Carbon Footprint Report

Carbon footprint of Volvo ES90

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Executive summary

At Volvo Cars, sustainability is at the core of what we do. We have a long-standing history of pursuing our sustainability ambitions and aim to lead the way in protecting people and the planet by working towards net zero greenhouse gas (GHG) emissions and a nature positive future, embracing the circular economy and conducting business responsibly.

Our strategy 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 life cycle assessment (LCA) of its carbon footprint. In doing so, we intend to show our consistent improvements over time, as well as being transparent towards our customers, employees, investors, and other stakeholders interested in our carbon footprint performance.

This report presents the carbon footprint of the fully electric Volvo ES90, which goes into production in 2025. It also contains comparisons with the Volvo S90 plug-in hybrid (PHEV) and mild hybrid (MHEV), vehicles of similar size with different propulsion technologies. The assessment examines global warming potential (GWP), according to ISO 14067 guidelines with characterisation factors determined by the Intergovernmental Panel on Climate Change (IPCC) and has been reviewed by the IVL Swedish Environmental Research Institute. The scope includes cradle-to-grave vehicle life cycles, from extracting and refining raw materials to end-of-life treatment. The study takes a conservative approach to avoid underestimation in its carbon footprint calculations. Its findings are not directly comparable with those of other studies, except where the same methodology and assumptions have been applied.

The ES90 is manufactured in Chengdu, China, and equipped with a 92 kWh or a 106 kWh battery. This study covers the 92 kWh battery only as this is expected to be the best-selling configuration of the ES90. The S90 PHEV and MHEV are manufactured in Daqing, China, 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 footprint is assessed for charging with European, Asia-Pacific (APAC) and global electricity mixes, as well as wind-generated electricity. For internal combustion engines, calculations are based on the 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 ES90 is approximately 50 per cent lower than the S90 MHEV and 30 per cent lower than the S90 PHEV, when the European electricity mix is used for charging. If charged with wind-generated electricity, the ES90's carbon footprint is further reduced in comparison with use of the European electricity mix.

In the sensitivity analysis, recycled steel content in primary steel production, several future energy scenarios, and lifetime distances are evaluated. Energy scenarios that reflect faster decarbonisation are beneficial for the ES90's carbon footprint.

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

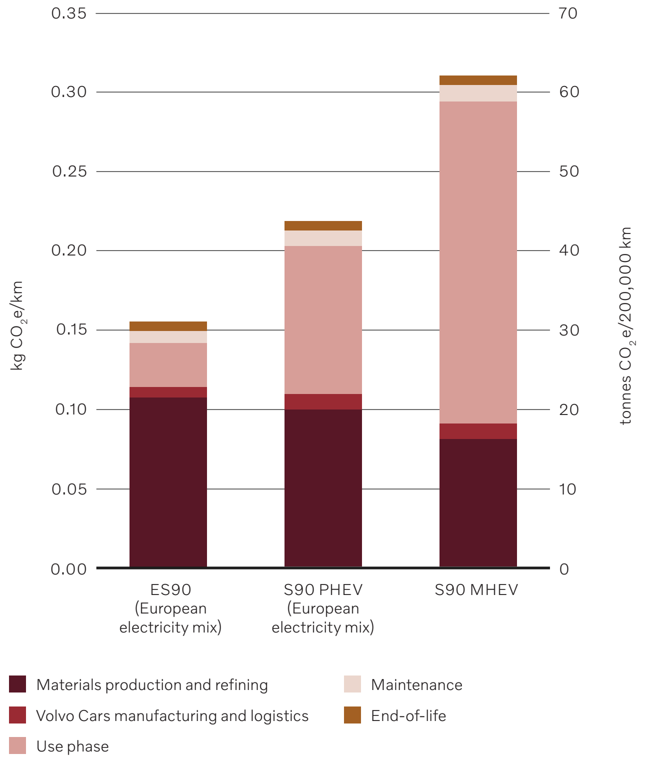

***Figure i.** Carbon footprint when charging with the European electricity mix.*

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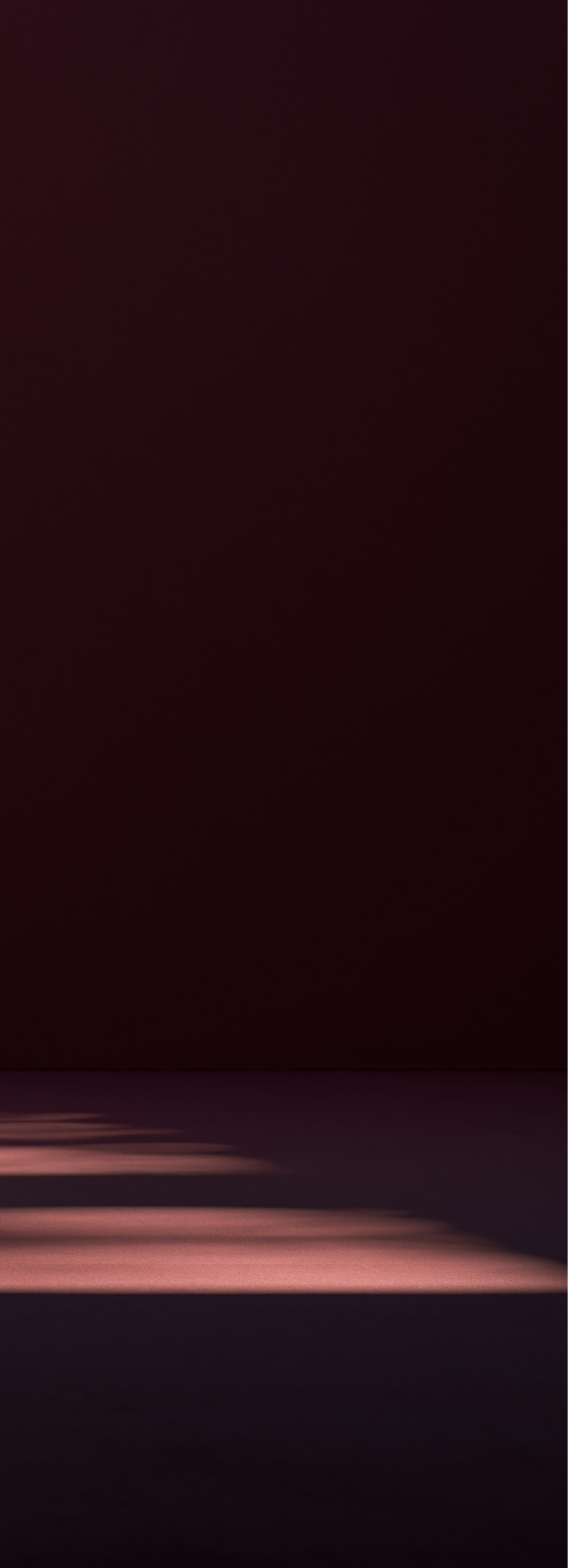
Key findings

- The life cycle carbon footprint of the ES90 is 31 tonnes CO_2e, when charged with the European electricity mix.
- The total carbon footprint of the ES90 is approximately 50 per cent lower than the S90 MHEV and 30 per cent lower than S90 PHEV, when charged with the European electricity mix.
- The total carbon footprint of the ES90 is lower than the S90 PHEV and S90 MHEV, when charged with any of the electricity sources evaluated in this study, including the European, APAC and global electricity mixes, and wind-generated electricity.
- Consumption of wind-generated electricity significantly reduces the life cycle carbon footprint of the ES90 to 26 tonnes CO_2e.
- Production of steel and iron, as well as aluminium have a significant impact on the carbon footprint of all vehicles in this study. For the ES90 specifically, aluminium accounts for the most significant proportion of its carbon footprint. The cathode and anode active materials in the Li-ion battery modules also play a significant part.
- Efforts have been made that improve the sustainability performance of the ES90. The use of recycled materials and materials produced with renewable energy or low-carbon technology, as well as renewable energy in our manufacturing facilities and throughout its supply chain, reduce its carbon footprint significantly.



Contents

Abbreviations

ABS:
Acrylonitrile Butadiene Styrene

APAC:
Asia-Pacific

APS:
Announced Pledges Scenario

BEV:
Battery Electric Vehicle

BOM:
Bill Of Materials

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

MHEV:
Mild Hybrid Electric Vehicle

NMC:
Nickel Manganese Cobalt

NZE:
Net Zero Emissions by 2050 scenario

PA:
Polyamide

PBT:
Polybutylene Terephthalate

PC:
Polycarbonate

PCB:
Printed Circuit Board

PET:
Polyethylene Terephthalate

PE:
Polyethylene

PHEV:
Plug-in Hybrid Electric Vehicle

PP:
Polypropylene

STEPS:
Stated Policies Scenario

Tonne:
Metric tonne (1000kg)

WLTP:
Worldwide Harmonized Light Vehicle Test Procedure

WLTC:
Worldwide Harmonised Light Vehicle Test Cycle

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1. Introduction

At Volvo Cars, sustainability is important to us – and we aim to reach net zero greenhouse gas emissions by 2040.

We are transitioning toward being a fully electric car company and aim to accompany each new battery electric vehicle (BEV) with a detailed carbon footprint analysis based on life cycle assessment (LCA) methodology. These studies are intended to increase transparency and support informed decisions by customers, employees, investors, and other stakeholders.

This report presents the life cycle carbon footprint of the Volvo ES90, a fully electric vehicle scheduled to enter production in 2025. The ES90 represents a significant step in our electrification strategy and has been assessed from cradle to grave, encompassing raw material extraction, production, use phase, and end-of-life treatment. The study follows ISO 14067 standard and applies global warming potential (GWP) factors as outlined by the Intergovernmental Panel on Climate Change (IPCC). A third-party review ensures methodological accuracy and reliability.

To provide context and meaningful comparison, the ES90's carbon footprint is evaluated alongside that of the Volvo S90 PHEV and S90 MHEV – vehicles of comparable size but with different powertrain technologies. The comparison uses consistent assumptions and data sources across all models.

By analysing emissions across different energy scenarios – including global, European, APAC, and wind-based electricity mixes – this study offers insights into how both vehicle design and energy source influence the overall environmental impact. The findings highlight the ES90's potential to significantly reduce greenhouse gas emissions relative to hybrid alternatives, especially when charged with low-carbon electricity.

This assessment supports our broader efforts to lower emissions across the vehicle value chain and contributes to our strategic ambition of achieving net zero greenhouse gas emissions. It also provides valuable data for continued improvement in sustainable product design, material selection, and supply chain development.

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2. Methodology

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

2.1 The products

This study assesses the carbon footprint of the ES90 battery electric vehicle (BEV) in comparison with two models of similar size – the S90 long-range plug-in hybrid vehicle (PHEV) and the S90 mild hybrid electric vehicle (MHEV)[1]. All three vehicles are produced by Volvo Cars and offered in different configurations. The best-selling configuration of the ES90 is chosen for this study. More details are listed in Table 1 below.

This study assesses a common equipment level for each vehicle:

- ES90 – electric, 5-seat
- S90 – plug-in hybrid, electric/petrol, 5-seat
- S90 – mild hybrid, petrol, 5-seat

Both the ES90 and S90 models are manufactured in China.

Table 1 *Sample vehicles used in the study.*

Vehicle	Mass (kg)	Battery type	Battery capacity (kWh)
ES90	2,381	NMC613	92
S90 PHEV	2,101	NMC811	18.8
S90 MHEV	1,807	NMC523	0.37

The foundation for the methodology used in this study was developed by Volvo Cars for carbon footprint studies of the EX40 in 2020. This methodology was further developed and updated when performing carbon footprint studies of the Volvo EC40, EX30 and EX90.

[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.

2.2 Goal of the study

Volvo Cars has the ambition to reach net zero greenhouse gas emissions[2] by 2040. We are working to make progress towards this ambition every day. The goal of this study is to evaluate the carbon footprint of the ES90 throughout its life cycle in comparison with two hybrid models of a similar size, and to improve transparency in its environmental reporting. It aims to identify stages and processes that make the greatest impact on carbon footprint, as well as providing data support for sustainable product design and further improvements. As the same methodology and assumptions have been applied consistently in all vehicle assessments, this comparison is valid. 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 carbon footprint performance of electric vehicles in general and our vehicles in particular.

2.3 Scope of the study

The study is a Life Cycle Assessment (LCA) that only considers greenhouse gas emissions. It has been carried out and reported in accordance with the ISO 14067 standard, which in turn is based on life cycle assessment principles in accordance with ISO 14040 and ISO 14044. It explores global warming potential (GWP), using characterization factors for 100-year global warming potential from the Sixth Assessment Report[3] by the Intergovernmental Panel on Climate Change (IPCC). Specific greenhouse gas emissions and removals are included in the main results of this study, as well as the sum of the following items:

- Fossil greenhouse gas emissions and removals
- Biogenic greenhouse gas emissions and removals
- Greenhouse gas emissions and removals from direct land use and land-use change
- Aircraft greenhouse gas emissions

The study takes an attributional approach and does not aim to capture systemic changes. No carbon offsetting is used in this study.

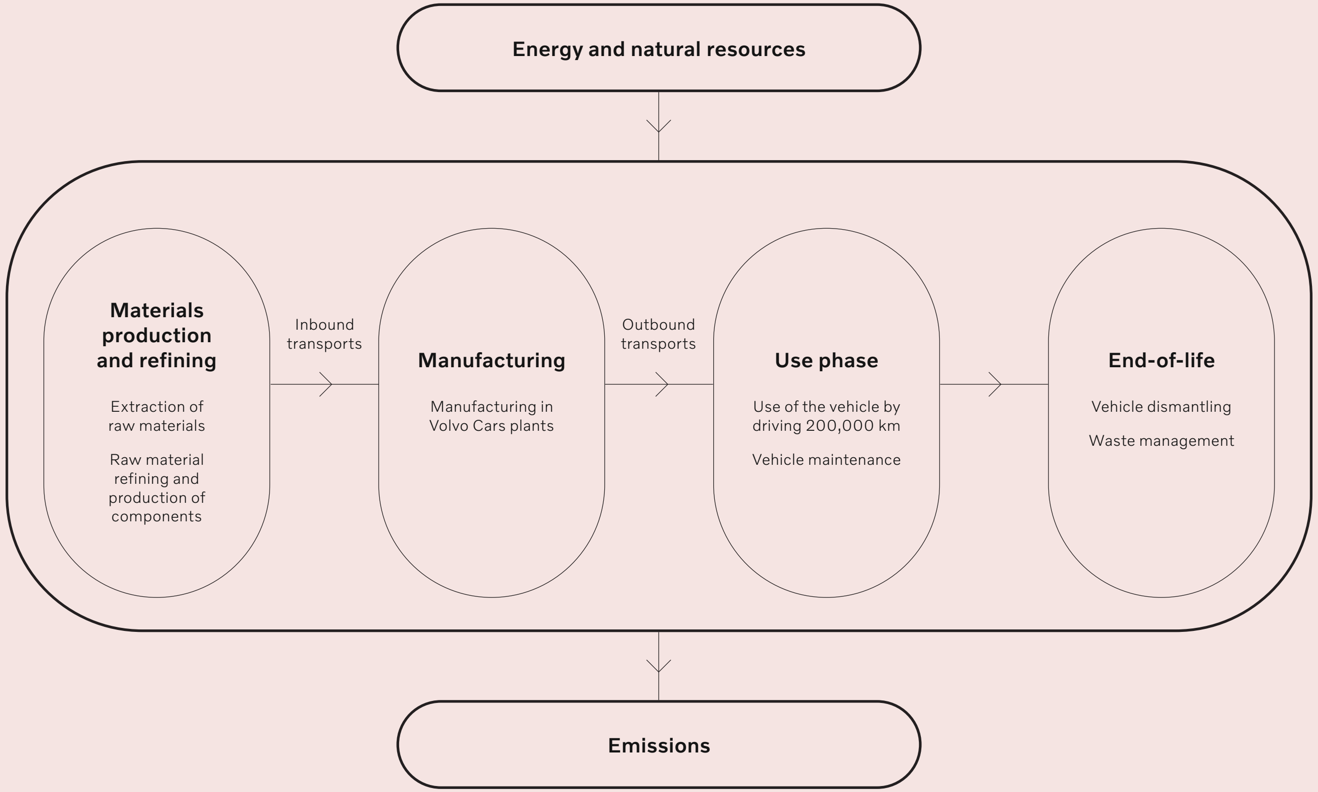

Figure 1 *System boundary of the study.*

This study covers cradle-to-grave vehicle life cycles, 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 and based on the vehicle maintenance service instructions.

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

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No cut-off criteria have been applied to the mass of materials in components or energy use. By doing this, we aim to include the complete inventory in carbon footprint calculations. Material content not specified by suppliers is included and modelled with a polymer dataset. For more information, see the Life Cycle Inventory Analysis.

The time boundary of the study relates to manufacturing in 2025 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 if they occurred at the start of the assessment period, without considering the impact of delayed emissions and removals. End-of-life handling aims to reflect global conditions in 2040, based on current conditions in Europe. 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 geographical boundary of the study is vehicle manufacturing in China, while vehicle use is considered on a global scale. The consumption of European, APAC and global electricity mixes are calculated in the use phase, as well as wind-generated electricity. Where available, generic datasets for specific countries or regions have been used for upstream processes, such as raw material extraction and refining, in order to improve data quality.

Generic data have been used for most upstream processes. The modelling of component production is based on material composition, with generic datasets for material production and manufacturing processes combined for each material. If no appropriate dataset was available to represent the manufacturing process of certain materials, resource use and emissions from raw material production have been multiplied by two as a compensatory measure.

Specific data from suppliers, as opposed to generic data, has been increasingly prioritised in this study in order to more accurately represent the carbon footprint of supply chains compared to previous carbon footprint reports. This includes supplier data for tyres in the S90 MHEV, Li-ion battery modules and tyres in the S90 PHEV, Li-ion battery modules, tyres, wheels, cross-car beam and instrument panel in the ES90. To better advance this work, a guideline has been developed to assist suppliers in calculating carbon footprints by using a consistent methodology.

2.3.1 Function and functional unit

The function of vehicles in this study is to transport persons and their belongings. The functional unit or declared unit chosen is vehicle-kilometre (vkm). In practice, carbon footprint is calculated for total life cycle and divided by the distance driven during the vehicles' lifespan. Carbon footprint results are also presented for the vehicle's total lifespan.

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

2.3.2 Allocation

This study uses the simple cut-off approach, also called the recycled content approach, which is the recommended allocation method in the International EPD[4] system. This method follows the polluter pays principle, which implies that if several product systems share the same material, the environmental burden is assigned to the product system that causes the waste. Reflecting this, the system boundary between life cycles occurs at the 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 to both waste material from manufacturing processes and end-of-life treatment that is sent for recycling. No system expansion has been applied in this study. Therefore, no credits are given for material recycling that potentially avoids other material production or for energy recovery from waste incineration that potentially avoids other energy production.

Material waste from production processes is also accounted for by including greenhouse gas emissions associated with the production of that material. This is especially relevant for steel and iron as well as aluminium, where significant amounts of scrap material that 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.

A co-product allocation approach is applied to vehicle manufacturing in this study. The total number of vehicles produced at a manufacturing facility is used as the allocation basis, irrespective of the models or variants manufactured. When calculating impact per vehicle, the annual resource use and waste generation at facilities is divided by the total production volume.

2.3.3 Primary assumptions, limitations and exclusions

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

The vehicles' use phase is estimated to be 15 years. Potential changes in European, APAC 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 considers only 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 the sensitivity analysis.

The vehicles' lifetime distance is assumed to be 200,000 kilometres. The relative impact of longer lifetime distances is evaluated in the sensitivity analysis. Component replacement related to maintenance is evaluated in this report. This does not include Li-ion batteries as it is assumed that they will not be replaced in the vehicles' estimated lifespan.

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 exclude the use of non-essential functions, such as infotainment and air conditioning.

The WLTC is based on analysis of a range of real-world driving conditions around the world. However, the WLTP is a laboratory test that does not consider individual driving styles, traffic and weather conditions, road inclination or load (passengers and luggage), all of which can have a significant impact on actual energy usage.

Euro 6e-bis[5,6] regulations came into effect in January 2025 for new vehicles sold in Europe that ensure testing more closely reflects actual vehicle use. The new regulations extend the driving distance required for emission tests, which more accurately measures exhaust emissions. Calculations in this study reflect the new regulations by adjusting the parameters used to derive the utility factor of the S90 PHEV.

This study does not include greenhouse gas

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

emissions derived from:

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

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2.3.4 Data quality requirements

In order to manage uncertainty, data quality is assessed against requirements in several aspects. 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, APAC 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 and Sphera are updated annually in response to, for example, changes in energy mixes. Geographic correlation varies, primarily due to the unknown origins of many materials. However, battery modules and some aluminium, both associated with high impact, are modelled using datasets with good geographic coverage. Electronics, also a high-impact category, have incomplete technical data from the complex product and its supply chain. The low data quality scores of electronics in terms of both time-related and geographic correlation 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 processes we monitor. The use phase is also modelled with good quality data, as electricity and fuel usage 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 achieves fewer good scores. This due to the use of current data, despite considerable uncertainty about how processing will change during the vehicles' lifespan. Similarly, waste handling varies significantly in different markets and changes are difficult to predict.

Overall, data quality for our operations and the use phase of vehicles is considered sufficient. Data quality for the production and refining of materials, as well as end-of-life treatment varies significantly. However, it is considered better for materials or components we source directly, such as Li-ion battery modules.

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

2.4 Report and critical review

This study was created by Volvo Cars for publication on its website in 2025. It is a complete study and there is no additional documentation. Its compliance with ISO 14067 standard has been reviewed by the IVL Swedish Environmental Research Institute, see Appendix 8.

2.5 Summary of Way of working

Figure 2 gives a high-level overview of how carbon footprint is calculated in this report.

This study uses LCA for Experts (LCA FE) modelling software developed by Sphera. Data is imported with the LCA BOM Import mapping tool, 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, which contain information on the material composition of components.
- LCI databases from ecoinvent (version 3.10) and Sphera (MLC version 2024.1).
- Data from Volvo Cars' operations, including manufacturing and logistics.
- Specific carbon footprint results from suppliers (Li-ion battery modules, tyres, wheels, cross-car beam and instrument panel).

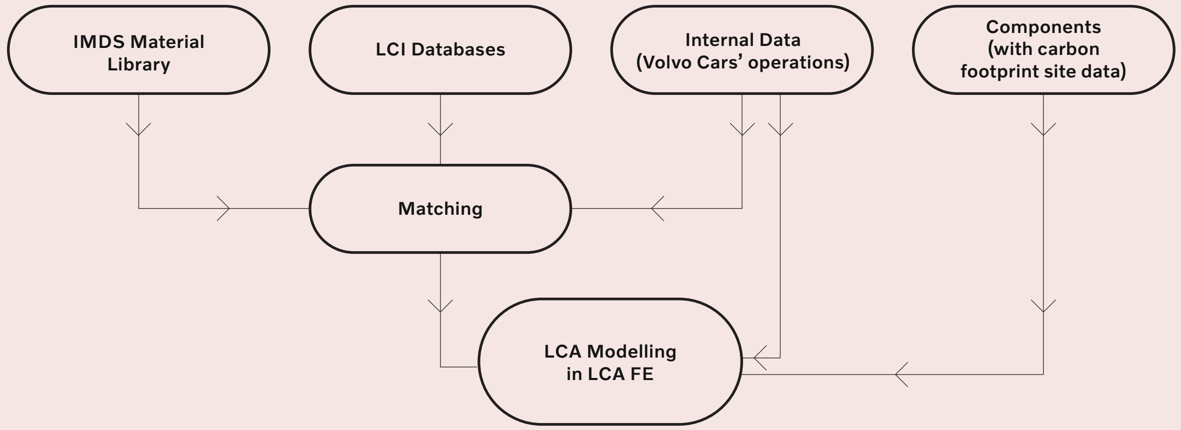

Figure 2 *Overview of way of working.*

2.6 Methodology for defining material composition

The primary data sources for material composition are IMDS datasheets for each vehicle component. A configuration is chosen that corresponds to the specific combination of components the vehicle contains. By combining datasheets for these configurations, the total amount of material 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
Copper	2
Other metals	8
Polymers	40 (including filled/unfilled)
Tyres	1
Natural materials	4
Electronics	15
Glass	3
Fluids	8
Undefined	1

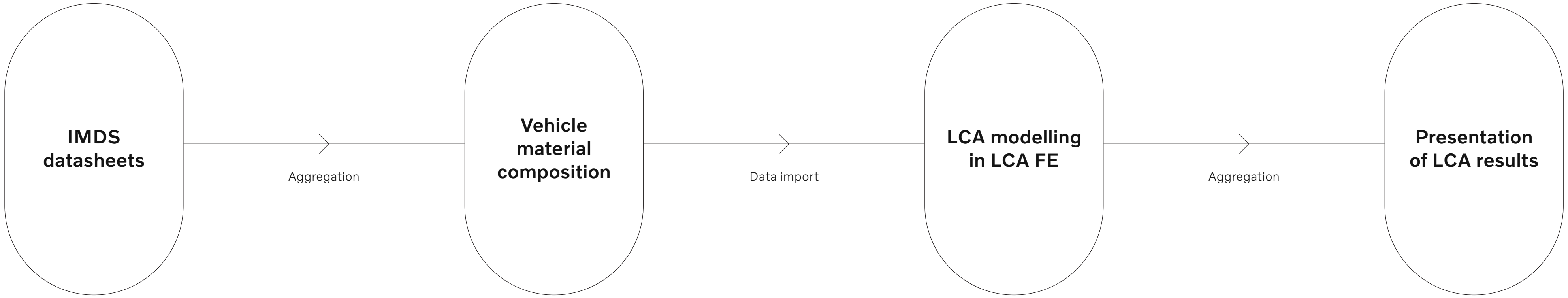

Figure 3 *Material aggregation steps.*

3. Life cycle inventory analysis

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

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3.1 Overview of the life cycle and data

Figure 4 is a life cycle flowchart for the ES90 and S90 models. The types of data used in the study are listed for different materials and life cycle stages When supplier specific carbon footprint data is available, they are being modelled in the lifecycle inventory. In the S90 models these specific components refer to battery modules and tyres. In the ES90 these specific components refer to battery modules, tyres, wheels, cross-car beam and instrument panel.

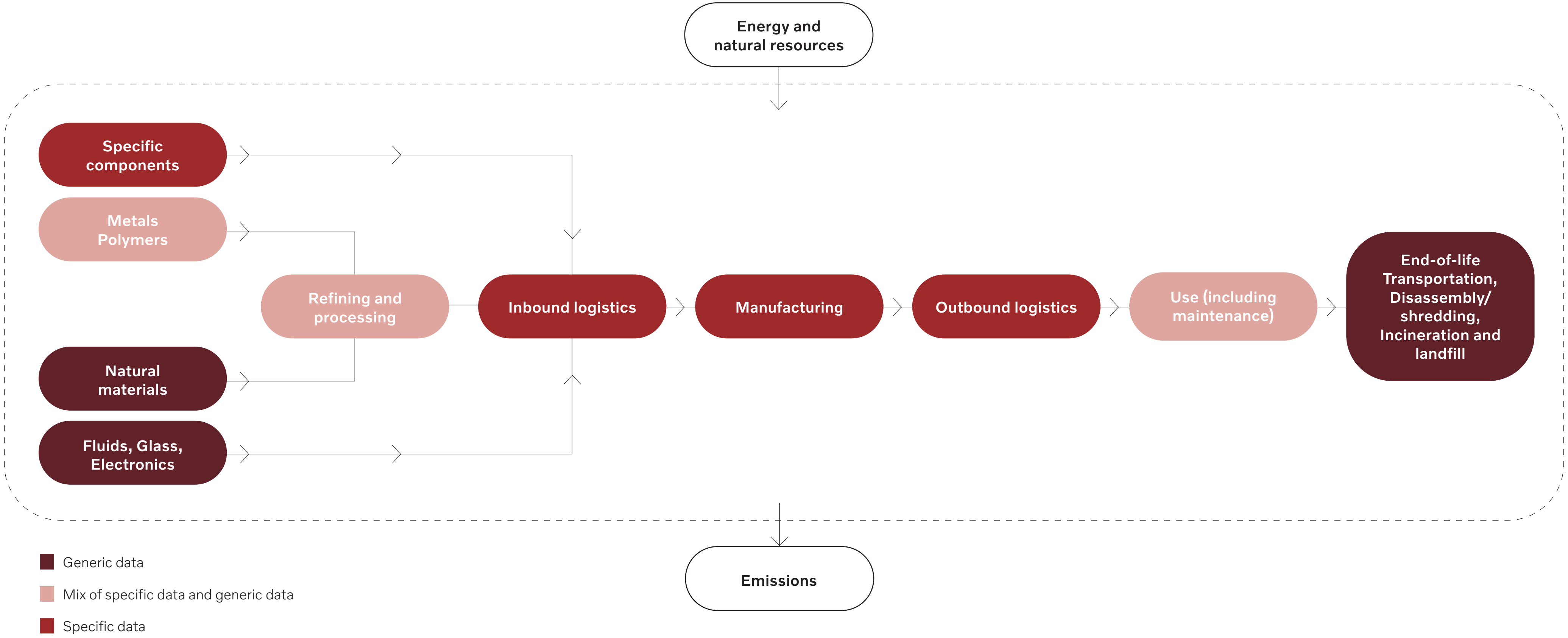

Figure 4 *Life cycle of the ES90 and S90s.*

3.2 Material production and refining

The BOM used for the LCA model is specifically developed for the purpose of this report and divides vehicle composition into around 90 material categories. Materials categorised as undefined amount to 1.3 per cent of total vehicle weight. As most of these contain undefined polymers, a dataset for polyamide (nylon 6) has been used for the purposes of approximation. This assumption is made as polyamide has the highest carbon footprint of any polymer in this study. Figure 5 shows material composition, while the percentages of each material category are shown in Table 4.

The usage of recycled materials is an effective way in reducing the carbon footprint. Considering data transparency and data traceability, Volvo Cars updated IMDS reporting requirements for recycled materials in 2023. Starting from September 2023, suppliers are required to submit recycled materials information in the IMDS.

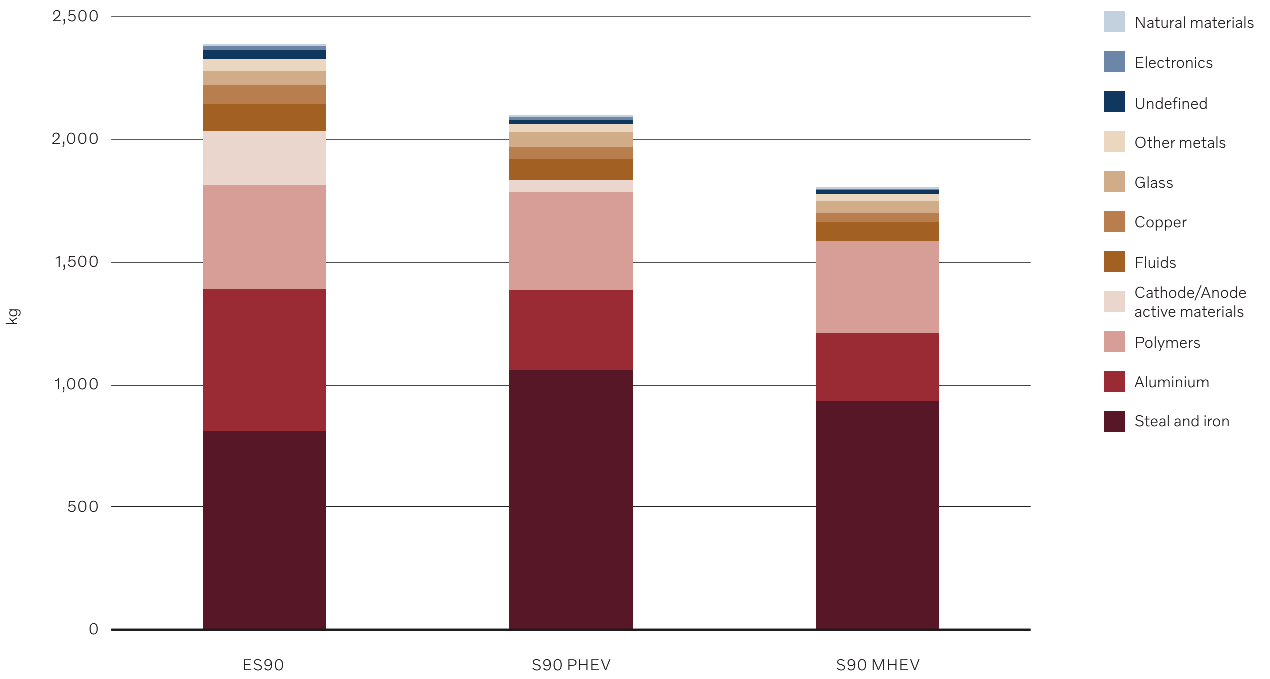

Figure 5 *Material composition by mass.*

Table 4 *Material composition as a percentage of total mass.*

Vehicle	Steel and iron	Aluminium	Polymers	Cathode/Anode active materials	Fluids	Copper	Glass	Other metals	Undefined	Electronics	Natural materials
ES90	34%	24%	18%	9.3%	4.4%	3.2%	2.5%	2.2%	1.3%	0.7%	0.1%
S90 PHEV	50%	15%	19%	2.4%	4.1%	2.6%	2.4%	1.8%	0.9%	0.6%	0.4%
S90 MHEV	52%	15%	21%	0.1%	4.4%	1.8%	2.8%	1.7%	0.9%	0.4%	0.3%

Materials are coupled with one or more LCI dataset, which represents production and refining in each material category. These are modelled with datasets from Sphera MLC and ecoinvent, see Appendix 2.

Increasing the use of recycled materials is an effective way of reducing the vehicles' carbon footprint. As of september 2023, our suppliers have been required to include information about their use of recycled material in the International Material Data System. The use of recycled materials is described in the following sections and used in data modelling. This requirement aims to improve transparency and traceability within our supply chain, enabling more accurate carbon footprint assessments.

3.2.1 Aluminium production and refining

The aluminium used in the ES90 and S90 models is primarily sourced in China. Based on IMDS data reported by the supply chain, it is calculated to be 46 per cent cast aluminium and 54 per cent wrought aluminium. In line with our conservative approach, an assumption is made that all wrought aluminium is processed into sheets, as sheet production results in greater material loss compared to other wrought aluminium processing methods. Cast aluminium is modelled with a die-casting process.

Production waste from aluminium component manufacturing is included in the 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 ES90 is:

- 43 per cent primary, produced with renewable energy.
- 29 per cent recycled.
- 28 per cent primary, produced with the average energy mix in the grid.

4 per cent of the aluminium content in the S90 models comes from recycled sources.

3.2.2 Steel and Iron production and refining

The steel and iron used in the ES90 and S90 models is primarily sourced in China. Most of the steel and iron are shown below, with confirmed recycled content from the supply chain:

- 8 per cent cast iron.
- 53 per cent flat steel.
- 2 per cent engineering steel.

The recycled content of the remaining steel is unknown, including stainless and sintered steel.

According to the World Steel Association[7], approximately 15 to 25 per cent steel scrap is used in conventional production. Among Chinese steel suppliers, this figure is slightly lower. The lowest recycled content among steel suppliers of the ES90 is 11 per cent. This value has been conservatively assumed as the average recycled content for the remaining 37 per cent of the steel used. Alternative assumptions for this remaining portion are explored in the sensitivity analysis.

The overall recycled content of steel and iron in the ES90 and S90 models is 18.4 per cent.

The dataset used for the unalloyed steel material category includes cold rolled and hot dip galvanised steel, with a ratio of 40 per cent to 60 per cent, based on IMDS data reported by the supply chain. This dataset is divided into two flows, each with an additional process step shown below:

1. Steel that is sourced, processed and stamped under our control, using a material utilisation rate based on internal data.
2. Steel sourced and processed by our suppliers, using a material utilisation rate based on the corresponding generic dataset.

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

3.2.3 Electronics production and refining

The Electronics category includes printed circuit boards (PCBs) and the components mounted on them. It does not include chassis, cables or other components in electronic control units, 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.

[7] *https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf*

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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. The ecoinvent datasets used to model all electronic components can be found in Appendix 2.

3.2.4 Polymer production and refining

This material category includes polymer materials, such as plastics. A dataset for injection moulding has been used to represent the processing of all plastic parts made from polymer raw materials. The material utilisation rate for plastic manufacturing processes can be found in Appendix 4.

Based on IMDS data reported by the supply chain, 16 per cent of polymers in the ES90 (including elastomers in its tyres) are recycled or biobased, in comparison with 1.6 per cent in the S90 models. Recycled plastic is modelled with a dataset for mechanically recycled plastics.

Filled polymers contain talc and/or glass fibres. The main polymer categories are 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)		30
PBT (filled)		30
PP (filled)	10	15

3.2.5 Material categories with no processing data

Approximately 1.3 per cent of total vehicle mass consists of raw materials with no processing data in LCI databases. In these cases, the material mass is doubled in order to compensate for missing processing data. Processing is, therefore, assumed to have the same carbon footprint as raw material production.

3.2.6 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. In LCI datasets that allow modification, the production of materials from known sources is assumed to use the Chinese future scenario electricity mix, while material production with unknown sources is assumed to use the global future scenario electricity mix, see Appendix 2.

3.2.7 Components with specific data

In comparison with previously published reports, more specific carbon footprint data from some suppliers is used in this study. This represents an additional step towards accurately representing the carbon footprints within our supply chains. Carbon footprint data for tyres used on the S90 MHEV is provided by our supplier. Carbon footprint data for Li-ion battery modules and tyres are provided by suppliers for the S90 PHEV, while additional data for wheels, cross-car beam, and instrument panel are included for the ES90.

A guideline has been developed to facilitate carbon footprint calculations within our supply chain that ensures consistent methodology. Suppliers are also required to conduct cradle-to-gate carbon footprint assessments, which are subject to review.

The system boundary used to assess component manufacturing is illustrated in Figure 6.

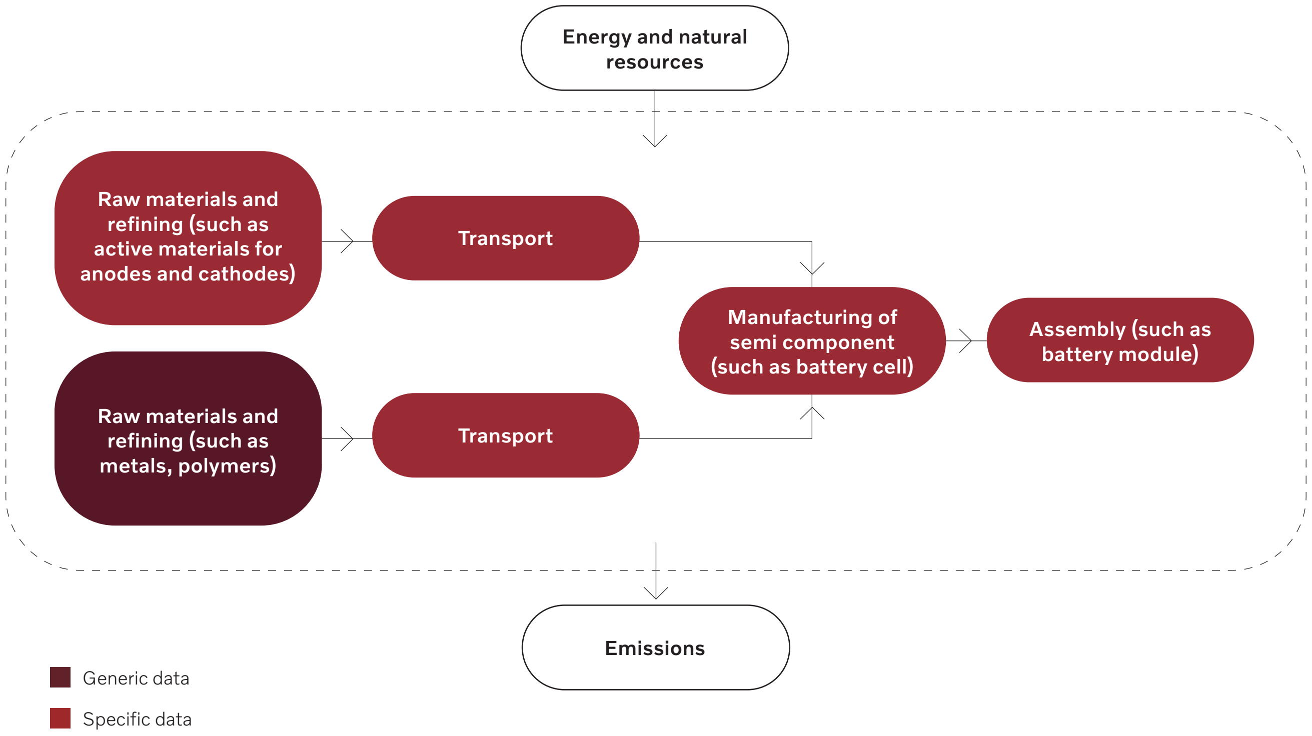

Figure 6 *Component manufacturing, cradle-to-gate.*

3.3 Manufacturing and logistics

3.3.1 Logistics

Company data is used to calculate the impact of inbound transport (components transported from direct suppliers to our manufacturing facilities). Total emissions from inbound transport are divided by the total number of vehicles produced. Internal data is also used to calculate the impact of outbound transport (products transported from our facilities to dealers). Total emissions from outbound transport are divided by the total number of vehicles sold.

As production of the ES90 began in 2025, annual logistics data for 2025 is not yet available at the time of the publication of this report, so forecasts based on historic data is used in the ES90. The estimation for ES90 is calculated as weighted average based on the volume plan and the markets to which ES90 are planned to be distributed. The logistics data of 2024 is used in the S90 models in this study. Sphera MLC datasets are used to model the impact of sea, rail, road and air transportation, see Appendix 2.

3.3.2 Vehicle manufacturing

Water use, energy consumption and waste generation data are collected at the manufacturing facility in Chengdu, for the ES90, and Daqing, for the S90 models, with allocation based on total output of vehicles.

As production of the ES90 began in 2025, annual manufacturing data for 2025 is not yet available. The historical data for manufacturing is stable and representative for 2025, and the impact of manufacturing is limited to the whole life cycle, so forecasts based on historic data are used for the ES90, while the manufacturing data of 2024 is used in the S90 models as the reference in this study.

The electricity used to manufacture the ES90 is generated from hydropower and solar panels. As the ratio between these sources differs over time, an assumption is made for modelling purposes that only solar power is used. The datasets used to model manufacturing impact are listed in Appendix 2.

3.4 Use phase

3.4.1 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)
ES90	16.0		16.0
S90 PHEV**	12.0	2.5	35.3
S90 MHEV		7.0	65.1

** The energy content in E5 petrol is 9.3 kWh/L[8]*

*** The weighted WLTP driving cycle corresponds to 70.5 per cent of total distance driven in electric mode, in accord with Euro 6e-bis[9] 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 7. These estimates are based on the ED11344 European Commission report (issue number 3[10]) and warranty data.

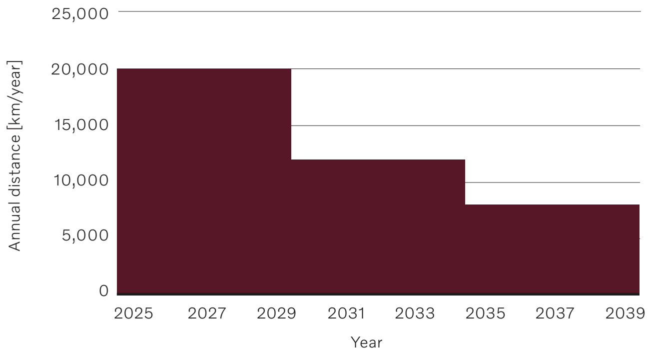

Figure 7 *Annual driving distance in the use phase.*

The impact of electricity generation is modelled on European, APAC 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.

[8] https://www.concawe.eu/wp-content/uploads/2017/01/rpt_13-13-2014-00668-01-e.pdf
[9] https://ec.europa.eu/transparency/comitology-register/screen/documents/082562/1/consult?lang=en (see Annexes 4-15, p27–28)
[10] https://climate.ec.europa.eu/system/files/2020-09/2020_study_main_report_en.pdf

The IEA's Global Energy and Climate Model explores possible future energy scenarios, based on a number of assumptions. In this study, the Stated Policies Scenario (STEPS) is used to evaluate potential changes in electricity generation used for vehicle charging, as shown in Figure 8 and Figure 9. STEPS reflects current and potential future policy in a range of sectors and countries. Two other IEA scenarios are evaluated in the sensitivity analysis.

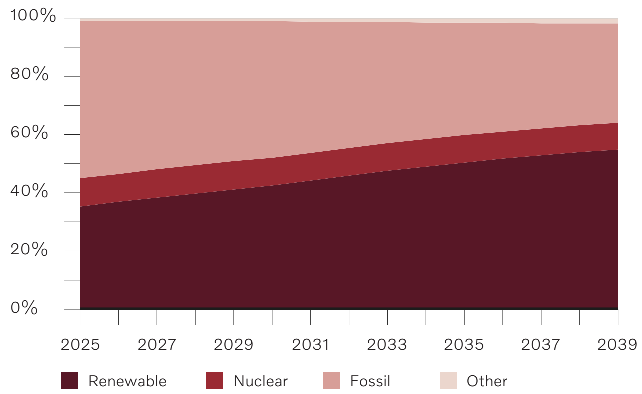

Figure 8 *Changes in the global electricity mix for STEPS.*

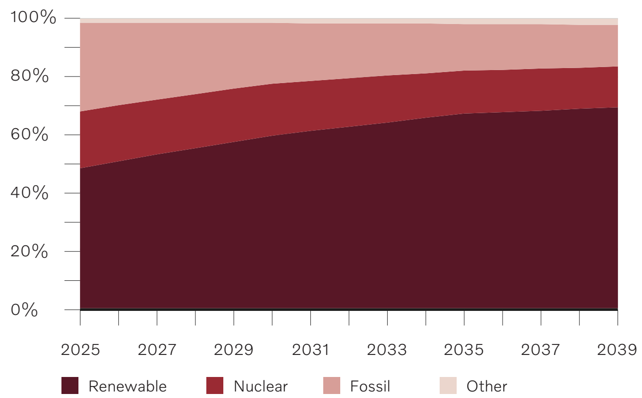

Figure 9 *Changes in the European electricity mix for STEPS.*

Weighted average use phase emissions, based on annual driving distances and according to STEPS projection, are 0.53 kg CO_2e/kWh for the APAC electricity mix, 0.40 kg CO_2e/kWh for the global electricity mix and 0.17 kg CO_2e/kWh for the European electricity mix.

The S90 models are assumed to consume petrol blended with 5 per cent ethanol (E5 petrol). 3.28 per cent of the carbon emission in WLTP emissions is allocated to biogenic emissions in the use phase, according to the petrol dataset in Sphera MLC.

3.4.2 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 for production and end-of-life handling applies the same methodology used for all other components.

3.5 End-of-life

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

A 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 disassembly, which removes components that are either recycled separately or hazardous. The disassembled parts are treated, while the remainder is shredded and separated for material recycling, incineration or landfill deposition.

The following hazardous and valuable components are removed at the disassembly stage:

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

Fluids are incinerated. An assumption is made that 55 per cent of tyres are recycled and 45 per cent incinerated. Airbags and seat belt pretensioners, which are removed for safety reasons, are incinerated. 12-volt batteries are sent for lead recovery, and the Li-ion battery is assumed to be recycled.

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 is 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, while non-combustible materials are sent to landfill.

Material losses in recycling and refining are outside the system boundary of this report, as determined by the simple cut-off approach.

An overview of end-of-life treatment modelling is shown below in Figure 10. More information can be found in Appendix 6.

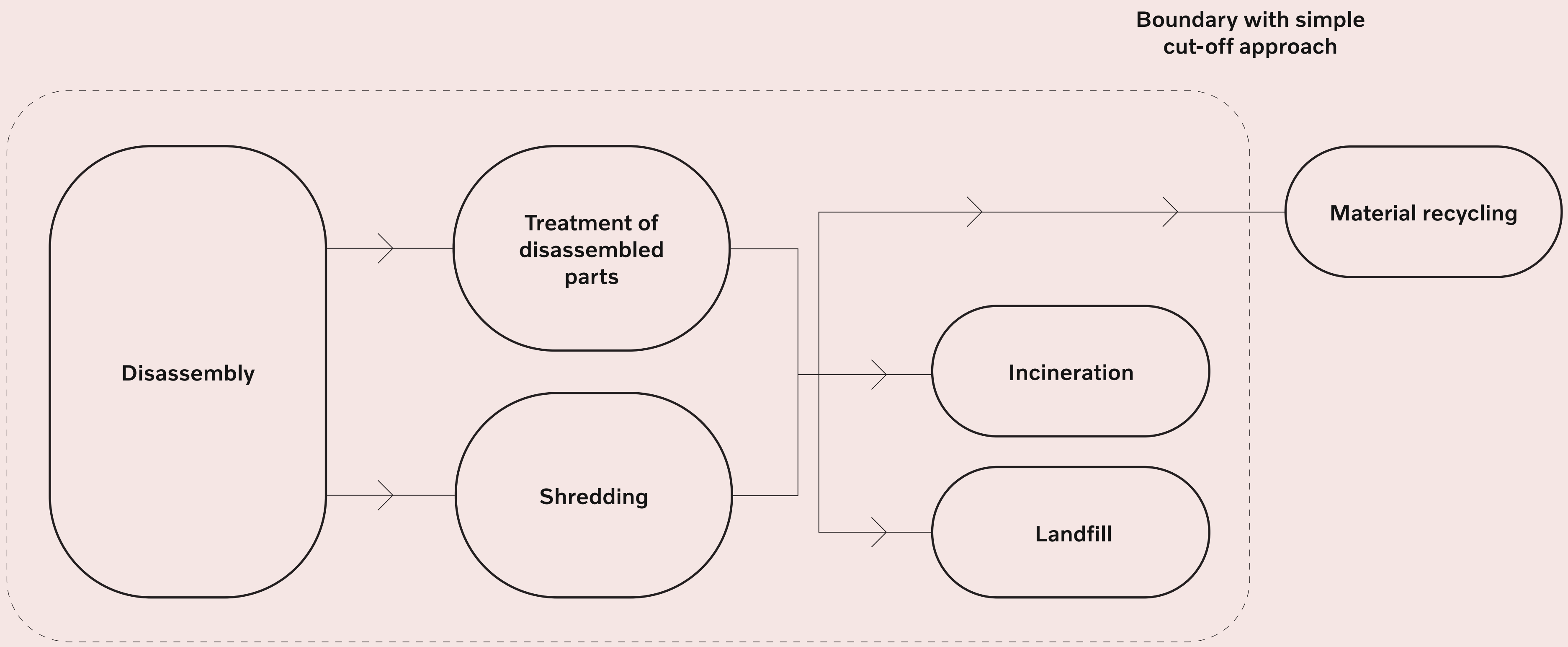

Figure 10 *System boundary for end-of-life.*

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3.6 Sustainability improvements in material use

A higher quantity of recycled materials and materials produced with renewable energy or low-carbon technology are used in the ES90 than the S90 models, which reduces environmental impact. The implementation of recycled materials has been done in a way that improves the circularity without degrading the performance compared to primary materials.

- 75 per cent recycled aluminium is used in wheels, with the remaining primary aluminium smelted with renewable energy.
- 30 to 40 per cent recycled aluminium is used in the battery tray and extruded aluminium in the vehicle body.
- 80 per cent recycled copper is used in electric motor wiring, Volvo Cars cooperate with suppliers to improve the recycled content rate in the near future.
- 80 per cent recycled magnesium is used in cross-car beam.
- Up to 50 per cent recycled PP and PC+ABS are used in instrument panel.
- 48 per cent natural materials are used in door panels, and 98 per cent natural materials are used in instrument panels and trim mouldings.
- 100 per cent recycled PA is used in carpet yarn.
- 67 per cent bio-based PA11, derived from castor oil, is used in battery cooling pipes.

The ES90 contains 17 per cent recycled content, consisting of 29 per cent recycled aluminium, 18.4 per cent recycled steel and iron, 16 per cent recycled polymer and bio-based material.

Electricity generated from renewable sources is used in our battery supplier's facility, to reduce the carbon footprint of battery modules.

3.7 Sustainability improvements among directly contracted suppliers

Volvo Cars aims to reduce the climate impact across its value chain by working with directly contracted suppliers. Our direct materials suppliers are requested to set targets and perform actions towards climate neutral energy sources in their own operations and upstream supply chains as part of our Sustainability Requirements.

In recent years, Volvo Cars has progressively encouraged its suppliers to reduce greenhouse gas emissions in their production processes. This results in the successful completion of Green Electricity projects in Daqing, Chengdu and Zhejiang, as well as Energy Action 100 projects with suppliers in the Asia-Pacific region. This has led to 11 directly contracted suppliers using 100 per cent renewable electricity in the manufacturing steps, leading to a reduction of around 0.1 tonnes CO_2e per vehicle in the material production and refining phase.

3.8 Sustainability improvements in manufacturing

As Volvo Cars aims to reach net zero greenhouse gas emissions by 2040, efforts have been made to minimize environmental impact and continuously decrease the climate footprint in manufacturing. All Volvo Cars' manufacturing facilities in China have achieved 100 per cent electricity from renewable energy sources and reduce gas consumption by recycling waste and residual heat. Since the beginning of 2025, the Chengdu Plant, where the ES90 is produced, has switched from natural gas to biogas. This has led to the carbon footprint reduction by around 50 per cent per vehicle in the manufacturing phase.

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4. Life cycle impact assessment

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In life cycle impact assessment, life cycle inventory data is interpreted in terms of potential contribution to carbon footprint. Specific greenhouse gas emissions and removals are included in the main results of this study, as well as the sum of the following items:

- Fossil greenhouse gas emissions and removals.
- Biogenic greenhouse gas emissions and removals.
- Greenhouse gas emissions and removals from direct land use and land-use change.
- Aircraft greenhouse gas emissions.

Results are based on available data at the time of the study. The results in this report have been rounded to two significant digits in order to improve clarity, consistency and acknowledge inherent uncertainties.

The life cycle carbon footprint of the ES90, when charged with four different electricity mixes is shown in Figure 11. Figure 12 shows the results for the ES90 and S90 models, when charged with the European electricity mix. Table 7 and Table 8 provide the values represented in the figures.

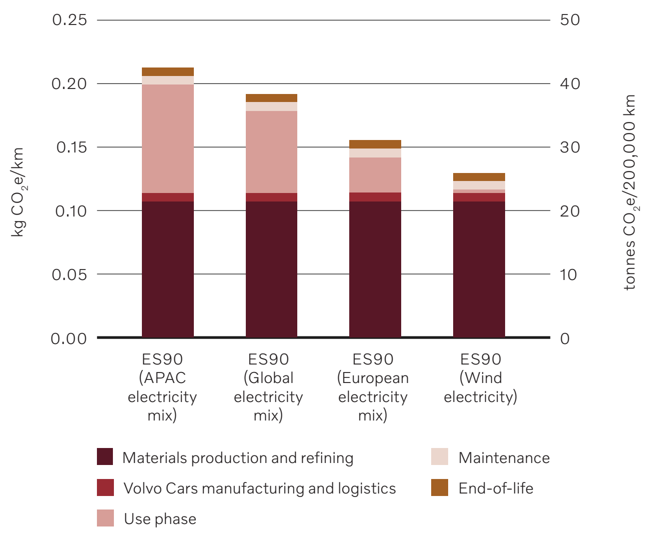

Figure 11 *The ES90's carbon footprint, when charged with different electricity mixes.*

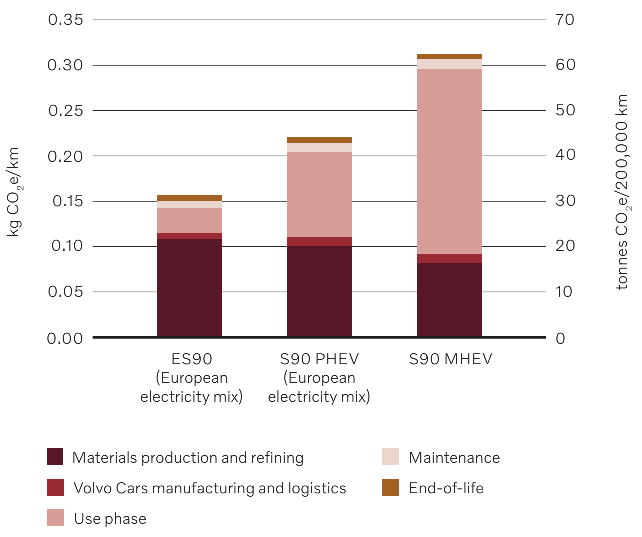

Figure 12 *Carbon footprint, when charged with the European electricity mix.*

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

	ES90 (APAC electricity mix)	ES90 (Global electricity mix)	ES90 (European electricity mix)	ES90 (Wind electricity)	S90 PHEV (APAC electricity mix)	S90 PHEV (Global electricity mix)	S90 PHEV (European electricity mix)	S90 PHEV (Wind electricity)	S90 MHEV
Carbon footprint (kg CO_2e/vehicle km)	0.21	0.19	0.15	0.13	0.26	0.25	0.22	0.20	0.31
Carbon footprint (tonnes CO_2e/200,000 km)	42	38	31	26	52	49	44	40	62

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

	Materials production and refining	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
ES90 (APAC electricity mix)	0.11	0.0073	0.085	0.0072	0.0061
ES90 (Global electricity mix)	0.11	0.0073	0.064	0.0072	0.0061
ES90 (European electricity mix)	0.11	0.0073	0.028	0.0072	0.0061
ES90 (Wind electricity)	0.11	0.0073	0.0021	0.0072	0.0061
S90 PHEV (APAC electricity mix)	0.099	0.010	0.14	0.0098	0.0062
S90 PHEV (Global electricity mix)	0.099	0.010	0.12	0.0098	0.0062
S90 PHEV (European electricity mix)	0.099	0.010	0.093	0.0098	0.0062
S90 PHEV (Wind electricity)	0.099	0.010	0.074	0.0098	0.0062
S90 MHEV	0.080	0.010	0.20	0.010	0.0059

The main conclusion from the result figures is the importance of the use phase and its energy supply. According to this study, the ES90 has the lowest carbon footprint when charged with wind-generated electricity. The carbon footprint of material production and refining is greater for the ES90 than for the S90 models, primarily due to emissions caused by Li-ion battery production. The ES90 causes fewer emissions over its full lifetime than the S90 PHEV. The ES90 causes significantly fewer emissions than the S90 MHEV, which consumes more E5 petrol than the PHEV variant.

Figure 13 shows accumulated use-phase emissions (when charging with the European electricity mix) for each model (non-use-phase emissions are summarised at 0 km distance driven) and illustrates the distance at which emissions intersect.

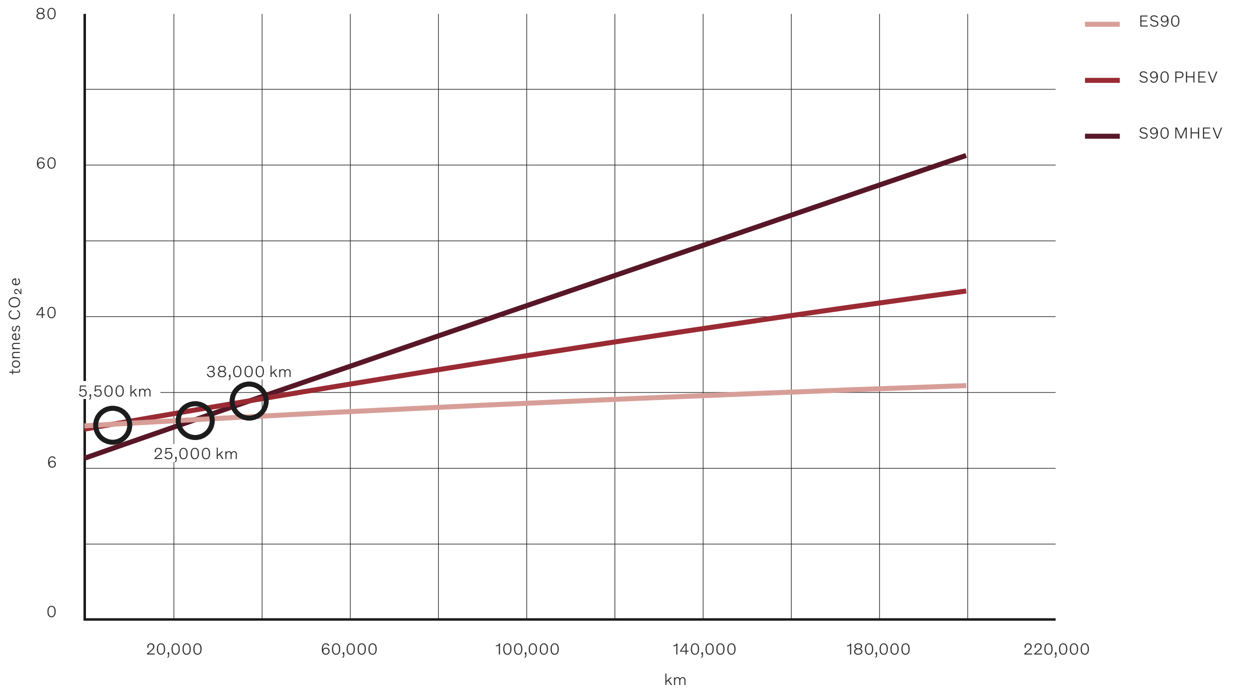

Figure 13 *Accumulated CO_2 emissions, when charging with European electricity mix. All non-use-phase emissions are summarised at 0 kilometres distance driven.*

Figure 14 and Table 9 illustrate the carbon footprint of material production and refining for the models in this study. For components with specific data from suppliers, the carbon footprint of material production and refining is summarised and aggregated into different material categories.

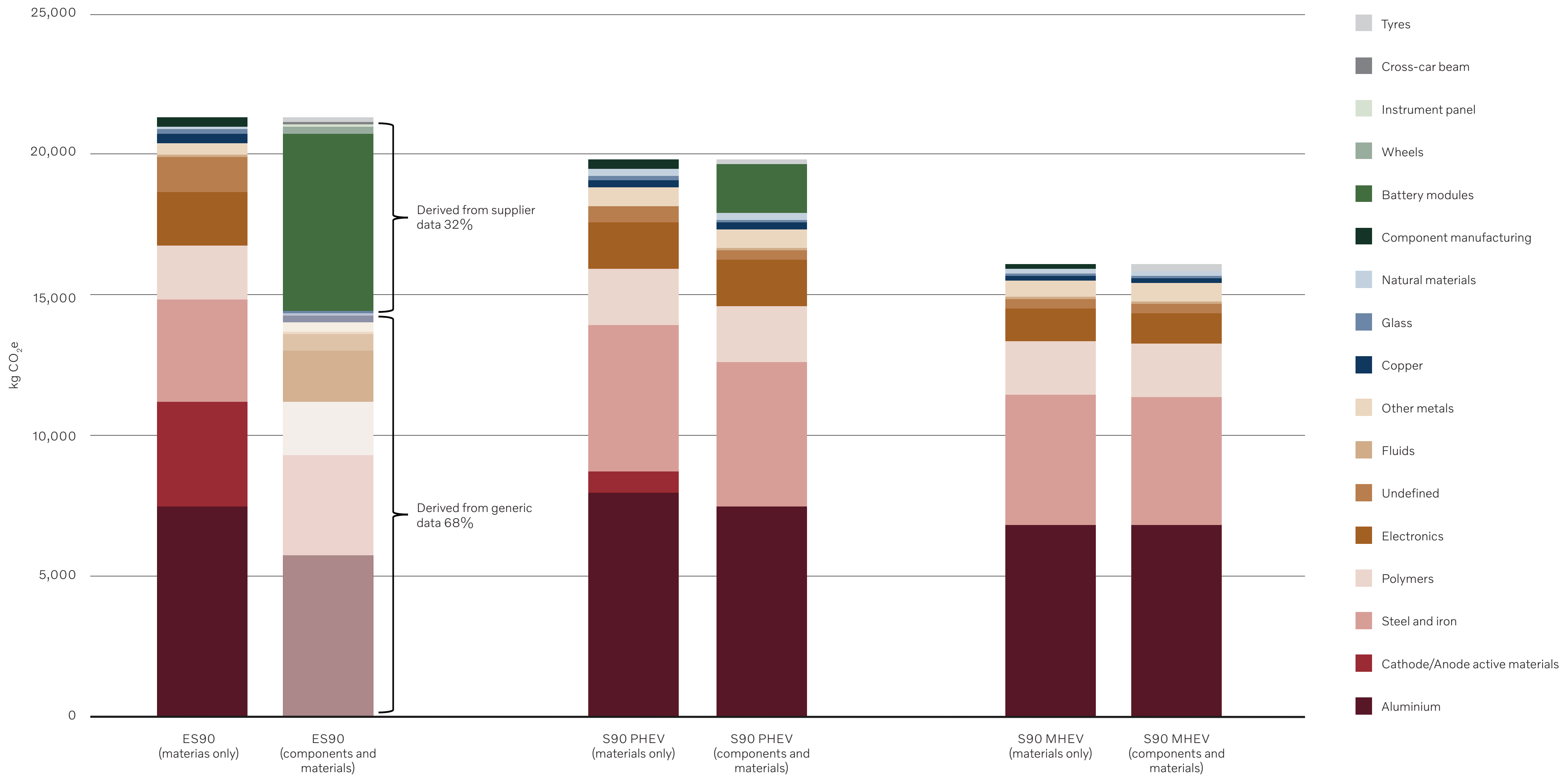

Figure 14 *Carbon footprint from materials production and refining, component manufacturing.*

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

Vehicle	Aluminium	Cathode/anode active materials	Steel and iron	Polymers	Electronics	Undefined	Other metals	Copper	Glass	Fluids	Natural materials	Component manufacturing*
ES90	35%	18%	17%	9.2%	8.7%	6.0%	2.1%	1.6%	0.67%	0.29%	0.17%	1.8%
S90 PHEV	40%	4.0%	26%	10%	8.1%	2.9%	3.3%	1.2%	0.69%	0.37%	1.1%	2.0%
S90 MHEV	42%	0.27%	29%	12%	7.1%	2.2%	3.6%	1.0%	0.81%	0.60%	0.94%	0.74%

** Component manufacturing refers the operations in suppliers for components with specific data, including logistic, manufacturing and waste treatment.*

The carbon footprint of logistics, manufacturing and waste treatment are summarised and aggregated into component manufacturing, showing as materials only (the first column for each model). In the meanwhile, the components with specific site carbon footprint are listed as well, showing as components and materials (the second column for each model). 32 per cent of the carbon footprint in the material production and refining phase derives from directly contracted suppliers.

Aluminium is the main contributor to material production and refining emissions for all three models, primarily due to high electricity consumption during electrolysis and smelting in aluminium production.

30 per cent of material production and refining emissions for the ES90 are caused by its Li-ion battery modules. Cathode and anode active materials contribute to 18 per cent of material production and refining emissions, while the aluminium in battery modules contributes to 7 per cent of material production and refining emissions. Steel and iron are the third largest contributor to production and refining emissions for the ES90 (17 per cent) and the second largest contributor to the S90 PHEV (26 per cent) and the S90 MHEV (29 per cent). These emissions are primarily caused by the use of the blast furnace/basic oxygen furnaces in steel production from iron ore.

Polymers account for 12 per cent of production and refining emissions in the S90 MHEV and 10 per cent in the S90 PHEV. This material category is the third largest contributor to emissions in both models.

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4.1 Specific greenhouse gas emissions and removals

As described in the scope of the study, carbon footprint consists of several specific greenhouse gas emissions and removals, see Figure 15-Figure 17 and Table 10-Table 12. If inventory data for material production does not contain separate values for aircraft emissions or emissions from land use, they are assumed to be included in fossil greenhouse gas emissions.

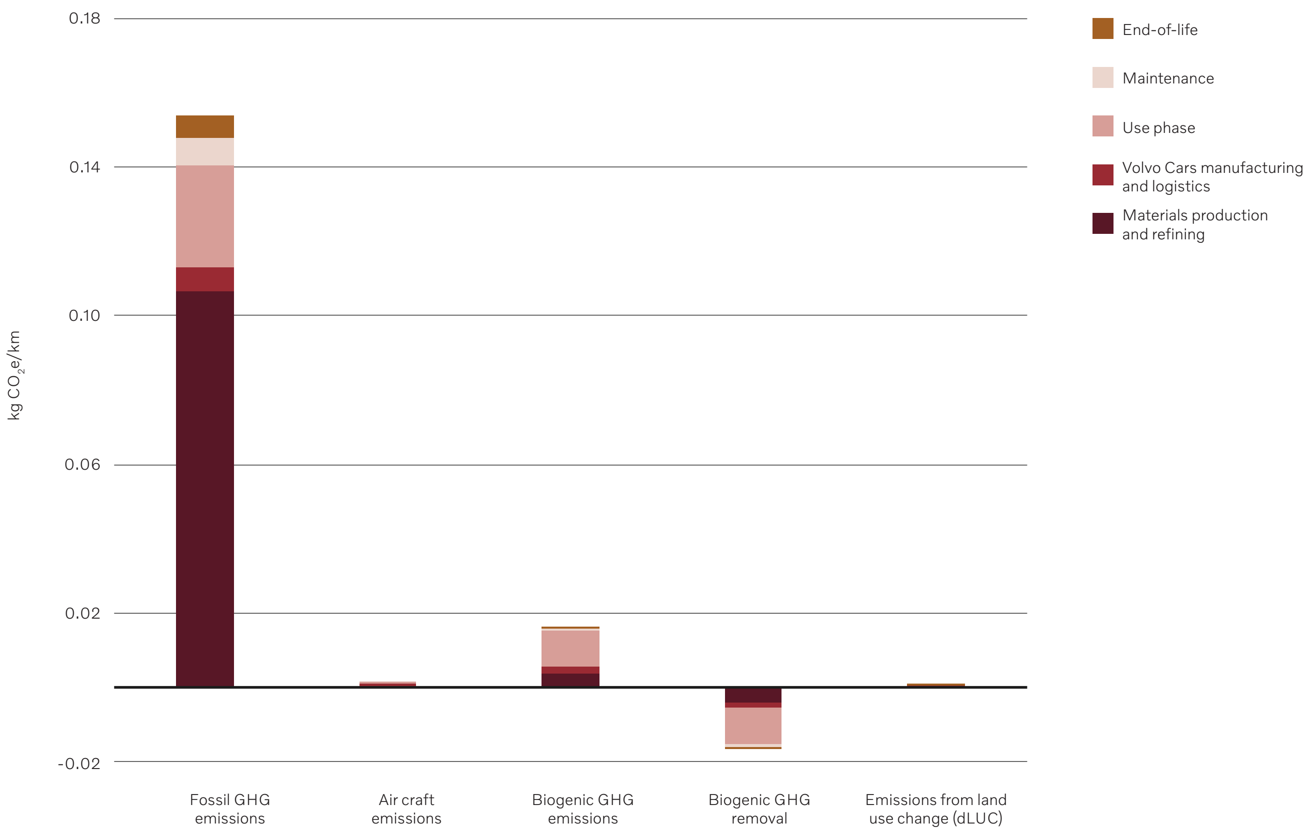

Figure 15 *Specific greenhouse gas emissions and removals for the ES90 when charged with European electricity mix.*

Table 10 *Specific greenhouse gas emissions and removals for the ES90 when charged with the European electricity mix.*

ES90 European electricity kg CO_2e per vehicle km	Materials production and refining	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
Fossil greenhouse gas emissions	1.1E-01	6.3E-03	2.8E-02	7.2E-03	6.0E-03
Aircraft emissions	6.4E-06	8.4E-04	1.2E-07	1.7E-08	5.3E-10
Biogenic greenhouse gas emissions	3.8E-03	1.6E-03	9.8E-03	7.2E-04	1.7E-04
Biogenic greenhouse gas removal	-4.1E-03	-1.5E-03	-9.8E-03	-7.8E-04	-3.3E-05
Emissions from land use change (dLUC)	1.5E-04	4.1E-05	5.2E-06	2.3E-06	6.5E-08

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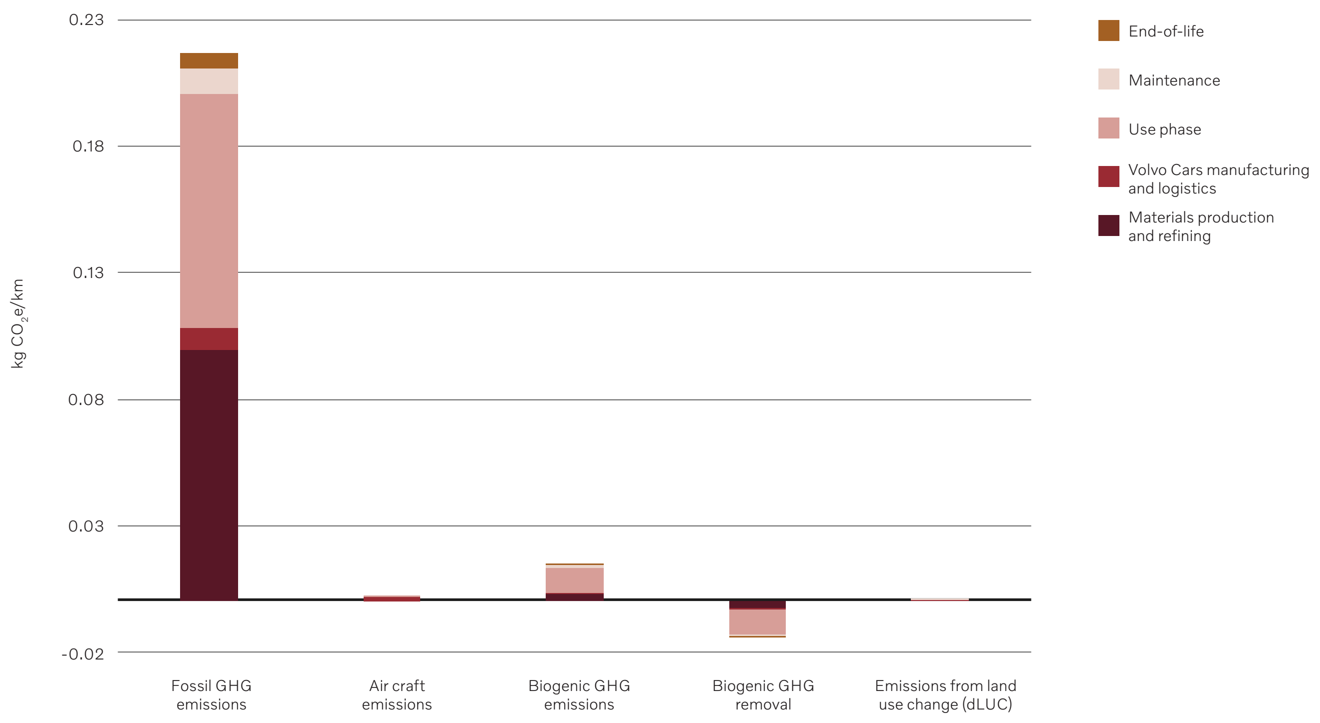

Figure 16 *Specific greenhouse gas emissions and removals for the S90 PHEV when charged with the European electricity mix.*

Table 11 *Specific greenhouse gas emissions and removals for the S90 PHEV when charged with the European electricity mix.*

S90 PHEV European electricity kg CO_2e per vehicle km	Materials production and refining	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
Fossil greenhouse gas emissions	9.9E-02	8.8E-03	9.3E-02	9.9E-03	6.1E-03
Aircraft emissions	1.5E-06	1.4E-03	9.2E-08	2.0E-09	4.7E-10
Biogenic greenhouse gas emissions	2.8E-03	6.3E-04	9.9E-03	6.8E-04	1.6E-04
Biogenic greenhouse gas removal	-2.9E-03	-5.9E-04	-9.9E-03	-7.2E-04	-3.0E-05
Emissions from land use change (dLUC)	1.3E-04	9.3E-05	1.1E-04	3.0E-06	6.5E-08

Almost all greenhouse gas emissions have fossil origin, with biogenic greenhouse gas emissions being the second largest contributor still ending up at significantly lower levels. Other components contribute to less than 1 per cent of the total emissions.

Material production, refining and the use phase are the primary contributors to fossil greenhouse gas emissions. The use phase contributes the most to biogenic greenhouse gas emissions and removals, with bioenergy electricity and bioethanol in petrol being the largest source. For land use change, the highest impact is related to maintenance, caused by replacements of tyres (containing natural rubber). Most aircraft emissions are related to inbound and outbound logistics.

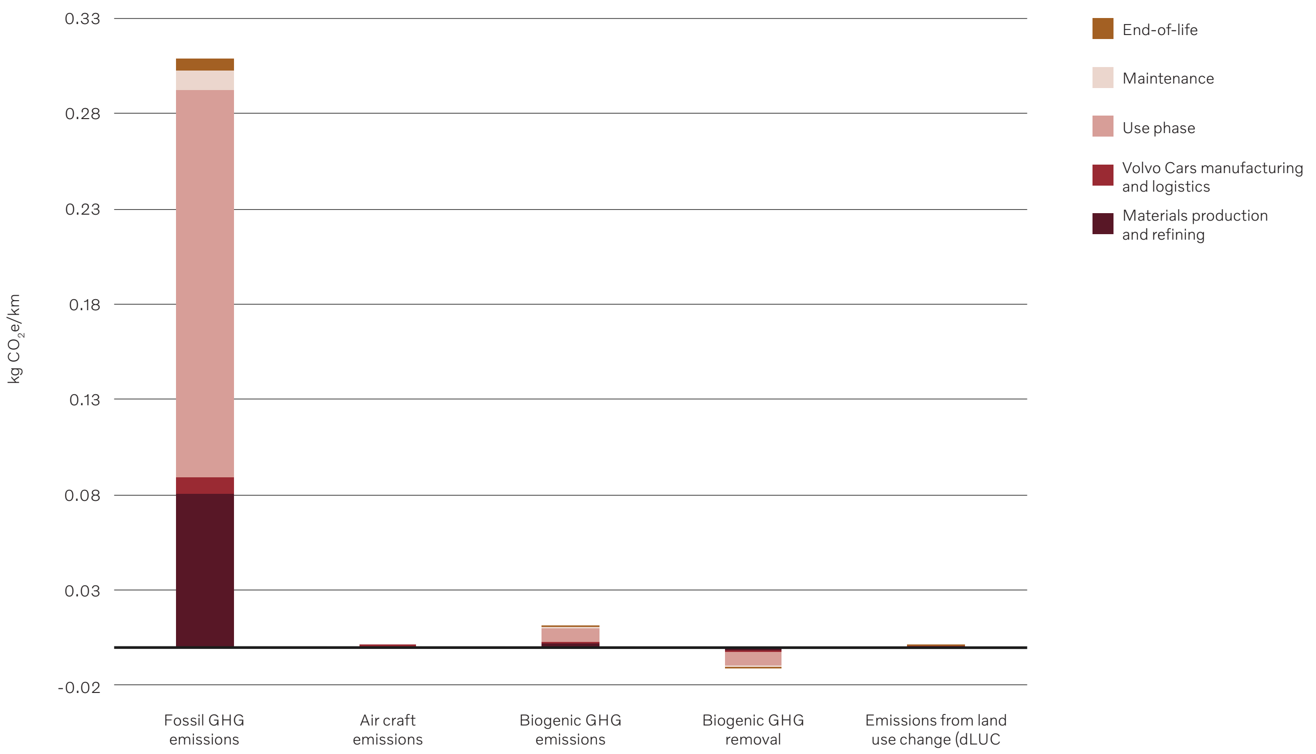

Table 12 Specific greenhouse gas emissions and removals for the S90 MHEV.

Figure 17 Specific greenhouse gas emissions and removals for the S90 MHEV.

S90 MHEV

kg CO_2e per vehicle km	Materials production and refining	Volvo Cars manufacturing and logistics	Use phase	Maintenance	End-of-life
Fossil greenhouse gas emissions	8.0E-02	8.8E-03	2.0E-01	1.0E-02	5.8E-03
Aircraft emissions	2.0E-08	1.4E-03	4.1E-09	2.0E-09	3.9E-10
Biogenic greenhouse gas emissions	1.9E-03	6.3E-04	7.2E-03	6.9E-04	1.5E-04
Biogenic greenhouse gas removal	-2.1E-03	-5.9E-04	-7.1E-03	-7.3E-04	-2.5E-05
Emissions from land use change (dLUC)	1.2E-04	9.3E-05	2.9E-04	3.1E-06	6.0E-08

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5. Sensitivity analysis

The purpose of the sensitivity analysis is to assess how uncertainties and variations of the parameters affect the final results. In this section, the effect of uncertain and various factors is evaluated.

5.1 Recycled steel content in primary steel production

In conventional primary steel production, steel scrap is added to the basic oxygen furnace in order to enhance processing performance and reduce the use of iron ore and coke and thereby reducing carbon dioxide emissions. Due to the complexity of components and supply chains in the automotive industry, obtaining accurate data about recycled steel content is challenging.

In this chapter we explore the effect on the materials production and refining phase by choosing different recycled content data for the remaining steel (37 per cent) with unclear recycled content data. World Steel Association data indicates that recycled content is between 15 per cent and 25 per cent in conventional primary steel production processes, although average figures tend to be lower in China (between 10 per cent and 25 per cent). Due to the lack of precise data, the lowest recycled content reported among existing steel suppliers (11 per cent) has been used as the consumption in a conservative approach. The lower recycled content in China (10 per cent, scenario 1 in Figure 18) and higher recycled content in line with the statistics from World Steel Association (25 per cent, scenario 2 in Figure 18) are chosen as two different scenarios for the remaining steel. The results are given in Figure 18.

Increasing the use of scrap steel in primary steel production can reduce carbon footprint. The uncertainty in scrap steel share caused minimal data fluctuation and the impact of different assumption on the carbon footprint in material phase is less than 1 per cent.

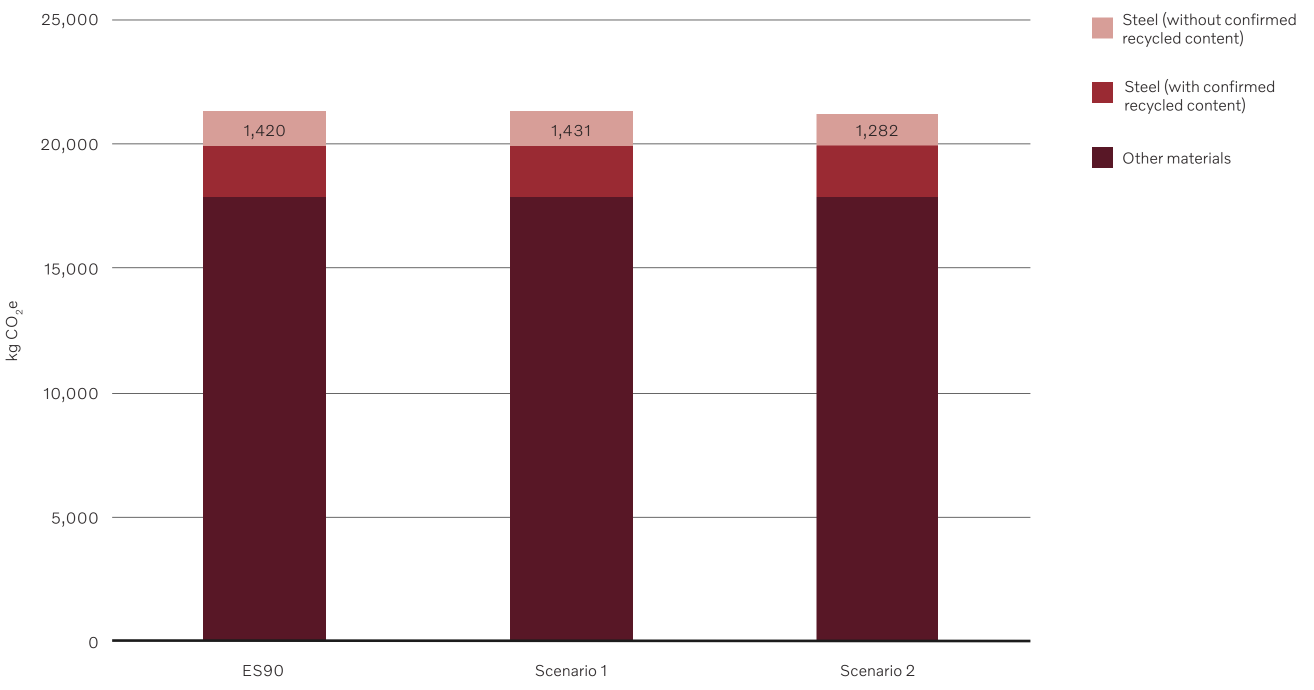

Figure 18 *The effect of changes in recycled steel content on the ES90.*

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5.2 Electricity generation

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

Table 13 *Definitions and objectives of the IEA scenarios[11].*

	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.

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

The IEA only provides NZE scenarios for World and Advanced economies (OECD, Bulgaria, Croatia, Cyprus, Malta and Romania), not for individual countries or regions. The effect of changes in electricity generation on carbon footprint is evaluated in Figure 19 and Figure 20.

Figure 19 indicates that changes in electricity mix make a significant impact on the carbon footprint of the ES90. Variations in electricity mix also reveal regional disparities. Figure 20 illustrates the changes in greenhouse gas emissions especially during the use phase for different vehicle models under various energy scenarios. There is a 5.6 per cent greenhouse gas emission reduction during the use phase for the ES90, compared to a 3.0 per cent greenhouse gas emissions reduction for the S90 PHEV. This also shows that BEV offers a stronger decarbonization advantage than PHEV in these alternative scenarios.

Promoting decarbonization in electricity generation is one of the most critical measures in reducing greenhouse gas emissions in the automotive industry. The renewable energy share in the power grid is a key factor influencing the greenhouse gas emissions of electric vehicles during their use phase. The widespread adoption of renewable energy will further amplify the lifecycle advantages of electric vehicles. To achieve our aim of reaching net zero greenhouse gas emissions by 2040, cross-company collaboration will play a key role. No single company can solve this challenge on their own. Strategic partnerships and collaborations with suppliers, energy providers, technology pioneers and policy makers will be critical to achieve the emission reductions across the ecosystem.

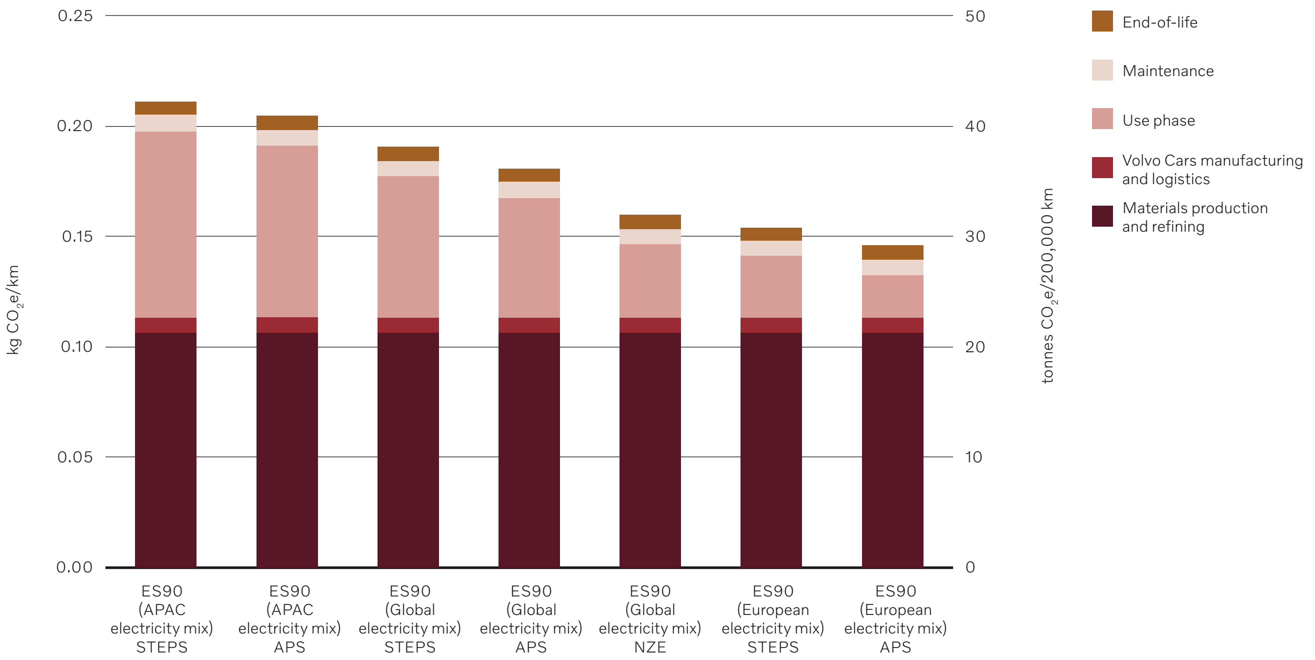

Figure 19 *The effect of changes in electricity generation on the carbon footprint of the ES90.*

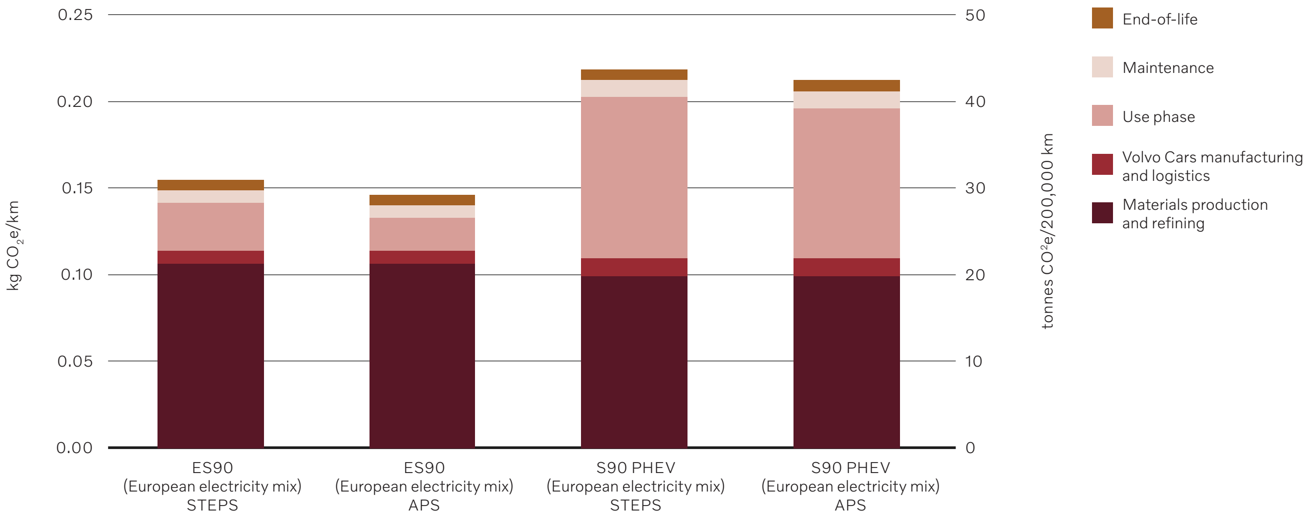

Figure 20 *The effect of changes in electricity generation on the carbon footprint of the ES90 and S90 PHEV.*

5.3 Lifetime distance

A lifetime distance of 200,000 kilometres is assumed for the purposes of this study, in line with the life cycle analysis of many other passenger vehicles. As the ES90 and S90 can exceed this estimate[12], we evaluate the effect on the carbon footprint of 250,000 and 300,000 kilometres lifetime distances. We also evaluate the effect of a 150,000-kilometre lifetime distance. The number of components replaced in routine maintenance are estimated in Appendix 5. The results are shown in Figure 21 and Table 14.

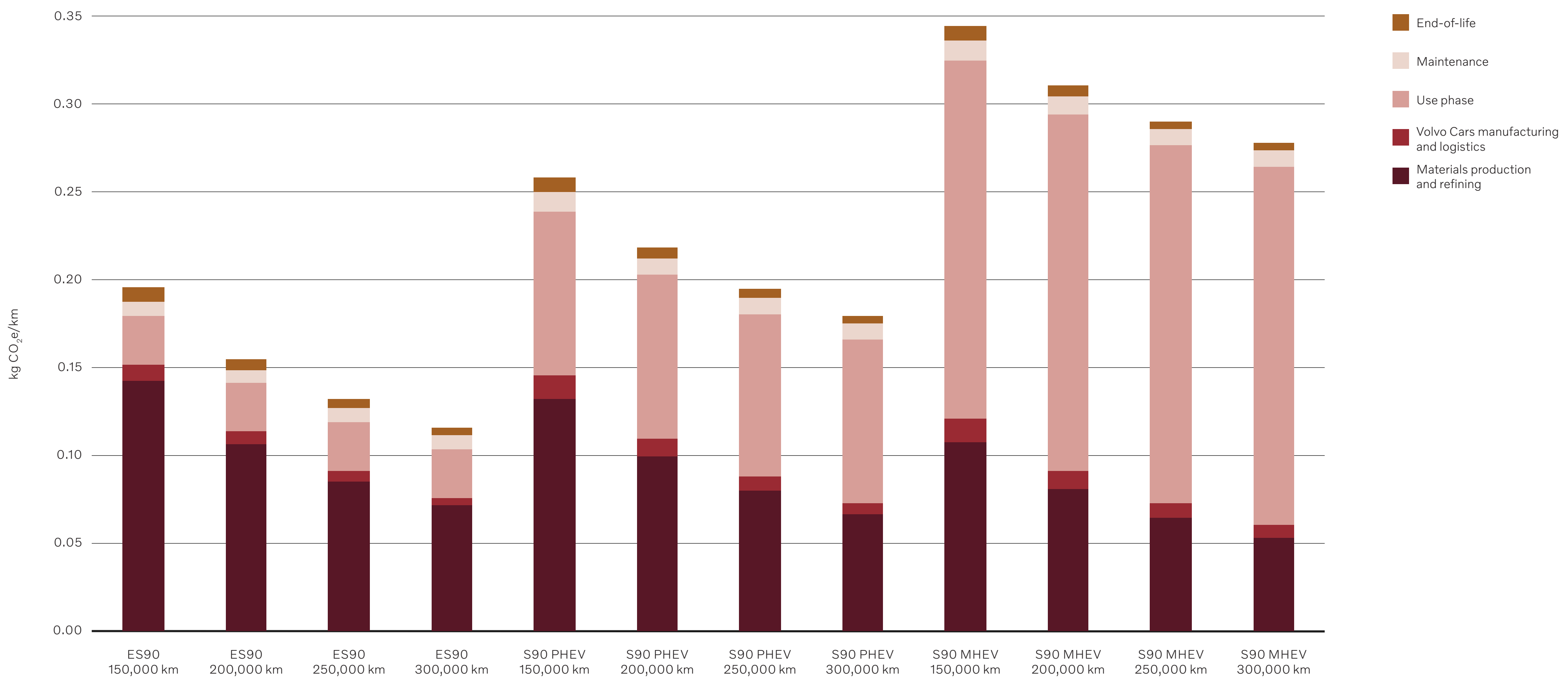

Figure 21 *The effect of lifetime distance on carbon footprint when charging with European electricity mix.*

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

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Lifetime distance is a key parameter in the life cycle assessment of vehicles. As the mileage increases, the total carbon footprint during the use phase also becomes larger. By comparing the greenhouse gas emission sensitivity of different types of vehicles across varying mileage scenarios, it becomes evident that electric vehicles demonstrate significant emission reduction advantages in long-lifetime use cases.

In Table 14, the greenhouse gas emissions per kilometer serve as a quantitative representation of vehicle utilisation efficiency. The total carbon footprint for other life cycle stages remains unchanged under varying mileage scenarios, however the carbon footprint per km decreases as the mileage increases. The data for per km indicates that higher vehicle utilisation rates or operational intensity can effectively reduce the greenhouse gas emissions in other life cycle phases.

Table 14 *The effect of lifetime distance on 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 ($tonnes\ CO_2e$)**
ES90	Use phase	0.028	4.1	0.028	5.5	0.028	6.9	0.028	8.3
	Maintenance	0.0077	1.2	0.0072	1.4	0.0080	2.0	0.0084	2.5
	Other life cycle stages	0.16	24	0.12	24	0.10	24	0.080	24
S90 PHEV	Use phase	0.093	14	0.093	19	0.093	23	0.093	28
	Maintenance	0.011	1.7	0.0098	2.0	0.0088	2.2	0.0095	2.8
	Other life cycle stages	0.15	23	0.12	23	0.093	23	0.077	23
S90 MHEV	Use phase	0.20	31	0.20	41	0.20	51	0.20	61
	Maintenance	0.012	1.7	0.010	2.0	0.0094	2.4	0.0098	2.9
	Other life cycle stages	0.13	19	0.10	19	0.077	19	0.064	19

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6. Completeness, consistency and sensitivity checks

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Checks are made on the results in this study to ensure validity, completeness, consistency and sensitivity.

- Completeness checks verify the adequacy of information to meet the goal and scope of the life cycle assessments.
- Consistency checks verify that assumptions, methods, and data are consistently applied in accordance with the goal and scope of the life cycle assessments.
- Sensitivity checks verify the relevance of sensitivity analysis in reaching conclusions and making recommendations.

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

- For components with specific carbon footprint data, all raw materials production, manufacturing, and logistics from suppliers' plants, are included and reported in accordance with the goal and scope of this study.
- All raw materials production, and manufacturing for main material categories in the modelling, are included and reported in accordance with the goal and scope of this study.
- All manufacturing processes at Volvo Cars' manufacturing facilities are included and reported in accordance with the goal and scope of this study.
- All emissions from Volvo Cars' logistics are included and reported in accordance with the goal and scope of this study.
- All use-phase emissions are included and reported in accordance with the goal and scope of this study.
- All maintenance emissions are included and reported in accordance with the goal and scope of this study.
- All end-of-life processing is included and reported in accordance with the goal and scope of this study.

All modelling is conducted according to the goal and scope of this study. A detailed sensitivity analysis has been carried out to evaluate the assumptions made in this study and ensure its conclusions are valid. The methodology used in this study has been evaluated by the IVL Swedish Environmental Research Institute in a third-party review. All completeness, consistency and sensitivity checks have been completed for this study.

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7. Discussion

This study assesses carbon footprint and its underlying causes in the life cycles of the ES90, S90 PHEV and S90 MHEV models. Its results and conclusions will be used to further reduce the carbon footprint of these models and future models. Comparing greenhouse gas emissions from electric and internal combustion engine vehicles reveals both the potential benefits and challenges of electrification.

7.1 Reflections

Although the ES90 makes the least overall impact on climate change, in comparison with the S90 models, emissions in its production phase can be substantially improved by making improvements during the developing phase. For example, the high impact of aluminium production can be reduced by the increased use of recycled material and primary aluminium from smelters using renewable electricity. The high impact of Li-ion battery modules can be reduced by the increased use of recycled materials and renewable energy in supply chain. Low-carbon steelmaking technologies, such as hydrogen direct reduced iron and electric arc furnaces, along with increasing the recycling rate of scrap, can reduce greenhouse gas emissions in steel production.

Although the use of lightweight materials reduces use-phase emissions, the benefits must be balanced against carbon footprint 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 using biobased variants.

7.2 The importance of electricity generation for BEVs and PHEVs

The source of electricity used for charging significantly affects vehicles' carbon footprint, with lower shares of fossil energy sources leading to lower impact. Nevertheless, charging the ES90 with the global electricity mix, which is still substantially generated from fossil fuels, results in a lower carbon footprint than the S90 PHEV.

The results in this report are based on the IEA's STEPS scenario, with APS and NZE scenarios evaluated in the sensitivity analysis. The climate benefits of the ES90, in comparison with the S90 PHEV, are even greater in these alternative scenarios. In addition, a general global electrification can lead to a change of the grid mix nationally and internationally. It is thus important that the electricity capacity expansion will proceed with renewable or low climate impact sources.

7.3 Battery

Over the vehicle's lifecycle, the battery accounts for a significant portion of the vehicle's total carbon footprint.

The carbon footprint of the ES90's battery is primarily affected by the extraction and refining of lithium, nickel, cobalt, graphite, and copper, as well as energy-intensive manufacturing, such as the production of cathode and anode active materials. While renewable electricity is used for battery cell and module production, Volvo Cars is actively investigating additional measures to mitigate the impact, such as the implementation of renewable energy in the battery supply chain and the use of aluminium that is produced with renewable energy.

Recycling is a key factor in reducing the carbon footprint 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 its vehicle batteries and facilitate effective recycling. Our aim is to increase the amount of recycled material used in battery production.

It is anticipated that rapid improvements in battery technology will continue. The ES90's battery reflects the knowledge and technology available at the time of its development. Future models and upgrades will benefit from battery technology improvements, including the potential reduction or elimination of high impact materials and battery designs adapted to customer needs and vehicle types.

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7.4 Extracting and refining of raw materials and production

Electrification leads to substantial reduction in carbon footprint and shifts 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 is required to accurately account for such improvement measures when calculating the carbon footprint.

We aim to reduce the climate impact of material production and refining in several ways, including the following:

- Increasing the use of renewable energy throughout our supply chains, with specific requirements for 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.
- Considering disassembly and recycling in the design phase of new products.
- Improving data transparency and traceability throughout our supply chains.

These actions will contribute to our sustainability ambition, which is to reach net zero greenhouse gas emissions and become a circular business by 2040.

The recycled materials avoid the use of primary materials and the corresponding mining resources and energy consumption. Some of these climate benefits are not fully reflected in this study due to lack of underlying datasets and sufficient analysis at this time. For example, the carbon footprint of copper is calculated based on a primary dataset, even if there is recycled copper implemented in the ES90. With improved data for recycled copper from our suppliers, the carbon footprint for copper in the ES90 will be further decreased when the recycled copper carbon footprint data is available.

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8. Conclusions

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The results in this study indicate that the carbon footprint of the ES90 is lower than those of the S90 PHEV and S90 MHEV when charged with electricity from any source evaluated in this study. Consumption of wind-generated electricity significantly reduces the carbon footprint in comparison with global, APAC and European electricity mixes. For the ES90, the primary contributors to greenhouse gas emissions related to materials production and refining are aluminium, Li-iron battery modules, and steel and iron. Among the specific greenhouse gas emissions and removals, fossil greenhouse gas emissions are clearly the most significant, with the largest contribution coming from material production and refining.

The use of recycled materials and materials produced with renewable energy or low-carbon technology throughout the vehicle, and the renewable energy in manufacturing facilities and supply chain can effectively reduce the carbon footprint. Promoting the decarbonization of the electricity mix is also important for the greenhouse gas emissions reduction during the use phase.

To achieve our aim of reaching net zero greenhouse gas emissions by 2040, cross-company collaboration will play a key role. No single company can solve this challenge on their own. Strategic partnerships and collaborations with suppliers, energy providers, technology pioneers and policy makers will be critical to achieve the emission reductions across the ecosystem.

Sensitivity analyses were conducted to assess how changes to some of the study's assumptions affect the carbon footprint. The uncertainty in scrap steel causes minimal data fluctuation and has little impact on the ES90's carbon footprint. In the alternative energy scenarios, the climate benefits of the ES90 are greater than those of the S90 PHEV. With increased lifetime distance, the case for the ES90 further improves compared to both the S90 PHEV and S90 MHEV.

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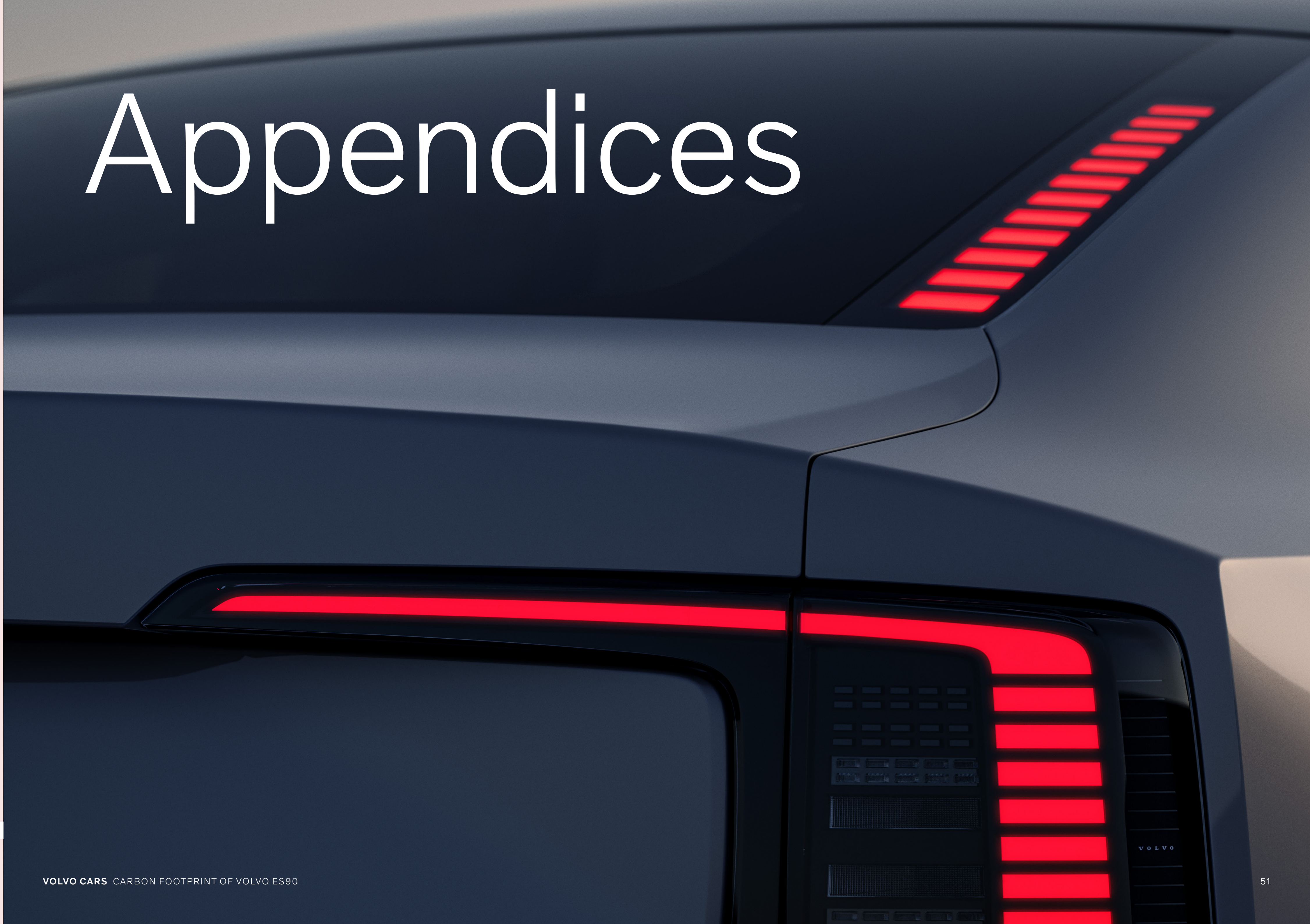
Appendices



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Appendix 1 – List of material categories

Table 15 *Material categories and types.*

Material category	Material type
Aluminium	Aluminium
Copper	Copper
Copper alloys	Copper
Anode	Other metals
Cathode	Other metals
Ferrite magnet	Other metals
Lead, battery	Other metals
Magnesium	Other metals
NdFeB	Other metals
Separator, Li battery	Other metals
Zinc	Other metals
Cast iron	Steel and iron
Steel, sintered	Steel and iron
Steel, stainless, austenitic	Steel and iron
Steel, stainless, ferritic	Steel and iron
Steel, unalloyed	Steel and iron
ABS (filled)	Polymers
E/P (filled)	Polymers
EVAC (filled)	Polymers
PA (filled)	Polymers
PBT (filled)	Polymers
PC (filled)	Polymers
PC+ABS (filled)	Polymers

Material category	Material type
PE (filled)	Polymers
PET (filled)	Polymers
PMMA (filled)	Polymers
POM (filled)	Polymers
PP (filled)	Polymers
PVB (filled)	Polymers
PVC (filled)	Polymers
ABS (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
Thermoplastics	Polymers
Thermoplastic elastomers	Polymers

Material category	Material type
Elastomer	Polymers
EPDM	Polymers
NR	Polymers
SBR	Polymers
Silicone rubber	Polymers
Polyurethane	Polymers
Damper	Polymers
Polyester	Polymers
Aramid	Polymers
Tyre	Tyres
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
Power PCB	Electronics
Signal PCB	Electronics
Capacitor	Electronics

Material category	Material type
Diode	Electronics
Electrolytic capacitor	Electronics
IC components	Electronics
Inductor	Electronics
LCDs	Electronics
LED	Electronics
Oscillator	Electronics
Resistor	Electronics
Solder	Electronics
Thermistor	Electronics
Transistor	Electronics
Brake fluid	Fluids
Electrolyte	Fluids
Glycol	Fluids
Lubricants (matcat)	Fluids
Petrol	Fluids
R-1234yf	Fluids
Sulphuric acid	Fluids
Washer fluid	Fluids
Undefined	Undefined

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Appendix 2 – LCI datasets

***Table 16** 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
Aluminium	CN	Aluminium ingot mix IAI 2015	22%	agg	IAI/Sphera
Aluminium, recycled	RoW	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	27%	agg	ecoinvent
Aluminium renewable energy	CN	Aluminium sheet (Renew. electr. LC)	51%	agg	Sphera
Anode	CN	Market for anode, graphite, for Li-ion battery		agg	ecoinvent
Aramid	DE	Aramide fiber (para aramid)		agg	Sphera
ASA	GLO	Market for acrylonitrile-butadiene-styrene copolymer		agg	ecoinvent
Brake fluid	GLO	Market for diethylene glycol		agg	ecoinvent
Cast iron	DE	Cast iron part (automotive) - open energy inputs		p-agg	Sphera
Catalytic coating	ZA	Market for platinum group metal concentrate		agg	ecoinvent
Cathode	CN	Market for cathode, NMC111, for Li-ion battery		agg	ecoinvent
Ceramic	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing		agg	ecoinvent
Copper	GLO	Copper (99.99%; cathode)		agg	ICA/Sphera
Copper alloys	GLO	Copper (99.99%; cathode)	13.5%	agg	ICA/Sphera
	GLO	Nickel (class 1, >99.8% Nickel)	4.5%	agg	Nickel Institute/Sphera
	RER	Brass (CuZn20)	49%	agg	Sphera
	GLO	Market for bronze	33%	agg	ecoinvent
Cotton	GLO	Market for textile, woven cotton		agg	ecoinvent
Damper	RoW	Synthetic rubber production	45%	agg	ecoinvent
	RoW	Market for calcium carbonate, precipitated	50%	agg	ecoinvent
	RER	Lubricants at refinery	5%	agg	Sphera
E/P	RoW	Polyethylene production, low density, granulate		agg	ecoinvent

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Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Elastomer	RoW	Market for calcium carbonate, precipitated	30%	agg	ecoinvent
	RoW	Market for lime	20%	agg	ecoinvent
	GLO	Market for carbon black	7%	agg	ecoinvent
	GLO	Market for polyethylene terephthalate, granulate, amorphous	5%	agg	ecoinvent
	GLO	Market for zinc oxide	3%	agg	ecoinvent
	GLO	Market for synthetic rubber	35%	agg	ecoinvent
Electrolyte	GLO	Market for dimethyl carbonate	7%	agg	ecoinvent
	GLO	Market for ethylene carbonate	80%	agg	ecoinvent
	GLO	Market for lithium hexafluorophosphate	13%	agg	ecoinvent
Electronics	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing		agg	ecoinvent
EPDM	DE	Ethylene Propylene Diene Elastomer (EPDM)		agg	Sphera
EVAC	RoW	Market for ethylene vinyl acetate copolymer		agg	ecoinvent
Ferrite magnet	GLO	Market for ferrite		agg	ecoinvent
FET	GLO	Market for transistor, wired, small size, through-hole mounting		agg	ecoinvent
Float glass	RER	Float flat glass		agg	Sphera
Friction	DE	Cast iron part (automotive) - open energy inputs	48%	agg	Sphera
	GLO	Market for zirconium oxide	12%	agg	ecoinvent
	GLO	Market for graphite	11%	agg	ecoinvent
	GLO	Market for barium sulfide	10%	agg	ecoinvent
	GLO	Market for barite	7%	agg	ecoinvent
	GLO	Market for aluminium hydroxide	5%	agg	ecoinvent
	GLO	Market for magnesium oxide	4%	agg	ecoinvent
	GLO	Market for expanded vermiculite	2%	agg	ecoinvent
	RER	Calcined petroleum coke	2%	agg	Sphera
GF-Fibre	GLO	Market for glass fibre		agg	ecoinvent
Glycol	RER	Ethylene glycol		agg	PlasticsEurope/Sphera
Lead, battery	DE	Lead (99,995%)		agg	Sphera

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

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Material category	Location	Name of LCI dataset	Input per output	Type	LCI database
Solder	GLO	Market for solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry		agg	ecoinvent
Steel, Sintered	GLO	Steel hot dip galvanized		agg	Worldsteel/Sphera
Steel, Stainless, Austenitic	RER	Stainless steel cold rolled coil (304)		p-agg	Eurofer/Sphera
Steel, Stainless, Ferritic	RER	Stainless steel cold rolled coil (430)		p-agg	Eurofer/Sphera
Steel, Unalloyed	Aisa	Steel hot dip galvanized*	55.5%	agg	Worldsteel/Sphera
	Aisa	Steel cold rolled coil*	37.1%	agg	Worldsteel/Sphera
Steel, recycled	DE	EAF Steel billet/slab/bloom (Hot and cold rolling processes added)	7.4%	agg	Sphera
Sulphuric acid	RER	Sulphuric acid (96%)		agg	Sphera
Talc (filler for polymers)	RER	Talcum powder (filler)		agg	Sphera
Thermoplastic elastomers	DE	Polypropylene/Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix		agg	Sphera
Thermoplastic	RoW	Market for nylon 6		agg	ecoinvent
Tyre**	DE	Styrene-butadiene rubber (S-SBR) mix	30%	agg	ecoinvent
	DE	Natural rubber (NR) (excl. LUC emissions)	30%	agg	Sphera
	GLO	Market for carbon black	26%	agg	ecoinvent
	RER	Lubricants at refinery	14%	agg	Sphera
	GLO	Market for paraffin***		agg	ecoinvent
	RER	Water (deionised) ***		agg	Sphera
Undefined	RoW	Market for nylon 6		agg	ecoinvent
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)		agg	Sphera
Wood (paper, cellulose ...)	RER	Laminated veneer lumber (EN15804 A1-A3)		agg	Sphera
Zinc	GLO	Special high grade zinc only from Zn concentrate		agg	IZA

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

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

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

Table 17 *Electronics datasets.*

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

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Table 18 *Datasets for manufacturing processes.*

Process	Location	Name	Type	Source
Aluminium manufacturing	DE	Aluminium die-cast part	u-so	Sphera MLC
Aluminium manufacturing	EU-28	Aluminium sheet – open input aluminium rolling ingot	p-agg	Sphera MLC
Aluminium manufacturing	DE	Aluminium sheet deep drawing	u-so	Sphera MLC
Polymers (all categories) manufacturing	DE	Plastic injection moulding part (unspecific)	u-so	Sphera MLC
Steel (all categories) manufacturing	DE	Steel sheet deep drawing (multi-level)	u-so	Sphera MLC
Copper manufacturing	DE	Copper wire (0,6mm)	u-so	Sphera MLC
Copper manufacturing	DE	Copper wire (0,06mm)	u-so	Sphera MLC
Energy for S90 MHEV battery cell production	CN	Electricity grid mix 1kV-60kV (2025) (Stated policies STEPS)	agg	Sphera MLC
Energy for S90 MHEV battery cell production	RER	Thermal energy from natural gas	agg	Sphera MLC

Table 19 *Global electricity mix datasets used for the production and refining of materials and end-of-life treatment.*

Source of electricity generation	Percentage used for materials production and refining in 2025	Percentage used for end-of-life treatment in 2039	Name of dataset	Source
Coal	31	18	RER: Electricity from lignite	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Natural gas	21	16	RER: Electricity from natural gas	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Hydro	15	14	RER: Electricity from hydropower	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Nuclear	10	9	RER: Electricity from nuclear	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Wind	10	19	RER: Electricity from wind power	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Solar	7	19	RER: Electricity from photovoltaic	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Bioenergy	3	4	RER: Electricity from biomass (solid)	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)
Oil	2	1	RER: Electricity from heavy fuel oil (HFO)	IEA WEO 2022 (for percentage of data usage)/Sphera MLC (for LCI dataset)

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Table 20 *Use phase electricity mix datasets.*

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

Table 21 *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
IBL/OBL Rail	RER	Diesel mix at filling station	agg	Sphera MLC
OBL Rail	FR	Electricity grid mix	agg	Sphera MLC
IBL Rail	GLO	Electricity mix production 2024 (based on European datasets)	u-so	Sphera MLC
IBL/OBL Sea	GLO	Container ship, 5,000 to 200,000 dwt payload capacity, deep sea	u-so	Sphera MLC
OBL Sea	US	Light fuel oil at refinery	agg	Sphera MLC
IBL Sea	RER	Light fuel oil at refinery	agg	Sphera MLC
IBL/OBL Road	GLO	Truck, Euro 6 A-C, more than 32t gross weight/24.7t payload capacity	u-so	Sphera MLC
IBL/OBL Road	RER	Diesel mix at refinery	agg	Sphera MLC
IBL/OBL Air	GLO	Cargo plane, 22 t payload	u-so	Sphera MLC
IBL/OBL Air	RER	Kerosene/Jet A1 at refinery	agg	Sphera MLC

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***Table 22** Datasets for manufacturing at Volvo Cars' facilities.*

Process	Location	Name	Type	Source
Incineration of hazardous waste	RoW	Treatment of waste mineral oil, hazardous waste incineration	agg	ecoinvent
Landfill of hazardous waste	RoW	Market for hazardous waste, for underground deposit	agg	ecoinvent
Landfill of non-hazardous waste	RER	Municipal solid waste on landfill	agg	Sphera MLC
Wastewater treatment	RER	Municipal waste water treatment (sludge incineration, cut-off)	agg	Sphera MLC
Transportation	GLO	Truck, Euro 6 D-E, 12–14t gross weight, 9.3t payload capacity	u-so	Sphera MLC
Transportation	CN	Diesel mix at refinery	agg	Sphera MLC
Electricity	CN	Electricity from wind power	agg	Sphera MLC
Electricity	CN	Electricity from photovoltaic	agg	Sphera MLC
Thermal energy from biogas	RoW	Thermal energy from biogas	agg	Sphera MLC

***Table 23** Energy sources at Volvo Cars' manufacturing facilities.*

Volvo Cars' manufacturing site	Energy source
Chengdu	Electricity from hydro power (CN)
	Thermal energy from biogas* (RoW)
Daqing	Electricity from photovoltaic (CN)
	Thermal energy from natural gas (CN)
	Thermal energy from biogas (RoW)

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

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Appendix 3 – Data quality assessment

Table 24 lists the data quality indicators used in this study. Each datapoint has received a score from 1 (best) to 5 (worst), based on five correlation aspects. Table 25 scores data used for material production and refining. Table 26 summarises the results.

Temporal, geographical, and technological correlation scores vary. The majority of data scores 1 for temporal correlation. 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. The majority of data scores 2 for technological correlation. Representativeness and precision have good scores, as the data comes from databases or is supplier specific.

Car manufacturing and logistics score well overall, as the data is collected from our manufacturing facilities and monitored processes. The use phase receives good scores, as electricity-use data is based on vehicle specific measurements. In addition, use-phase impact calculations are based on relatively recent emission factors from the Sphera MLC database and the IEA's electricity mix data. End-of-Life treatment scores less well, largely due to the high degree of uncertainty about future developments. It is highly uncertain how waste handling will be (and in some cases currently is) performed in different markets.

Table 24 *Data quality indicator matrix.*

Aspect	1	2	3	4	5
Temporal correlation (time related coverage)	Less than 3 years before date of study	Less than 6 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 experts)	Non-qualified estimates

***Table 25** Quality assessment of material and processing data.*

Material/process	Location	Dataset name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
ABS	GLO	Market for acrylonitrile-butadiene-styrene copolymer	2023	ecoinvent	1	4	2	1	1
Aluminium	CN	Aluminium ingot mix IAI 2015	2015	IAI/Sphera MLC	3	1	2	1	1
Aluminium, recycled	RoW	Treatment of Aluminium scrap, post-consumer, prepared for recycling, at remelter	2023	ecoinvent	1	3	2	1	1
Aluminium renewable energy	CN	Aluminium sheet (Renew. electr. LC)	2023	IAI/Sphera MLC	1	2	2	1	1
Anode	CN	Market for anode, graphite, for Li-ion battery	2023	ecoinvent	1	1	2	1	1
Aramid	DE	Aramide fiber (para aramid)	2019	Sphera MLC	2	5	2	1	1
ASA	GLO	Market for acrylonitrile-butadiene-styrene copolymer	2023	ecoinvent	1	4	2	1	1
Brake fluid	GLO	Market for diethylene glycol	2022	ecoinvent	1	4	2	1	1
Capacitor	GLO	Market for capacitor, for surface-mounting	2023	ecoinvent	1	4	2	1	1
Cast iron	DE	Cast iron part (automotive) – open energy inputs	2023	Sphera MLC	1	5	2	1	1
Catalytic coating	ZA	Market for platinum group metal concentrate	2023	ecoinvent	1	5	2	1	1
Cathode	CN	Market for cathode, NMC111, for Li-ion battery	2023	ecoinvent	1	1	2	1	1
Ceramic	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing	2023	ecoinvent	1	4	2	1	1
Copper	GLO	Copper (99.99%; cathode)	2022	Sphera MLC	1	4	2	1	1
Copper alloys	GLO	Copper (99.99%; cathode)	2022	Sphera MLC	1	4	2	1	1
Copper alloys	GLO	Nickel (class 1, >99.8% Nickel)	2022	Sphera MLC	1	4	2	1	1
Copper alloys	RER	Brass (CuZn20)	2023	Sphera MLC	1	5	2	1	1
Copper alloys	GLO	Market for bronze	2023	ecoinvent	1	4	2	1	1
Cotton	GLO	Market for textile, woven cotton	2023	ecoinvent	1	4	2	1	1
Damper	RoW	Synthetic rubber production	2023	ecoinvent	1	3	2	1	1
Damper	RoW	Market for calcium carbonate, precipitated	2023	ecoinvent	1	3	2	1	1
Damper	RER	Lubricants at refinery	2020	Sphera MLC	2	5	2	1	1
Diode	GLO	Market for diode, glass-, for surface-mounting	2023	ecoinvent	1	4	2	1	1
E/P	RoW	Polyethylene production, low density, granulate	2023	ecoinvent	1	3	3	1	1

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Material/process	Location	Dataset name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
Elastomer	RoW	Market for calcium carbonate, precipitated	2023	ecoinvent	1	3	2	1	1
Elastomer	RoW	Market for lime	2023	ecoinvent	1	3	2	1	1
Elastomer	GLO	Market for carbon black	2023	ecoinvent	1	4	2	1	1
Elastomer	GLO	Market for polyethylene terephthalate, granulate, amorphous	2023	ecoinvent	1	4	2	1	1
Elastomer	GLO	Market for zinc oxide	2023	ecoinvent	1	4	2	1	1
Elastomer	GLO	Market for synthetic rubber	2023	ecoinvent	1	4	2	1	1
Electrolyte	GLO	Market for dimethyl carbonate	2023	ecoinvent	1	4	4	1	1
Electrolyte	GLO	Market for ethylene carbonate	2023	ecoinvent	1	4	4	1	1
Electrolyte	GLO	Market for lithium hexafluorophosphate	2023	ecoinvent	1	4	2	1	1
Electronics	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing	2023	ecoinvent	1	4	2	1	1
EPDM	DE	Ethylene Propylene Diene Elastomer (EPDM)	2023	Sphera MLC	1	5	2	1	1
EVAC	RoW	Market for ethylene vinyl acetate copolymer	2023	ecoinvent	1	3	2	1	1
FET	GLO	Market for transistor, wired, small size, through-hole mounting	2023	ecoinvent	1	4	2	1	1
Ferrite magnet	GLO	Market for ferrite	2023	ecoinvent	1	4	3	1	1
Float glass	RER	Float flat glass	2023	Sphera MLC	1	5	2	1	1
Friction	DE	Cast iron part (automotive) – open energy inputs	2023	Sphera MLC	1	5	4	1	1
Friction	GLO	Market for zirconium oxide	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for graphite	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for barium sulfide	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for barite	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for Aluminium hydroxide	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for magnesium oxide	2023	ecoinvent	1	4	4	1	1
Friction	GLO	Market for expanded vermiculite	2023	ecoinvent	1	4	4	1	1
Friction	RER	Calcined petroleum coke	2023	Sphera MLC	1	5	4	1	1
GF-Fibre	GLO	Market for glass fibre	2023	ecoinvent	1	4	4	1	1
Glycol	RER	Ethylene glycol	2008	PlasticsEurope	5	5	2	1	1

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Material/process	Location	Dataset name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
IC	GLO	Market for integrated circuit, logic type	2023	ecoinvent	1	4	2	1	1
Inductor	GLO	Market for inductor, ring core choke type	2023	ecoinvent	1	4	2	1	1
LCD	GLO	Market for liquid crystal display, unmounted	2023	ecoinvent	1	4	2	1	1
Lead, battery	DE	Lead (99,995%)	2023	Sphera MLC	1	5	2	1	1
Leather	DE	Cattle hide, fresh (beef cattle, from slaughterhouse, PEFCR allocation)	2023	Sphera MLC	1	5	2	1	1
LED	GLO	Market for light emitting diode	2023	ecoinvent	1	4	2	1	1
Lubricants (matcat)	RER	Lubricants at refinery	2020	Sphera MLC	2	5	2	1	1
Magnesium	CN	Magnesium	2023	Sphera MLC	1	2	2	1	1
MOSFET	GLO	Market for transistor, wired, small size, through-hole mounting	2023	ecoinvent	1	4	2	1	1
NdFeB	GLO	Market for permanent magnet, for electric motor	2023	ecoinvent	1	4	2	1	1
Oscillator	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing	2023	ecoinvent	1	4	2	1	1
NR	DE	Natural rubber (NR)	2023	Sphera MLC	1	5	2	1	1
PA	RoW	Market for nylon 6	2023	ecoinvent	1	3	2	1	1
PBT	DE	Polybutylene terephthalate granulate (PBT) mix	2023	Sphera MLC	1	5	2	1	1
PC	GLO	Market for polycarbonate	2022	ecoinvent	1	4	2	1	1
PC+ABS	GLO	Market for polycarbonate	2022	ecoinvent	1	4	2	1	1
PC+ABS	GLO	Market for acrylonitrile-butadiene-styrene copolymer	2023	ecoinvent	1	4	2	1	1
PE	RoW	Polyethylene production, low density, granulate	2023	ecoinvent	1	3	2	1	1
PET	GLO	Market for polyethylene terephthalate, granulate, amorphous	2023	ecoinvent	1	4	2	1	1
Petrol	RER	Gasoline mix (regular) at refinery	2020	Sphera MLC	2	5	2	1	1
Petrol	BR	Bioethanol from sugar cane at filling station	2022	Sphera MLC	1	5	2	1	1
Petrol	US	Bioethanol from corn	2022	Sphera MLC	1	5	2	1	1
PMMA	RER	Polymethylmethacrylate sheet	2005	PlasticsEurope	5	5	2	1	1
Polymer, recycled	RER	Plastic granulate secondary (low metal contamination)	2023	Sphera MLC	1	5	3	1	1
Polyester	GLO	Market for fibre, polyester	2023	ecoinvent	1	4	2	1	1
Polyurethane	RoW	Market for polyurethane, rigid foam	2023	ecoinvent	1	3	2	1	1

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Material/process	Location	Dataset name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
POM	RER	Polyoxymethylene (POM)	2010	PlasticsEurope	4	5	2	1	1
Power PCB	GLO	Market for printed wiring board, for power supply unit, desktop computer, Pb containing	2023	ecoinvent	1	4	2	1	1
PP	GLO	Market for polypropylene, granulate	2023	ecoinvent	1	4	2	1	1
PVB	DE	Polyvinyl butyral granulate (PVB) by-product ethyl acetate	2023	Sphera MLC	1	5	2	1	1
PVC	RoW	Polyvinylchloride production, suspension polymerisation	2023	ecoinvent	1	3	2	1	1
R-1234yf	DE	R-1234yf production	2019	Sphera MLC	2	5	3	1	1
Resistor	GLO	Market for resistor, surface-mounted	2023	ecoinvent	1	4	2	1	1
SBR	DE	Styrene-butadiene rubber (S-SBR) mix	2023	Sphera MLC	1	5	2	1	1
Separator li battery	GLO	Market for battery separator	2023	ecoinvent	1	4	2	1	1
Signal PCB	GLO	Printed wiring board production, mounted mainboard, desktop computer, Pb containing	2023	ecoinvent	1	4	2	1	1
Silicon rubber	DE	Silicone rubber (RTV-2, condensation)	2023	Sphera MLC	1	5	2	1	1
Solder	GLO	Market for solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry	2023	ecoinvent	1	4	2	1	1
Steel, Sintered	GLO	Steel hot dip galvanised	2022	Worldsteel	1	4	3	1	1
Steel, Stainless, Austenitic	RER	Stainless steel cold rolled coil (304)	2014	Eurofer	3	5	2	1	1
Steel, Stainless, Ferritic	RER	Stainless steel cold rolled coil (430)	2014	Eurofer	3	5	2	1	1
Steel, Unalloyed	Asia	Steel hot dip galvanised	2022	Worldsteel	1	4	2	1	1
Steel, Unalloyed	Asia	Steel cold rolled coil	2022	Worldsteel	1	4	2	1	1
Steel, recycled	DE	EAF Steel billet / slab / bloom (Hot and cold rolling processes added)	2022	Sphera MLC	1	5	2	1	1
Sulphuric acid	RER	Sulphuric acid (96%)	2023	Sphera MLC	1	5	2	1	1
Talc (filler for polymers)	RER	Talcum powder (filler)	2023	Sphera MLC	1	5	2	1	1
Thermistor	GLO	Market for printed wiring board, surface mounted, unspecified, Pb containing	2023	ecoinvent	1	4	2	1	1
Thermoplastic elastomers	DE	Polypropylene / ethylene propylene diene elastomer granulate (PP/EPDM, TPO, TPE-O) mix	2023	Sphera MLC	1	5	3	1	1
Thermoplastics	RoW	Market for nylon 6	2023	ecoinvent	1	3	3	1	1

Material/process	Location	Dataset name	Year	Source	Time	Geo.	Tech.	Repr.	Prec.
Tyre	RER	Synthetic rubber production	2023	ecoinvent	1	5	2	1	1
Tyre	DE	Natural rubber (NR)	2023	Sphera MLC	1	5	2	1	1
Tyre	GLO	Market for carbon black	2023	ecoinvent	1	4	2	1	1
Tyre	RER	Lubricants at refinery	2020	Sphera MLC	2	5	2	1	1
Tyre	GLO	Market for paraffin*	2023	ecoinvent	1	4	2	1	1
Tyre	RER	Water (deionised)	2023	Sphera MLC	1	5	2	1	1
Undefined	RoW	Market for nylon 6	2023	ecoinvent	1	3	5	1	1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)	2023	Sphera MLC	1	5	3	1	1
Wood (paper, cellulose ...)	RER	Laminated veneer lumber (EN15804 A1-A3)	2023	Sphera MLC	1	5	3	1	1
Zinc	GLO	Special high grade zinc only from Zn concentrate	2022	IZA	1	4	2	1	1
Component LCAs			2024	Supplier data	1	1	1	1	2
Manufacturing									
Aluminium, manufacturing	DE	Aluminium die-cast part	2023	Sphera MLC	1	5	3	1	1
Aluminium, manufacturing	DE	Aluminium sheet deep drawing	2021	Sphera MLC	1	5	3	1	1
Aluminium, manufacturing	RER	Aluminium sheet – open input Aluminium rolling ingot	2023	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 (all energy inputs connected)	2021	Sphera MLC	1	5	3	1	1
Energy for S90 battery cell production	CN	Electricity grid mix 1kV-60kV (2025) (Stated policies STEPS)	2020	Sphera MLC	2	2	3	1	1
Energy for S90 battery cell production	RER	Thermal energy from natural gas	2020	Sphera MLC	2	3	3	1	1

** Only used for maintenance BOM.*

*** See Table 18 for a complete list of electronics datasets, the same rating is used for all.*

Table 26 *Summarised 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	4

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Appendix 4 – Assumptions for component manufacturing

Table 27 *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
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	Steel scrap generated from stamping at Volvo Cars' factories is included, that is the steel in vehicle structures workstream	Confidential
Stainless steel	Steel sheet deep drawing	Adheres to the conservative approach	63%
Copper (wire)	Wire drawing	Represents metalworking process for copper wire	100%
Polymers	Injection moulding process	Represents different forms of processing	98%
Other materials	Raw material mass x2	Compensates for further refining and processing where manufacturing process is unknown	50%

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Appendix 5 – Maintenance

Table 28 *Number of components replaced during routine maintenance over a distance of 200,000 kilometres.*

Component	S90 mild hybrid	S90 plug-in hybrid	ES90
Wiper blades	26	26	26
Tyres	16	16	16
Brake fluid (kg)	4.5	4.5	4.5
Brake pads	20	8	8
Brake discs	2	0	0
12 V batteries	3	3	3
Steering joint	2	2	2
Link arms	2	2	2
Condensers	1	1	1
AC fluid	2	2	2
Cabin filters	10	10	10
Engine oil (kg)	89	88	N/A
Oil filters	15	15	N/A
Automatic transmission oil (kg)	4	10	N/A
Air filters (engine)	3	3	N/A
Fuel filters	1	1	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

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

Transportation

Emissions from the transportation of waste to recycling, incineration, and landfill sites are calculated based on road freight covering 500 kilometres in this report. According to the European Commission's Environmental Footprint Method[13], waste from manufacturing and construction sites is assumed to be transported 100 kilometres for end-of-life treatment. However, since waste from end-of-life vehicles is separated into many recycling categories that may require more specific handling, certain waste fractions might need to be transported over longer distances. Therefore, the assumption in this study exceeds the EC guidelines.

Disassembly

As most disassembly is carried out manually, energy use is not calculated. Transportation emissions are not calculated for disassembled components as their mass is low. But transportation emissions after disassembly are included for the following components:

- 12-volt batteries
- Tyres
- Li-ion batteries

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 is used. The electricity used for this process is modelled as a 2039 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. 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.

[13] 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 29 *Waste handling of material fractions.*

Disassembly stage	Pre-processing stage	Final disposal
Li-ion batteries	Disassembly and shredding	Material recycling
Lead acid batteries	Disassembly	Material recycling
Catalytic converters	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 and shredding	According to material category*
Rest of vehicle	Shredding	According to material category*

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

Table 30 *Datasets for end-of-life treatment.*

Process	Location	Name	Type	Source
Incineration of hazardous waste	Europe without Switzerland	Treatment of waste mineral oil, hazardous waste incineration	agg	ecoinvent
Catalyst treatment	RER	Treatment of automobile catalyst	agg	ecoinvent
Incineration of shredder light fraction	EU-28	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW)	p-agg	ELCD/CEWEP
Landfill of Non-combustible materials	EU-28	DUPLICATE – Glass/inert waste on landfill	agg	Sphera MLC
Transport	GLO	Truck, Euro 6 A-C, 28 – 32t gross weight/22t payload capacity	u-so	Sphera MLC
Transport	RER	Diesel mix at refinery	agg	Sphera MLC

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Appendix 7 – Greenhouse gas emission factors

Table 31 *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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Appendix 8 – Critical review

IVL Swedish Environmental Research Institute

Review of study[1] - Carbon footprint assessment of the Volvo ES90

Carbon footprint study for review and verification
Carbon footprint assessment of the Volvo ES90 made by Volvo Cars.
Version: 1.0, Date: 9 June 2025, Issued by: Volvo Cars.

LCA study conducted by
Volvo Cars - Sustainability Centre of Engineering, Volvo Cars Asia Pacific

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Study commissioned by
Volvo Cars, Sweden

Review period of the study
December 2024 to June 2025

Verifiers
Håkan Stripple, Julia Lindholm, Rui Wang, Juanjuan Yao
IVL Swedish Environmental Research Institute Ltd.
Håkan Stripple and Rui Wang are independent individual verifiers in the International EPD system[2].

[1] ***Legal disclaimer***
This review and verification have been conducted based on the information and documentation provided by the commissioner of the study. The owner of the LCA study has the sole ownership, liability, and responsibility for the LCA study and its consequences. The reviewers and their organizations cannot be held liable for any decisions made or actions taken based on the findings of this report.
[2] https://www.environdec.com/resources/verifiers/individual-verifiers

Background and Scope
At Volvo Cars, sustainability is just as important as safety. Volvo Cars' long-term aim is to become a fully electric car company and are committed to accompanying the release of each battery electric vehicle (BEV) with a comprehensive life cycle assessment (LCA) covering its carbon footprint (CF).

Volvo Cars also has a long experience of development and design to reduce the climate impacts from its production as well as reducing the carbon footprint in collaboration with their suppliers along the entire value chain.

In this case, the carbon footprint of the fully electric Volvo ES90 is evaluated and compared with the Volvo S90 plug-in hybrid (PHEV) and the Volvo S90 mild hybrid (MHEV), vehicles of similar size but with different propulsion systems. Volvo ES90 is produced in Chengdu, China.

The task of the verifiers was to review the study including layout and methodology of the study, the CF report, the CF model, the CF background information, underlying data, and detailed calculations. The verification is performed to check and verify the calculations and validity of the system boundaries chosen and product model defined, as well as consistency with the steering documents, which mainly are ISO14040:2006, ISO14044:2006, ISO14067:2018 and Volvo Cars' guidelines.

Review process
The critical review of this study has been carried out as a parallel review, i.e. the reviewers were engaged early in the study and has thus reviewed the study step by step to ensure a good final result.

IVL has reviewed the study according to the standardised procedures for a critical review for LCA and CF described in the ISO standards. The review is based on the written materials from the study (the LCA/CF report, CF model and relevant supporting documents) and sample checks of this and other materials. The review statement and conclusions are given with regard to the current state of art and the information, that has been received from Volvo Cars. The comments and corrections are documented directly in the documents. The information in the review process is thus traceable throughout the entire review process.

Due to the use of a parallel review and verification process, online meetings were held in order to follow up the development process of the LCA/CF study. The documentation was sent to the verifiers for review by e-mail. After reading and comments, the different remarks were discussed and commented by Volvo Cars' personnel online as well as in a review meeting. The *Carbon footprint assessment of the Volvo ES90 made by Volvo Cars and relevant documents such as LCA reports from some of the suppliers and other supporting documents* were mainly reviewed.

The reports explain the goal and scope, methodologies, and main assumptions. After discussions and request in the review process, including the technical processes at site, editorial aspects and layout, CF model calculations, data used, energy calculations and measurements, functional unit, lifetime of the vehicles, recycling in production, system boundaries and completeness, internal and external recycling, allocation at production site, use of units, and naming of parameters in the CF model, satisfactory changes were made. The reviewers have checked the entire product chain including upstream data, core processes, and downstream data including also recycling data. The reviewers have checked the product specifications, the product systems and boundaries, the data gaps and cut offs, the methodology applied, the data used, and assumptions made in the study. The procedure for calculations and the selection of studied product has also been checked. The review process also includes minor editorial changes.

All remarks were accounted for in a satisfactory manner in the revised versions of the CF model, LCA/CF report, and governing documents.

Statement
The verification covers the above-mentioned study *Carbon footprint assessment of the Volvo ES90 made by Volvo Cars*. The undersigned verifiers verify that the attached study LCA/CF reports are in consistency with the steering documents identified under the above-mentioned scope of this review and has relevant data sources. Also, the sample check of methodology and calculations are reasonable and acceptable.

IVL Swedish Environmental Research Institute Ltd.

Håkan Stripple   Julia Lindholm   Rui Wang   Juanjuan Yao

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