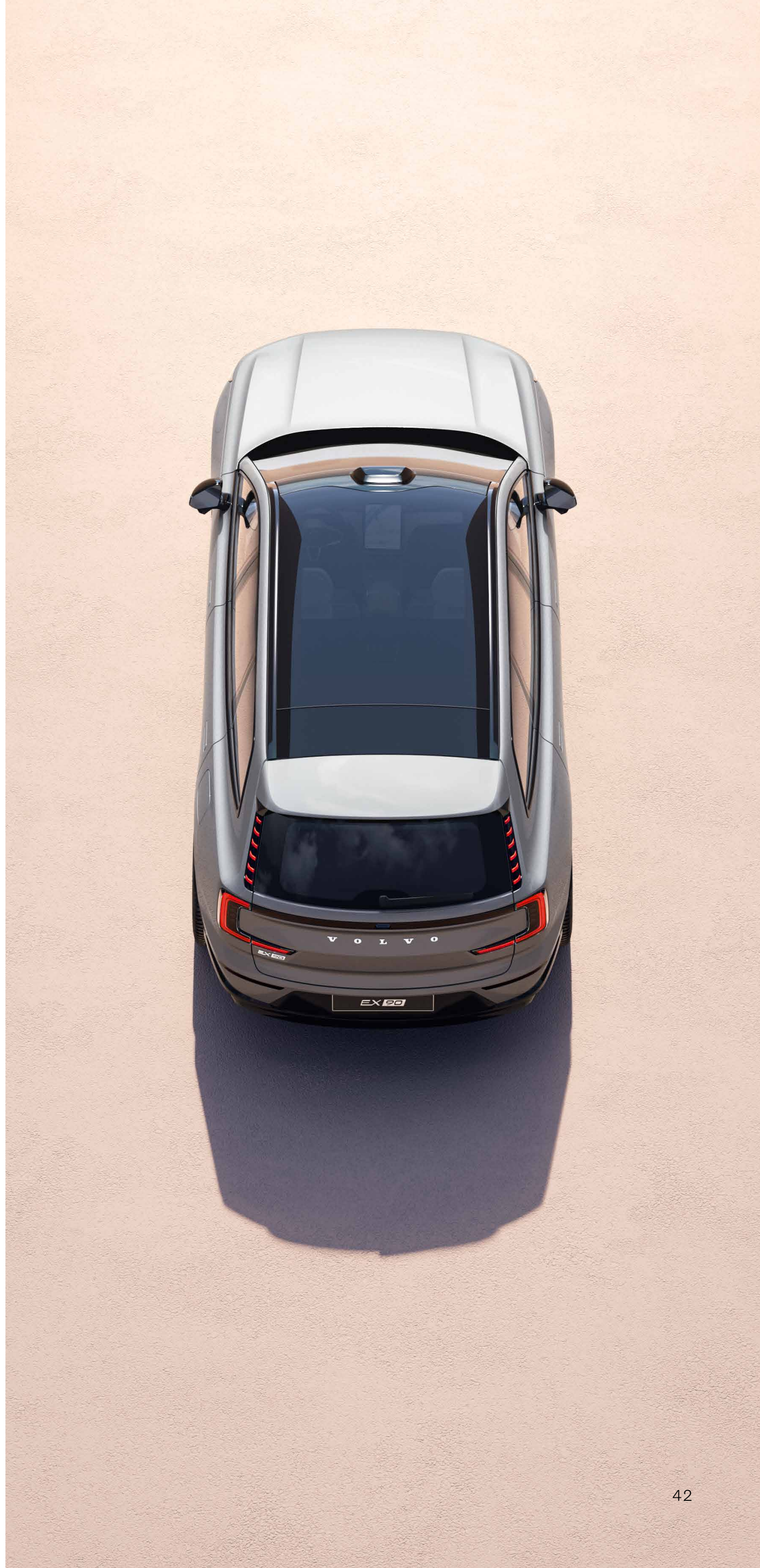
7.4 Occupancy rate

The EX90 and XC90 models in this study are seven seat-vehicles. Depending on the number of passengers, the lifecycle climate impact can be distributed among the occupants to obtain a passenger-km functional unit. A sensitivity analysis exploring the implication of a passenger-km functional unit is interesting as it emphasises the relevance of occupancy. While the average use phase occupancy is unknown, fixed occupancy rates of one to seven persons are evaluated. The results are shown in Table 16.

Table 16 *The effect of occupancy rate on the carbon footprint.*

		Average number of occupants						
	Functional unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**
EX90 (European electricity mix)	Carbon footprint per vehicle km (kg CO_2e)	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Carbon footprint per passenger km (kg CO_2e)	0.18	0.09	0.06	0.045	0.036	0.030	0.026
XC90 PHEV (European electricity mix)	Carbon footprint per vehicle km (kg CO_2e)	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	Carbon footprint per passenger km (kg CO_2e)	0.24	0.12	0.08	0.06	0.048	0.04	0.034
XC90 MHEV	Carbon footprint per vehicle km (kg CO_2e)	0.37	0.37	0.37	0.37	0.37	0.37	0.37
	Carbon footprint per passenger km (kg CO_2e)	0.37	0.19	0.12	0.093	0.074	0.062	0.053



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8. Completeness, consistency and sensitivity checks

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- Checks were made on this study's results in order to ensure validity, completeness, consistency and sensitivity.
- Completeness checks verify the adequacy of information to meet the goal and scope of lifecycle assessments.
- Consistency checks verify that assumptions, methods and data are consistently applied in accordance with the goal and scope of lifecycle assessments.
- Sensitivity checks verify the relevance of sensitivity analysis in reaching conclusions and making recommendations.

The methodology used and assumptions made in this lifecycle assessment are adequately explained in relation to its goal and scope. Before extracting results from LCA For Experts, modelling checks were carried out to ensure that processes are within the system boundary of this study. Modelling was verified for alignment with the assumptions, goal and scope of this study.

- All raw materials production and their manufacturing, excluding the Li-ion batteries and tyres, is included and reported, according to the goal and scope of this study.
- All manufacturing processes are included and reported, according to the goal and scope of this study.
- All emissions from logistics are included and reported, according to the goal and scope of this study.
- All use phase emissions are included and reported, according to the goal and scope of this study.
- All maintenance emissions are included and reported, according to the goal and scope of this study.
- All end-of-life processing is included and reported, according to the goal and scope of this study.

No information or data is missing, no overlaps were found, and all modelling was conducted according to the goal and scope of this study. A detailed sensitivity analysis was carried out to evaluate the assumptions made in this study and ensure its conclusions are valid. The methodology used in this study was evaluated by the environmental consulting company Ricardo, a third-party auditor. All completeness, consistency and sensitivity checks were completed for this study.

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9. Discussion

This LCA study assesses carbon footprint and its underlying causes in the life cycles of the EX90, XC90 PHEV and XC90 MHEV. Its results and conclusions will be used to further reduce the carbon footprint of these models. Comparing emissions from electric and internal combustion engine vehicles reveals both potential benefits and challenges of electrification.

9.1 Reflections

Although the EX90 causes the least overall impact to climate change, in comparison with the XC90 models, emissions in its production phase can be substantially improved. For example, the high impact of aluminium production can be reduced by the increased use of recycled material and primary aluminium from smelters utilising renewable electricity.

As vehicle mass affects energy consumption in the use phase, the use of lightweight materials reduces these emissions. However, there are trade-offs between mass, CO_2 emissions from material production, and end-of-life treatment. For example, plastics generally have low mass but emissions from their production are relatively high, which motivates actions to reduce emissions by increasing the recycled content and to utilise biobased variants.

9.2 The importance of electricity generation for BEVs and PHEVs

The source of electricity used for charging significantly affect the carbon footprint, with lower shares of fossil energy sources leading to lower impacts. Nevertheless, charging the EX90 with the global electricity mix, with a substantial part generated from fossil fuels, results in a lower carbon footprint than the XC90 MHEV.

Results are based on the IEA’s STEPS scenario, with APS and NZE scenarios evaluated in the sensitivity analysis. The climate benefits of the EX90, in comparison with the XC90 MHEV, are even greater in these alternative scenarios.

9.3 Battery impact and mitigation

Although electric vehicles do not necessarily consume fossil fuels, their batteries cause significant climate impact.

The climate impact of the EX90’s batteries are primarily caused by the extraction and refining of lithium, nickel, cobalt, graphite and copper, as well as energy-intensive manufacturing. While renewable electricity is utilised for the anode, cathode and battery cell and module production, Volvo Cars is actively investigating additional measures to mitigate the impact of battery production.

9.3.1 Recycled materials

Recycling is a key factor in reducing the climate impact of battery-related materials. Recycling rates are expected to increase as more end-of-life vehicle batteries become available and recycling processes improve. Legislative changes are also expected to require a greater use of recycled material in battery production.

Volvo Cars has established regional battery centres to repair, refurbish, and remanufacture batteries from its vehicles and facilitate effective recycling. Our aim is to increase the amount of recycled material used in battery production. In a joint venture with Northvolt, we are building a battery cell manufacturing facility in Sweden for which the production scrap will be recycled and used again as input material.

9.3.2 New battery technology and cell types

It is anticipated that rapid improvements in battery technology will continue. The choices made when developing the battery for EX90 reflects the best knowledge and available technologies at that point in time, while future models and upgrades will benefit from technological advances. Future battery technology may reduce or eliminate the use of high impact materials. Benefits can also be gained by utilising improved battery cell and pack designs adapted to customer needs for different vehicle types.

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9.4 Extracting and refining of raw materials, and production

Vehicle electrification will lead to substantial reduction in climate impact and shift the main emission contributions from the use phase to production throughout the supply chains. This highlights the need for increased focus on improvement measures in all extraction, refining and manufacturing processes. In parallel, better data quality will be required to accurately account for such improvement measures when calculating the carbon footprint.

All Volvo Cars' manufacturing plants utilise renewable electricity and by 2025 the intention is to also have all heating to be from renewable energy sources or recovered industrial waste heat.

Our company aims to reduce the climate impact of material production and refining in the following ways:

- Increasing the use of renewable energy throughout our supply chains, with specific requirements on direct suppliers.
- Seeking suppliers of low-carbon metals and setting emission requirements for steel and aluminium suppliers.
- Improving material utilisation in our manufacturing processes.
- Increasing the use of recycled and biobased materials.
- Mega casting aluminium at our manufacturing facilities.
- Consider disassembly and recycling in the design phase of new products.
- Improving data transparency and traceability throughout our supply chains.

These actions will contribute to the fulfilment of our ambitions – reaching net zero greenhouse gas emissions by 2040 and becoming a circular business.

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10. Conclusions

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Results in this study indicate that the carbon footprint of the EX90 is smaller than those of XC90 PHEV and XC90 MHEV. Beyond a driving distance of 33,000 kilometres, the EX90, charged with the European electricity mix, causes less GHG emissions than the XC90 MHEV. Primary contributors to GHG emissions related to materials production and refining are aluminium, Li-ion battery modules, and steel and iron. Among the carbon footprint components, fossil GHG emissions is clearly the most significant one.

Several sensitivity analyses were performed to assess how changes to some of the study's assumptions affect the carbon footprint. The relative outcome (from highest to lowest impact) between the compared vehicles remained the same in all of them, and in most of them (for alternative energy scenarios, increased lifetime distance, and increased energy use in the use phase) the case for EX90 improved compared to that of XC90 PHEV and XC90 MHEV.

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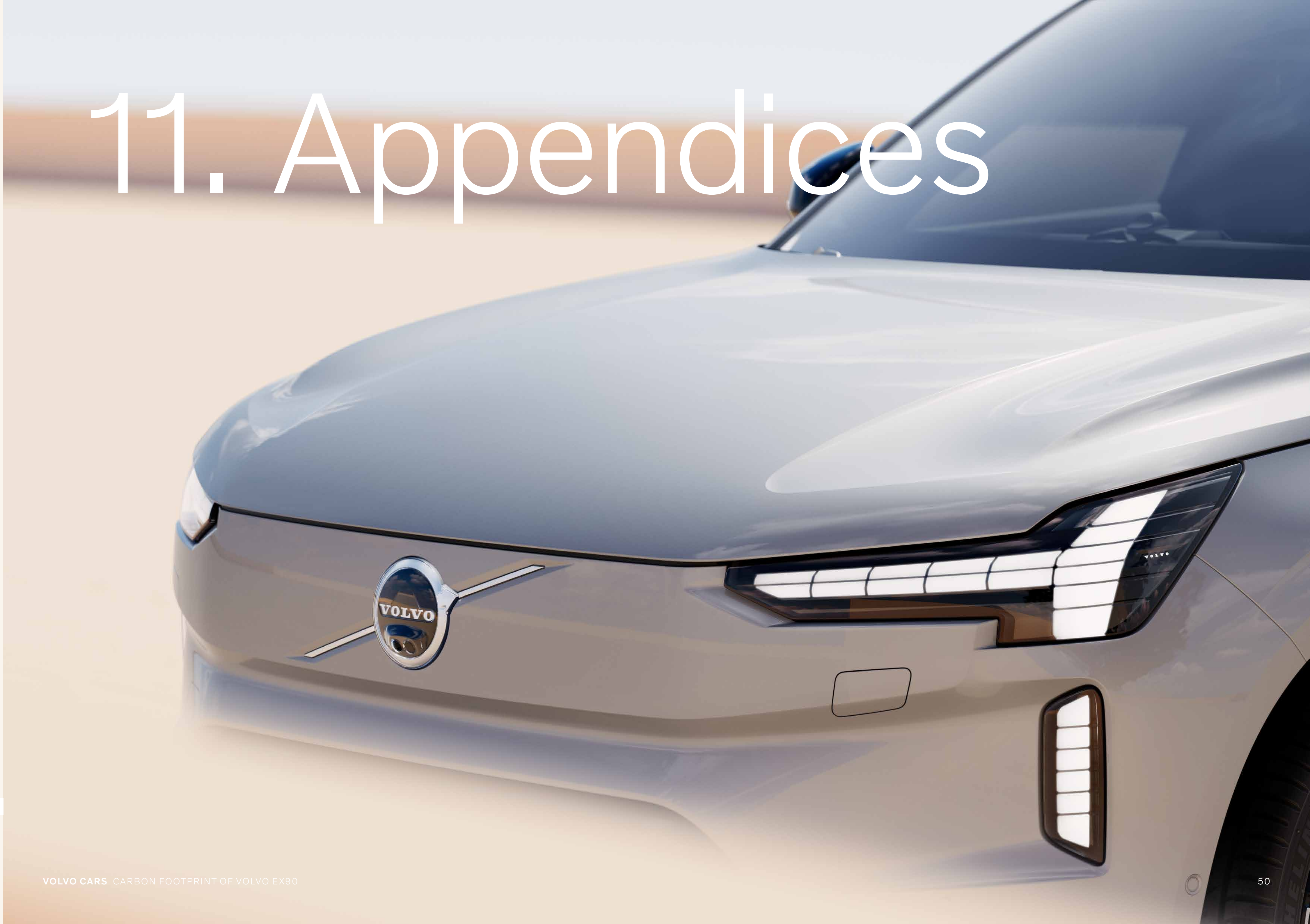
11. Appendices



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11. Appendix 1 – List of material categories

Table 17 *Material categories and types.*

Material category	Material type
Steel, sintered	Steel and iron
Steel, unalloyed	Steel and iron
Steel, stainless, austenitic	Steel and iron
Steel, stainless, ferritic	Steel and iron
Cast iron	Steel and iron
Aluminium	Aluminium
Copper	Copper
Copper alloys	Copper
Anode	Other Metals
Cathode	Other Metals
Magnesium	Other Metals
Zinc	Other Metals
Lead, battery	Other Metals
NdFeB	Other Metals
Ferrite magnet	Other Metals
Separator, Li battery	Other Metals
ABS (filled)	Polymers
ASA (filled))	Polymers
E/P (filled)	Polymers
EVAC (filled)	Polymers
PA (filled)	Polymers
PBT (filled)	Polymers
PC (filled)	Polymers
PC+ABS (filled)	Polymers
PE (filled)	Polymers
PET (filled)	Polymers
PMMA (filled)	Polymers
POM (filled)	Polymers
PP (filled)	Polymers
PVB (filled)	Polymers
PVC (filled)	Polymers
ABS (unfilled)	Polymers
ASA (unfilled)	Polymers
E/P (unfilled)	Polymers
EVAC (unfilled)	Polymers
PA (unfilled)	Polymers
PBT (unfilled)	Polymers
PC (unfilled)	Polymers
PC+ABS (unfilled)	Polymers
PE (unfilled)	Polymers
PET (unfilled)	Polymers
PMMA (unfilled)	Polymers
POM (unfilled)	Polymers
PP (unfilled)	Polymers
PVB (unfilled)	Polymers
PVC (unfilled)	Polymers

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Material category	Material type
Thermoplastics	Polymers
Thermoplastic elastomers	Polymers
Elastomer	Polymers
EPDM	Polymers
NR	Polymers
SBR	Polymers
Silicone rubber	Polymers
Epoxy	Polymers
Polyurethane	Polymers
Damper	Polymers
Polyester	Polymers
Aramid	Polymers
Tyre	Tyres
Elastomer	Polymers
Cotton	Natural Materials
Leather	Natural Materials
Wood (paper, cellulose ...)	Natural Materials
Friction	Natural materials
Catalytic coating	Glass
Float glass	Glass
GF-fibre	Glass
Electronics	Electronics
Lubricants	Fluids
Brake fluid	Fluids

Material category	Material type
Glycol	Fluids
R-1234yf	Fluids
R-134a	Fluids
Sulphuric acid	Fluids
Washer fluid	Fluids
AdBlue	Fluids
Undefined	Fluids
Petrol	Fluids
Electronics	Electronics
power PCB	Electronics
signal PCB	Electronics
IC components	Electronics
LCDs	Electronics
LED	Electronics
Resistor	Electronics
Capacitor	Electronics
Electrolytic capacitor	Electronics
Diode	Electronics
Inductor	Electronics
Transistor	Electronics
Solder	Electronics
Oscillator	Electronics
Thermistor	Electronics

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11. Appendix 2 – LCI datasets

Table 18 *Material datasets.*

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
ABS	GLO	Market for acrylonitrile-butadiene-styrene copolymer		agg	ecoinvent 3.9.1
Aluminium	GLO	Aluminium ingot mix IAI 2015	61.3%	agg	IAI/Sphera MLC 2023.2
	CA	Aluminium ingot mix IAI 2015	2%	agg	IAI/Sphera MLC 2023.2
	CN	Aluminium ingot mix IAI 2015	4%	agg	IAI/Sphera MLC 2023.2
	RER	Aluminium ingot mix	10.6%	agg	Sphera MLC 2023.2
Aluminium, recycled	RER	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	22.1%	agg	ecoinvent 3.9.1
Anode	CN	Market for anode, graphite, for Li-ion battery		agg	Ecoinvent 3.9.1
Aramid	DE	Aramide fiber (para aramid)		agg	Sphera MLC 2023.2
ASA	GLO	Market for acrylonitrile-butadiene-styrene copolymer		agg	ecoinvent 3.9.1
Brake fluid	GLO	Market for diethylene glycol		agg	ecoinvent 3.9.1
Cast iron	DE	Cast iron part (automotive) - open energy inputs		p-agg	Sphera MLC 2023.2
Catalytic coating	ZA	Market for platinum group metal concentrate		agg	ecoinvent 3.9.1
Cathode	CN	Market for cathode, NMC111; for Li-ion battery		agg	ecoinvent 3.9.1
Ceramic	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing		agg	ecoinvent 3.9.1
Copper	GLO	Copper (99,99%; cathode)		agg	ICA/Sphera MLC 2023.2
Copper alloys	RER	Brass (CuZn20)	49%	p-agg	Sphera MLC 2023.2
	GLO	Market for bronze	33%	agg	ecoinvent 3.9.1
	GLO	Nickel (class 1, >99.8% Nickel)	5%	agg	Nickel Institute/ Sphera MLC 2023.2
	GLO	Copper (99,99%, cathode)	14%	agg	ICA/Sphera MLC 2023.2
Cotton	GLO	Market for textile, woven cotton		agg	ecoinvent 3.9.1
Damper	RER	Polymethylmethacrylate sheet (PMMA)	60%	agg	PlasticsEurope/ Sphera MLC 2023.2
	RoW	Market for lime	40%	agg	ecoinvent 3.9.1
E/P	RoW	polyethylene production, low density, granulate		agg	ecoinvent 3.9.1

Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Elastomer	RoW	Market for calcium carbonate, precipitated	30%	agg	ecoinvent 3.9.1
	RoW	Market for lime	20%	agg	ecoinvent 3.9.1
	GLO	Market for carbon black	7%	agg	ecoinvent 3.9.1
	GLO	Market for polyethylene terephthalate, granulate, amorphous	5%	agg	ecoinvent 3.9.1
	GLO	Market for zinc oxide	3%	agg	ecoinvent 3.9.1
	GLO	Market for synthetic rubber	35%	agg	ecoinvent 3.9.1
Electrolyte	GLO	Market for dimethyl carbonate	7%	agg	ecoinvent 3.9.1
	GLO	Market for ethylene carbonate	80%	agg	ecoinvent 3.9.1
	GLO	Market for lithium hexafluorophosphate	13%	agg	ecoinvent 3.9.1
EPDM	DE	ethylene Propylene Diene Elastomer (EPDM)		agg	Sphera MLC 2023.2
Epoxy	GLO	Market for epoxy resin, liquid		agg	ecoinvent 3.9.1
EVAC	RoW	Market for ethylene vinyl acetate copolymer		agg	ecoinvent 3.9.1
Ferrite magnet	GLO	Market for ferrite		agg	ecoinvent 3.9.1
Float glass	RER	Float flat glass		agg	Sphera MLC 2023.2
Friction	DE	Cast iron part (automotive) – open energy inputs	48%	p-agg	Sphera MLC 2023.2
	GLO	Market for zirconium oxide	12%	agg	ecoinvent 3.9.1
	GLO	Market for graphite	11%	agg	ecoinvent 3.9.1
	GLO	Market for barium sulfide	1%	agg	ecoinvent 3.9.1
	GLO	Market for barite	7%	agg	ecoinvent 3.9.1
	GLO	Market for aluminium hydroxide	5%	agg	ecoinvent 3.9.1
	GLO	Market for magnesium oxide	4%	agg	ecoinvent 3.9.1
	GLO	Market for expanded vermiculite	2%	agg	ecoinvent 3.9.1
	RER	Calcined petroleum coke	2%	agg	Sphera MLC 2023.2
GF-fibre (filler for polymers)	GLO	Market for glass fibre		agg	ecoinvent 3.9.1
Glycol	RER	Ethylene glycol		agg	PlasticsEurope
Lead, battery	DE	Lead (99,995%)		agg	Sphera MLC 2023.2
Leather	DE	Cattle hide, fresh, from slaughterhouse (economic allocation)		agg	Sohera MLC 2023

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Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Lubricants	EU-28	Lubricants at refinery		agg	Sphera MLC 2023.2
Magnesium	CN	Magnesium		agg	Sphera MLC 2023.2
NdFeB	GLO	Market for permanent magnet, electric passenger car motor		agg	ecoinvent 3.9.1
NR	DE	Natural rubber (NR)		agg	Sphera MLC 2023.2
PA	RoW	Market for nylon 6		agg	ecoinvent 3.9.1
PBT	DE	Polybutylene Terephthalate Granulate (PBT) Mix		agg	Sphera MLC 2023.2
PC	GLO	Market for polycarbonate		agg	ecoinvent 3.9.1
PC + ABS	GLO	Market for polycarbonate	65%	agg	ecoinvent 3.9.1
	GLO	Market for acrylonitrile-butadiene-styrene copolymer	35%	agg	ecoinvent 3.9.1
PE	RoW	Polyethylene production, low density, granulate		agg	ecoinvent 3.9.1
PET	GLO	Market for polyethylene terephthalate, granulate, amorphous		agg	ecoinvent 3.9.1
Petrol	RER	Gasoline mix 8regular) at refinery	95%	agg	Sphera MLC 2023.2
	BR	Bioethanol from sugar cane at filling station	1.7%	agg	Sphera MLC 2023.2
	US	Bioethanol from corn	3.4%	agg	Sphera MLC 2023.2
PMMA	RER	Polymethylmethacrylate sheet (PMMA)		agg	PlasticsEurope/ Sphera MLC 2023.2
Polymer, recycled	RER	Plastic granulate secondary (low metal contamination)		agg	Sphera MLC 2023.2
Polyester	GLO	Market for fibre, polyester		agg	ecoinvent 3.9.1
Polyurethane	RoW	Market for polyurethane, rigid foam		agg	ecoinvent 3.9.1
POM	RER	Polyoxymethylene (POM)		agg	PlasticsEurope
PP	GLO	Market for polypropylene, granulate		agg	ecoinvent 3.9.1
PS	GLO	Market for polystyrene, general purpose		agg	ecoinvent 3.9.1
PVB	DE	Polyvinyl butyral granulate (PVB) by-product ethyl acetate		agg	Sphera MLC 2023.2
PVC	RoW	Polyvinylchloride production, suspension polymerisation		agg	ecoinvent 3.9.1
R-1234yf	DE	R-1234yf production (approximation)		agg	Sphera MLC 2023.2
SBR	DE	Styrene-butadiene rubber (S-SBR) mix		agg	Sphera MLC 2023.2
Separator li battery	GLO	Market for battery separator		agg	ecoinvent 3.9.1
Silicone rubber	DE	Silicone rubber (RTV-2, condensation)		agg	Sphera MLC 2023.2

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Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Steel, Sintered	GLO	Steel hot dip galvanised		agg	Worldsteel/ Sphera MLC 2023.2
Steel, Stainless, Austenitic	RER	Stainless steel cold rolled coil (304)		p-agg	Eurofer/ Sphera MLC 2023.2
Steel, Stainless, Ferritic	RER	Stainless steel cold rolled coil (430)		p-agg	Eurofer/ Sphera MLC 2023.2
Steel, Unalloyed	GLO	Steel hot dip galvanised*	42%	agg	Worldsteel/ Sphera MLC 2023.2
	GLO	Steel cold rolled coil*	37%	agg	Worldsteel/ Sphera MLC 2023.2
	Europe	Steel cold rolled coil*	12.5%	agg	Worldsteel/ Sphera MLC 2023.2
Steel, recycled, unalloyed	DE	EAF Steel billet / slab / bloom (Hot and cold rolling processes added)	8.5%	agg	Sphera MLC 2023.2
Sulphuric acid	RER	Sulphuric acid (96%)		agg	Sphera MLC 2023.2
Talc (filler for polymers)	RER	Talcum powder (filler)		agg	Sphera MLC 2023.2
Thermoplastic elastomers	DE	Polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix		agg	Sphera MLC 2023.2
Thermoplastics	RoW	Market for nylon 6		agg	ecoinvent 3.9.1
Tyre**	RER	Synthetic rubber production	50%	agg	ecoinvent 3.9.1
	DE	Natural rubber (NR) (excl. LUC emissions)	35%	agg	Sphera MLC 2023.2
	GLO	Market for carbon black	10%	agg	ecoinvent 3.9.1
	RER	Lubricants at refinery	5%	agg	Sphera MLC 2023.2
	GLO	Market for paraffin***		agg	ecoinvent 3.9.1
	RER	Water (deionised) ***		agg	Sphera MLC 2023.2
Undefined	RoW	Market for nylon 6		agg	ecoinvent 3.9.1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)		agg	Sphera MLC 2023.2
Wood (paper, cellulose ...)	RER	Laminated veneer lumber (EN15804 A1-A3)		agg	Sphera MLC 2023.2
Zinc	GLO	Steel hot dip galvanised		agg	Worldsteel/ Sphera MLC 2023.2

** reflecting conventional steel production, this dataset includes some recycled content.*

*** only used for tyres replaced during maintenance.*

**** only used for the vulcanisation of natural rubber.*

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Table 19 Electronics datasets.

Material	Location	Name	Type	Source
Electronics	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing	agg	ecoinvent 3.9.1
Power PCB	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing	agg	ecoinvent 3.9.1
Signal PCB	GLO	Printed wiring board production, mounted mainboard, desktop computer, Pb containing, GLO	agg	ecoinvent 3.9.1
IC components	GLO	Market for integrated circuit, logic type	agg	ecoinvent 3.9.1
LCDs	GLO	Market for liquid crystal display, unmounted	agg	ecoinvent 3.9.1
LED	GLO	Market for light emitting diode	agg	ecoinvent 3.9.1
Resistor	GLO	Market for resistor, surface-mounted	agg	ecoinvent 3.9.1
Capacitor	GLO	Market for capacitor, for surface-mounting	agg	ecoinvent 3.9.1
Electrolytic capacitor	GLO	Market for capacitor, electrolyte type, < 2 cm height	agg	ecoinvent 3.9.1
Diode	GLO	Market for diode, glass-, for surface-mounting	agg	ecoinvent 3.9.1
Inductor	GLO	Market for inductor, ring core choke type	agg	ecoinvent 3.9.1
Transistor	GLO	Market for transistor, wired, small size, through-hole mounting	agg	ecoinvent 3.9.1
Solder	GLO	Market for solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry	agg	ecoinvent 3.9.1
Oscillator	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing	agg	ecoinvent 3.9.1
Thermistor	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing	agg	ecoinvent 3.9.1

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Table 20 *Datasets for manufacturing processes.*

Process	Location	Name	Type	Source
Aluminium manufacturing	DE	Aluminium die-cast part	u-so	Sphera MLC 2023.2
Aluminium manufacturing	EU-28	Aluminium sheet – open input aluminium rolling ingot	p-agg	Sphera MLC 2023.2
Aluminium manufacturing	DE	Aluminium sheet deep drawing	u-so	Sphera MLC 2023.2
Polymers (all categories) manufacturing	DE	Plastic injection moulding part (unspecific)	u-so	Sphera MLC 2023.2
Stainless (all categories) manufacturing	DE	Steel sheet deep drawing (multi-level)	u-so	Sphera MLC 2023.2
Copper manufacturing	DE	Copper wire (0,6 mm)	u-so	Sphera MLC 2023.2
Copper manufacturing	DE	Copper wire (0,06 mm)	u-so	Sphera MLC 2023.2
Energy for XC90 MHEV battery cell production	CN	Electricity grid mix 1kV-60kV	agg	Sphera MLC 2023.2
	RER	Thermal energy from natural gas	agg	Sphera MLC 2023.2

Table 21 *Global electricity mix datasets used for production and refining of materials and end-of-life treatment.*

Source of electricity generation	Percentage used for materials production and refining in 2024	Percentage used for end-of-life treatment in 2038	Name of dataset	Data source
Coal	32	18	RER: Electricity from lignite	IEA WEO 2022/Sphera MLC 2023.3
Natural gas	22	16	RER: Electricity from natural gas	IEA WEO 2022/Sphera MLC 2023.3
Hydro	15	14	RER: Electricity from hydropower	IEA WEO 2022/Sphera MLC 2023.3
Nuclear	10	9	RER: Electricity from nuclear	IEA WEO 2022/Sphera MLC 2023.3
Wind	9	18	RER: Electricity from wind power	IEA WEO 2022/Sphera MLC 2023.3
Solar	7	18	RER: Electricity from photovoltaic	IEA WEO 2022/Sphera MLC 2023.3
Bioenergy	3	4	RER: Electricity from biomass (solid)	IEA WEO 2022/Sphera MLC 2023.3
Oil	2	1	RER: Electricity from heavy fuel oil (HFO)	IEA WEO 2022/Sphera MLC 2023.3

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Table 22 *Use phase electricity mix datasets.*

Source	Location	Name	Type	Source
Electricity from gas	RER	Electricity from natural gas	agg	Sphera MLC 2023.2
Electricity from coal	RER	Electricity from lignite	agg	Sphera MLC 2023.2
Electricity from hydro power	RER	Electricity from hydro power	agg	Sphera MLC 2023.2
Electricity from nuclear	RER	Electricity from nuclear	agg	Sphera MLC 2023.2
Electricity from heavy fuel oil (HFO)	RER	Electricity from heavy fuel oil (HFO)	agg	Sphera MLC 2023.2
Electricity from photovoltaic	RER	Electricity from photovoltaic	agg	Sphera MLC 2023.2
Electricity from geothermal	RER	Electricity from geothermal	agg	Sphera MLC 2023.2
Electricity from biomass	RER	Electricity from biomass (solid)	agg	Sphera MLC 2023.2
Electricity from wind power	RER	Electricity from wind power	agg	Sphera MLC 2023.2

Table 23 *Datasets for inbound and outbound logistics.*

Process	Location	Name	Type	Source
IBL/OBL Rail	GLO	Rail transport cargo - average, average train, gross tonne weight 1,000t /726t payload capacity	u-so	Sphera MLC 2023.2
IBL/OBL Rail	RER	Diesel mix at filling station	agg	Sphera MLC 2023.2
OBL Rail	FR	Electricity grid mix	agg	Sphera MLC 2023.2
IBL Rail	GLO	Electricity mix production 2024 (based on Eu datasets)	u-so	Sphera MLC 2023.2
IBL/OBL Sea	GLO	Container ship, 5.000 to 200.000 dwt payload capacity, deep sea	u-so	Sphera MLC 2023.2
OBL Sea	US	Light fuel oil at refinery	agg	Sphera MLC 2023.2
IBL Sea	RER	Light fuel oil at refinery	agg	Sphera MLC 2023.2
IBL/OBL Road	GLO	Truck, Euro 6 A-C, more than 32t gross weight /24.7t payload capacity	u-so	Sphera MLC 2023.2
IBL/OBL Road	RER	Diesel mix at refinery	agg	Sphera MLC 2023.2
IBL/OBL Air	GLO	Cargo plane, 22 t payload	u-so	Sphera MLC 2023.2
IBL/OBL Air	RER	Kerosene /Jet A1 at refinery	agg	Sphera MLC 2023.2

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Table 24 Datasets for manufacturing at Volvo Cars' facilities.

Process	Location	Name	Type	Source
Incineration of hazardous waste	Europe (excl. Switzerland)	Treatment of waste mineral oil, hazardous waste incineration	agg	ecoinvent 3.9.1
Landfill of hazardous waste	RER	Market for hazardous waste, for underground deposit	agg	ecoinvent 3.9.1
Landfill of non-hazardous waste	RER	Municipal solid waste on landfill	agg	Sphera MLC 2023.2
Wastewater treatment	RER	Municipal waste water treatment (sludge incineration, Cut-off)	agg	Sphera MLC 2023.2
Transport of recyclable waste	GLO	Truck, Euro 6 D-E, 12 - 14t gross weight, 9.3t payload capacity	u-so	Sphera MLC 2023.2
Transport of recyclable waste	RER	Diesel mix at refinery	agg	Sphera MLC 2023.2
Landfill of non-hazardous waste (mainly commercial waste)	RER	Commercial waste (AT, DE, IT, LU, NL, SE, CH) on landfill	p-agg	Sphera MLC 2023.2
Incineration of non-hazardous waste	EU-28	Waste incineration of municipal solid waste (MSW)	agg	ELCD/CEWEP
Electricity	SE	Electricity grid mix 1 kV-60kV	agg	Sphera MLC 2023.2
Thermal energy from biogas	SE	Thermal energy from biogas	agg	Sphera MLC 2023.2
Thermal energy from biogas	US	Thermal energy from biogas (East)	agg	Sphera MLC 2023.2
Electricity	US	Electricity from hydro power	agg	Sphera MLC 2023.2
Electricity	US	Electricity from photovoltaic	agg	Sphera MLC 2023.2

Table 25 Energy sources at Volvo Cars' manufacturing facilities.

Volvo Cars manufacturing site	Energy source
Torslanda	Electricity from hydro power (SE)
	Thermal energy from biogas*
Charleston	Electricity from hydro power
	Electricity from photovoltaic
	Electricity from natural gas (East) (US)
Olofström	Electricity from hydro power (SE)
Skövde	Electricity from hydro power (SE)

** The lower heating value has been used to convert volume of biogas to energy.*

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11. Appendix 3 – Data quality assessment

Table 23 lists the data quality indicators used in this study. Each datapoint has received a score from 1 (best) to 5 (worst), according to five correlation aspects. Table 24 scores data used for material production and refining. Table 25 summarises the results.

Temporal and geographical correlation scores vary. Ecoinvent datasets are generally more than 10 years old, while Sphera MLC datasets tend to be less than three years old. Aluminium and battery modules, materials that have a high impact, score 1 to 2 for geographical coverage. Electronics scores poorly for both temporal and geographical correlation. Overall, technological correlation scores vary, however, the majority of the data scores 2. Representativeness and precision have good scores, as the data is from databases or supplier specific.

Car manufacturing and logistics receive good scores overall, as the data is collected from our manufacturing facilities and monitored processes. Use phase scores are positive, as electricity use data is based on vehicle specific measurements and impact calculations are based on fairly new emission factors from the ecoinvent database and IEA electricity mix data. End-of-Life treatment achieves less good scores, as there is a high degree of uncertainty about how well it will correlate with future developments. It is highly uncertain how waste handling will be (and in some cases currently is) performed in different markets.

Table 26 *Data quality indicator matrix.*

Aspect	1	2	3	4	5
Temporal correlation (time related coverage)	Less than three years before date of study	Less than six years before date of study	Less than 10 years before date of study	Less than 15 years before date of study	Age of data unknown or more than 15 years before date of study
Geographical correlation	Data from enterprises, processes and materials under study	Average processing data from area that includes area of origin	Data from area with comparable production conditions	Processing data from unknown areas	Data from areas with different production conditions
Technological correlation	Processing and material data from enterprises under study	Processing and material data from other enterprises or groups	Processing and material data from enterprises under study, using different technology	Processing and material data for equivalent technology (e.g. using data for ceramic glass to represent production of MICA)	Processing and material data for different or unknown technology
Representative	Data of adequate sample size over an adequate time period, including future projections (if necessary)	Data from a small sample over an adequate time period	Data of adequate sample size over a shorter time period	Data from a small sample and shorter time period or incomplete data of adequate sample size and time	Unknown or incomplete data from a small sample and/or shorter time period
Precision	Verified data based on measurements	Verified data based partly on assumptions or non-verified data based on measurements	Non-verified data based partly on assumptions	Qualified estimates (e.g. by industrial expert)	Non-qualified estimates

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Table 27 Quality assessment of material and processing data.

Material/process	Location	Name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
ABS	GLO	Market for acrylonitrile-butadiene-styrene copolymer	2011	ecoinvent 3.9.1	4	4	2	1	1
Aluminium	GLO	Aluminium ingot mix IAI 2015	2015	IAI/Sphera MLC	3	4	2	2	1
Aluminium	CA	Aluminium ingot mix IAI 2015	2015	IAI/Sphera MLC	3	1	2	2	1
Aluminium	CN	Aluminium ingot mix IAI 2015	2015	IAI/Sphera MLC	3	1	2	2	1
Aluminium	RER	Aluminium ingot mix	2022	Sphera MLC	1	2	2	2	1
Aluminium, recycled	RER	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	2005	ecoinvent 3.9.1	5	4	2	2	1
Anode	CN	Market for anode, graphite, for Li-ion battery	2022	ecoinvent 3.9.1	1	1	2	2	1
Aramid	DE	Aramide fiber (para aramid)	2021	Sphera MLC	1	5	2	1	1
ASA	GLO	Market for acrylonitrile-butadiene-styrene copolymer	2011	ecoinvent 3.9.1	4	4	2	1	1
Battery modules			2022	Supplier data	1	1	1	1	2
Brake fluid	GLO	Market for diethylene glycol	2011	ecoinvent 3.9.1	4	4	2	1	1
Cast iron	DE	Cast iron part (automotive) - open energy inputs	2021	Sphera MLC	1	5	2	1	1
Catalytic coating	ZA	Market for platinum group metal concentrate	2015	ecoinvent 3.9.1	3	5	2	1	1
Cathode	CN	Market for cathode, NMC111; for Li-ion battery	2022	ecoinvent 3.9.1	1	1	2	2	1
Ceramic	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb	2022	ecoinvent 3.9.1	1	4	3	1	1
Copper	GLO	Copper (99,99%); cathode)	2013-2020	Sphera MLC	3	4	2	1	1
Copper alloys	RoW	Market for brass	2021	ecoinvent 3.9.1	1	4	2	1	1
Copper alloys	GLO	Market for bronze	2023	ecoinvent 3.9.1	1	4	2	1	1
Copper alloys	GLO	Nickel (class 1, >99,8% Nickel)	2023	Sphera MLC	1	4	2	1	1
Copper alloys	GLO	Copper (99,99%, cathode)	2013-2020	Sphera MLC	3	4	2	1	1
Cotton	GLO	Market for textile, woven cotton	2011	ecoinvent 3.9.1	4	4	2	1	1
Damper	RER	Polymethylmethacrylate sheet (PMMA)	2005	PlasticsEurope	5	5	2	1	1
Damper	RoW	Market for lime	2011	ecoinvent 3.9.1	5	5	2	1	1

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Material/process	Location	Name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
E/P	GLO	Polyethylene production, low density, granulate	2011-2016	ecoinvent 3.9.1	3	4	3	1	1
Electrolyte	GLO	Market for dimethyl carbonate	2015-2022	ecoinvent 3.9.1	1	4	4	1	1
Electrolyte	GLO	Market for ethylene carbonate	2011-2022	ecoinvent 3.9.1	1	4	4	1	1
Electrolyte	GLO	Market for lithium hexafluorophosphate	2011-2022	ecoinvent 3.9.1	1	4	2	1	1
Electronics**	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing	2011	ecoinvent 3.9.1	4	4	2	1	1
EPDM	DE	Ethylene propylene Diene Elastomer (EPDM)	2021	Sphera MLC	1	5	2	1	1
Epoxy	GLO	Market for epoxy resin, liquid	2011	ecoinvent 3.9.1	4	4	2	1	1
EVAC	GLO	Market for ethylene vinyl acetate copolymer	2011	ecoinvent 3.9.1	4	4	2	1	1
Ferrite magnet	GLO	Market for ferrite	2011	ecoinvent 3.9.1	4	4	3	1	1
Float glass	EU-28	Float flat glass	2021	Sphera MLC	1	5	2	1	1
Friction	DE	Cast iron part (automotive) – open energy inputs	2021	Sphera MLC	1	5	4	1	1
Friction	GLO	Market for zirconium oxide	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	Market for graphite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	Market for barium sulfide	2015-2020	ecoinvent 3.9.1	1	4	4	1	1
Friction	GLO	Market for barite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	Market for aluminium hydroxide	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	Market for magnesium oxide	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	Market for expanded vermiculite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	EU-28	Calcined petroleum	2021	Sphera MLC	1	5	4	1	1
GF-fibre	GLO	Market for glass fibre	2011	ecoinvent 3.9.1	4	4	4	1	1
Glycol	EU-28	Ethylene glycol	2008	PlasticsEurope	4	5	2	1	1
Lead, battery	DE	Lead (99,995%)	2021	Sphera MLC	1	5	2	1	1
Leather	DE	Cattle hide, fresh, from slaughterhouse (economic allocation)	2022	Sphera MLC	1	5	2	1	1

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Material/process	Location	Name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
Lubricants	EU-28	Lubricants at refinery	2018	Sphera MLC	2	5	2	1	1
Magnesium	CN	Magnesium	2021	Sphera MLC	1	5	2	1	1
NdFeB	GLO	Market for permanent magnet, electric passenger car motor	1995-2002	ecoinvent 3.9.1	5	4	2	1	1
NR	DE	Natural rubber (NR)	2021	Sphera MLC	1	5	2	1	1
PA	GLO	Market for nylon 6	2011	ecoinvent 3.9.1	4	4	2	1	1
PBT	DE	Polybutylene terephthalate granulate (PBT) Mix	2021	Sphera MLC	1	5	2	1	1
PC	GLO	Market for polycarbonate	2011	ecoinvent 3.9.1	4	4	2	1	1
PE	RoW	Polyethylene production, low density, granulate	2011-2016	ecoinvent 3.9.1	3	5	2	1	1
PET	GLO	Market for polyethylene terephthalate, granulate, amorphous	2011	ecoinvent 3.9.1	4	4	2	1	1
Petrol	RER	Gasoline mix (regular) at refinery	2019	Sphera MLC	2	2	2	1	1
Petrol	BR	Bioethanol from sugar cane at filling	2021	Sphera MLC	1	1	2	1	1
Petrol	US	Bioethanol from corn Sphera	2021	Sphera MLC	1	1	2	1	1
PMMA	RER	Polymethylmethacrylate sheet (PMMA)	2005	PlasticsEurope	5	5	2	1	1
Polymer, recycled	EU-28	Plastic granulate secondary (low metal contamination)	2021	Sphera MLC	1	5	3	1	1
Polyester	GLO	Market for fibre, polyester	2007-2022	ecoinvent 3.9.1	1	4	2	1	1
Polyurethane	RoW	Market for polyurethane, rigid foam	2011	ecoinvent 3.9.1	4	5	2	1	1
POM	EU-28	Polyoxymethylene (POM)	2010	PlasticsEurope	4	5	2	1	1
PP	GLO	Market for polypropylene, granulate	2011	ecoinvent 3.9.1	4	4	2	1	1
PS	GLO	Market for polystyrene, general purpose	2011	ecoinvent 3.9.1	4	4	2	1	1
PVB	DE	Polyvinyl butyral granulate (PVB) by-product ethyl acetate	2021	Sphera MLC	1	5	2	1	1
PVC	GLO	Polyvinylchloride production, suspension polymerisation	2013-2018	ecoinvent 3.9.1	2	4	2	1	1
R-1234yf	DE	R-1234yf production (approximation)	2021	Sphera MLC	1	5	3	1	1
SBR	DE	Styrene-butadiene rubber (S-SBR) mix	2021	Sphera MLC	1	5	2	1	1
Separator li battery	GLO	Market for bettery separator	2022	ecoinvent 3.9.1	1	4	2	1	1

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Material/process	Location	Name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
Silicone rubber	DE	Silicone rubber (RTV-2, condensation)	2021	Sphera MLC	1	5	2	1	1
Steel, Sintered	GLO	Steel hot dip galvanised	2020	worldsteel	1	4	3	1	1
Steel, Stainless, Austenitic	EU-28	Stainless steel cold rolled coil (304)	2014	Eurofer	3	5	2	1	1
Steel, Stainless, Ferritic	EU-28	Stainless steel cold rolled coil (430)	2014	Eurofer	3	5	2	1	1
Steel, unalloyed	GLO	Steel hot dip galvanised	2020	worldsteel	1	4	2	1	1
Steel, unalloyed	GLO	Steel cold rolled coil	2022	worldsteel	1	4	2	1	1
Steel, unalloyed	Europe	Steel cold rolled coil	2022	worldsteel	1	2	2	1	1
Steel, recycled, unalloyed	DE	EAF Steel billet / slab / bloom (Hot and cold rolling processes added)	2022-2025	Sphera MLC	1	5	2	1	1
Sulphuric acid	EU-28	Sulphuric acid (96%)	2021	Sphera MLC	1	5	2	1	1
Thermoplastic elastomers	DE	Polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix	2021	Sphera MLC	1	5	3	1	1
Thermoplastics	GLO	Market for nylon 6	2011	ecoinvent 3.9.1	1	4	3	1	1
Tyre			2022	From supplier	1	1	1	1	2
Tyre*	DE	Natural rubber (NR) (excl. LUC emissions)	2022-2025	Sphera MLC	1	5	2	1	1
Tyre*	RER	Synthetic rubber production	2022	ecoinvent 3.9.1	1	5	2	1	1
Tyre*	GLO	Market for carbon black	2022	ecoinvent 3.9.1	1	4	2	1	1
Tyre*	RER	Lubricants at refinery	2019-2025	Sphera MLC	1	5	2	1	1
Tyre*	RER	Electricity from lignite	2019-2025	Sphera MLC	1	5	2	1	1
Tyre*	GLO	Market for paraffin	2022	ecoinvent 3.9.1	1	4	2	1	1
Tyre*	RER	Water (deionised)	2022-2025	Sphera MLC	1	5	2	1	1
Undefined	GLO	Market for nylon 6	2011	ecoinvent 3.9.1	1	4	5	1	1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)	2021	Sphera MLC	1	5	3	1	1
Wood (paper, cellulose ...)	EU-28	Laminated veneer lumber (EN15804 A1-A3)	2021	Sphera MLC	1	5	3	1	1

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Material/process	Location	Name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
Zinc	GLO	Steel hot dip galvanised	2020	worldsteel	1	4	2	1	1
Aluminium manufacturing	DE	Aluminium die-cast part	2021	Sphera MLC	1	5	3	1	1
Aluminium manufacturing	EU-28	Aluminium sheet – open input aluminium rolling ingot	2021	Sphera MLC	1	5	3	1	1
Aluminium manufacturing	DE	Aluminium sheet deep drawing	2021	Sphera MLC	1	5	3	1	1
Polymers (all categories) manufacturing	DE	Plastic injection moulding part (unspecific)	2021	Sphera MLC	1	5	2	1	1
Steel (all categories) manufacturing	DE	Steel sheet deep drawing (multi-level)	2021	Sphera MLC	1	5	3	1	1
Energy for XC90 MHEV battery cell production	CN	Electricity grid mix 1kV-60kV	2020	Sphera MLC	2	2	3	1	1
Energy for XC90 MHEV battery cell production	RER	Thermal energy from natural gas	2020	Sphera MLC	2	3	3	1	1

** only used for maintenance BOM.*

*** see Table 19 for a complete list of electronics datasets, the same rating is used for all.*

Table 28 *Summarized quality assessment of data used in the study.*

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

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11. Appendix 4 – Assumptions for component manufacturing

Table 29 *Summary of data choices and assumptions for component manufacturing.*

Material	Assumption	Comment	Material utilisation rate in additional component manufacturing
Cast iron	No extra manufacturing processes	Dataset includes production of finished components for use in automotive applications	N/A
Fluids	No extra manufacturing processes	Fluids need no further refining after raw material production	N/A
Tyres	No extra manufacturing processes	Processing after vulcanisation causes minimal GHG-emissions	N/A
Copper (wire)	No extra manufacturing processes	Processing into copper wire after manufacturing causes minimal emissions and waste	N/A
NdFeB magnets	No extra manufacturing processes	Dataset includes production of finished magnets for use in automotive electric motors	N/A
Electronics (PCBs)	No extra manufacturing processes	The chosen dataset already includes the production of a finished printed circuit board	N/A
Cast aluminium	Die-casting process		96%
Wrought aluminium	Rolling and Aluminium sheet deep drawing	Represents different forms of wrought processing	62%
Steel (in parts, processed at suppliers)	Steel sheet deep drawing	Adheres to the conservative approach	63%
Steel (stamped at Volvo Cars' facility)	Scrap generated at Volvo Cars' facilities	The steel scrap generated at stamping in the Volvo factories are included, that is the steel in vehicle structures workstream	Confidential
Stainless steel	Steel sheet deep drawing	Adheres to the conservative approach	63%
Polymers	Injection moulding process	Represents different forms of processing	98%
Other materials	Raw material mass x 2	Compensates for further refining and processing where manufacturing process is unknown	50%

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11. Appendix 5 – Maintenance

Table 30 *Number of components replaced during routine maintenance over a distance of 200,000 kilometres.*

Component	XC90 mild hybrid	XC90 plug-in hybrid	EX90
Wiper blades	39	39	39
Tyres	16	16	16
Brake fluid (litres)	4	4	4
Brake pads	20	8	0
Brake discs	2	0	0*
12 V batteries	3	3	3
Steering joint	1	1	1
Link arms	2	2	2
Condensers	1	1	1
AC fluid	2	2	2
Cabin filters	12	12	12
Engine oil (litres)	75	75	N/A
Oil filters	15	15	N/A
Automatic transmission oil (litres)	2	4.8	N/A
Air filters (engine)	3	3	N/A
Fuel filters	1	0	N/A
Spark plugs	12	12	N/A
Camshaft belts	1	1	N/A
Water pump belts	1	1	N/A
Seatbelt tensioners and idler rollers	2	2	N/A
Auxiliary belts	3	3	N/A

** EX90 has high regenerative braking, which means low usage of friction brakes, resulting in zero disc changes in the first 200,000 km for the average customer. EX90 has more regenerative braking than XC90 PHEV.*

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11. Appendix 6 – End-of-life treatment – assumptions and methodology

Transportation

Emissions from the transportation of waste to recycling, incineration and landfill sites and calculated for road freight covering 500 kilometres. According to European Commission recommendations for Environmental Footprint methods[16], waste from manufacturing and construction sites is assumed to travel 100 kilometres for end-of-life treatment. As waste from end-of-life vehicles is separated into many recycling categories could be considered more specific, thus certain waste fractions may have to be transported longer distances, the assumption in this study exceeds EC guidelines.

Disassembly

Most disassembly is carried out manually, therefore, energy use is not calculated. As the mass of disassembled components is low, transportation emissions are not calculated.

Pre-treatment

Emissions from pre-treatment is included for the following components:

- 12 volt batteries
- Tyres
- Li-ion batteries

Ecoinvent datasets were used for the pre-treatment of batteries and tyres. An assumption is made that Li-ion batteries are transported 500 kilometres by road. No emissions are calculated for the remaining components, as they are disassembled as a safety precaution. Fluids that are incinerated do not undergo pre-treatment.

Shredding

In the shredding process, the vehicles are milled to smaller fractions. This process uses electricity. To estimate the amount of energy needed, the energy usage per kg in the dataset "treatment of used glider," passenger car, shredding from ecoinvent 3.9 was used. The electricity used for this process was modelled as a 2038 global electricity mix, based on the IEA *STEPS* scenario. 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 as occurring at the same site as dismantling.

Material recycling

Metal and battery recycling use the cut-off approach for end-of-life modelling and are not considered within the boundaries of vehicle lifecycles. Only emissions from transportation to recycling facilities are calculated.

Final disposal – incineration and landfill

An assumption is made that fluids and the combustible elements of shredder light fraction are incinerated without energy recovery.

Emissions from the incineration of shredder light fraction is modelled with a Sphera MLC dataset for the incineration of mixed plastics, as its content is primarily plastic.

Non-combustible materials in shredder light fraction, such as ceramics and glass, are sent to landfill sites or recycled into filler material. These are modelled with a Sphera MLC dataset for landfilling of glass/inert matter.

An assumption is made that fractions separated from shredded material are transported 500 kilometres by road to recycling facilities.

[16] https://environment.ec.europa.eu/document/download/680503dc-5a19-4f6a-bb92-84d9bfc8f312_en?filename=Annexes%201%20to%202.pdf

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End-of-life waste handling

Table 31 *Waste handling of material fractions.*

Disassembly stage	Pre-processing stage	Final disposal
Li-ion batteries	Disassembly and shredding	Material recycling
Lead acid battery	Disassembly	Material recycling
Catalytic converter	Disassembly	Material recycling
Tyres	Disassembly	55% material recycling and 45% incineration
Liquids (coolants, brake fluids)	Tapping	Incineration
Engine oil	Disassembly	Recycling
Airbags and seat belt pretensioners	Disarming of explosives. Shredding	According to material category*
Rest of vehicle	Shredding	According to material category*

** Metals are recycled, combustible materials (mainly plastics) incinerated and the remainder sent to landfill sites.*

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11. Appendix 7 – Greenhouse gas emission factors

Table 32 *Greenhouse gas emission factors.*

GWP 100 used for carbon footprint calculations according to ISO 14067 (IPCC AR6, kg CO_2e/kg CO_2)	Fossil GHG emissions	GHG emissions from land use change (dLUC)	Biogenic GHG emissons	Biogenic GHG removal	Fossil GHG emissions for high altitude flights
Methane	29.8		29.8		
Nitrous oxide (laughing gas)	273				
Carbon dioxide (fossil or biogenic)	1		1	1	
Carbon dioxide (land use change [Inorganic emissions to air]		1			
Carbon dioxide (peat oxidation) [Inorganic emissions to air]		1			
Carbon dioxide, from soil or biomass stock [ecoinvent long-term to air]		1			
Carbon dioxide, from soil or biomass stock [Inorganic emissions to air]		1			
Carbon dioxide, to soil or biomass stock [Inorganic emissions to agricultural soil]		-1			
Carbon dioxide, to soil or biomass stock [Inorganic emissions to industrial soil]		-1			
Methane, from soil or biomass stock [ecoinvent long-term to air]		29.8			
Methane, from soil or biomass stock [Organic emissions to air (group VOC)]		29.8			
Emission factor used at Volvo Cars for high altitude flights (reaches above 8,000 m)					
CO_2 emissions for flights longer than 785 km					2

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11. Appendix 8 – Critical review

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VOLVO EX90 LCA - INDEPENDENT CRITICAL REVIEW STATEMENT

Ricardo confirms that a critical review was performed of the following carbon footprint study of the Volvo EX90.

Table 1: Details of Carbon Footprint Study

Aspect	Details
Scope of study	Critical review of the carbon footprint assessment prepared by Volvo Cars to calculate the potential carbon footprint of the new electric Volvo EX90.
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	Volvo Cars
Version of report to which the critical review belongs	Version 1.1 / 09th September 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 September 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 Principal 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 EX90 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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