Life cycle assessment

Carbon footprint of Polestar 5

Disclaimer

This report is for information only and (1) is based solely on an analysis of Polestar 5 (model year 2026, the first model year) and does not include information regarding any other Polestar vehicle and (2) does not include any commitments for current or future products or carbon footprint impacts. To get a complete understanding of the methodology used to calculate the carbon footprint in this report, it is recommended to read the present report in full.

The result of this study is dependent upon agreed and validated information from Polestar's suppliers and sub-suppliers. During a vehicle program life there could arise changes and non-compliances within the supply chain, should such changes or non-compliances arise, Polestar will take corrective actions to achieve the results presented in this report.

Content

List of abbreviation

ABS: Acrylonitrile Butadiene Styrene

BEV: Battery Electric Vehicle

BOM: Bill of Materials

CN: China

EoL: End-of-Life

GEC: Global Energy and Climate

GHG: Greenhouse Gas

GWP: Global Warming Potential

IEA: International Energy Agency

IMDS: International Material Data System

IPCC: Intergovernmental Panel on Climate Change

iPCA: iPoint compliance agent and approval

LCA: Life Cycle Assessment

NMC: Nickel Manganese Cobalt

OEM: Original Equipment Manufacturer

PC: Polycarbonate

PCB: Printed Circuit Board

PE: Polyethylene

PET: Polyethylene Terephthalate

PP: Polypropylene

RER: Europe

RNA: North America

RoW: Rest of World

STEPS: Stated Policies Scenario

WLTP: Worldwide Harmonized Light Vehicle Test Procedure

WTW: Well-to-Wheel

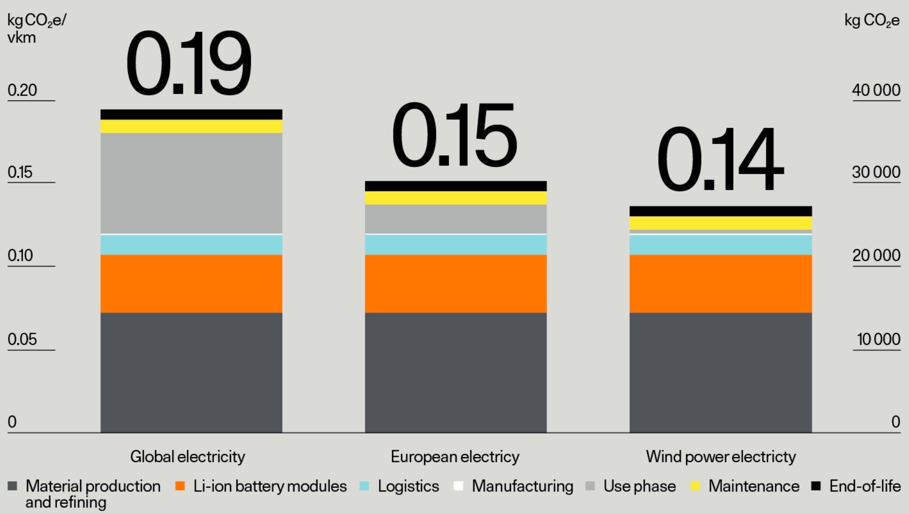
Polestar is dedicated to ensuring transparency regarding the environmental impact of its vehicles. This investigation aims to enhance openness by disclosing the carbon footprint associated with our passenger vehicles. The audience includes customers, Polestar employees, investors, automotive OEMs, and other stakeholders with an interest in the environmental performance of our vehicles.

The analysis conducted is a Life Cycle Assessment (LCA) focused exclusively on greenhouse gas (GHG) emissions, commonly referred to as a carbon footprint analysis. This assessment analyses the global warming potential (GWP) in accordance with ISO 14067 guidelines, utilising characterization factors established by the Intergovernmental Panel on Climate Change (IPCC, 2021). The scope of the study spans the entire life cycle of the vehicle, from the extraction and refinement of raw materials to the end-of-life stage.

This report estimates the carbon footprint of the Polestar 5, which enters manufacturing in the end of 2025. The study considers a driving distance of 200 000 kilometres with a functional unit of "1 vehicle-kilometre". In general, this study adopts conservative assumptions to prevent underestimating the climate impact. There is presently no official standard for LCA for vehicles, thereby the findings of this study should be approached with caution when making comparisons with those of other OEMs. The study's objective is to comprehend the carbon footprint of the vehicle in its entire lifespan. The aim is to offer valuable insights that can help in making well-informed decisions for potential customers of Polestar vehicles but also identify opportunities of vehicle carbon footprint minimisation. From previous reports conducted by Polestar, aluminium production and battery modules manufacturing have been pointed out as highly contributing factors of greenhouse gas emissions in battery electric vehicles. Due to this, Polestar is actively working towards reducing these impacts.

In conclusion, the climate impact of the cradle-to-gate study reveals that 60% is due to the materials utilised in the vehicle's production (excluding battery modules), aluminium representing 52% of these materials emissions, and iron and steel contributing with 17%. Following closely, the production of battery modules emerges as a significant factor, constituting 29% of the cradle-to-gate climate impact. This battery has relatively low impact, this is mainly due to the use of 100% renewable electricity in the production of the anode and cathode active material as well as in cell production of the battery modules. Of the cradle-to-gate emissions, 11% can be attributed to manufacturing and logistics.

Total cradle-to-grave carbon footprint in kg CO_2e for the different electricity mixes



← Figure 1

Total cradle-to-grave carbon footprint in kg CO_2e for the different electricity mixes. The axis to the left presents the functional unit of 1 vkm and the axis to the right presents the vehicle's lifetime of 200 000 km.

The results of the cradle-to-grave study, showed in figure 1, reveals a total carbon footprint for the complete life cycle of the vehicle of 38.6 tonnes CO_2e with global electricity mix in the use phase. 37% of the total climate impact is due to the material production and refining (excluding the battery modules). Following this, the next highest share is for the use phase, contributing 31% of the vehicle's total climate impact, and then the battery modules, constituting 18% of the overall climate impact.

Renewable energy sources, particularly wind power, demonstrate potential in reducing lifetime emissions during the use phase. Sensitivity analysis indicates a lower carbon footprint per kilometre for longer distances, emphasizing the importance of optimizing vehicle usage for sustainability. Promoting the prolonged use and lifespan of vehicles can be a strategic approach to curbing emissions. By extending the time a vehicle remains in service, the overall demand for new vehicles is reduced.

Key findings:

- The cradle-to-gate study (from raw material production and refining up until the vehicle reaches the customer) for Polestar 5 reveals a total carbon footprint of 23.8 tonnes CO_2e. Materials utilised in the vehicle's production, excluding the battery modules, account for 60% of the cradle-to-gate impact. The battery modules contribute significantly, accounting for 29%, while 11% is associated with manufacturing and logistics.

- The cradle-to-grave life cycle assessment for Polestar 5, depicted in Figure 1, reveals a total carbon footprint of 38.6 tonnes CO_2e with global electricity mix in the use phase. 37% of the total climate impact is due to the material production and refining (excluding the battery modules). Following this, the next highest share is for the use phase, contributing 31% of the vehicle's total climate impact, and then the battery modules, constituting 18% of the overall climate impact..

- Renewable energy sources, particularly wind power, demonstrate potential in minimising lifetime GHG emissions during the use phase. The sensitivity analysis indicates lower GHG emissions per vehicle kilometre for higher lifetime activity, meaning longer total driving distance, emphasising the importance of optimising vehicle usage.

Authors

Emil Inberg
Environmental Sustainability Specialist, Polestar

Contacts

Emil Inberg
Environmental Sustainability Specialist, Polestar
emil.inberg@polestar.com

Alexandra Odbjer
Manager Sustainability, Polestar
alexandra.odbjer@polestar.com

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1

This chapter describes the methodology of the conducted life cycle assessment (LCA) study.

1.1 The product

Polestar has developed one plug-in hybrid electric vehicle (Polestar 1) and three battery electric vehicles (BEV) (Polestar 2, 3 and 4). This study assesses the fourth BEV produced by Polestar, the performance grand tourer Polestar 5. The study assesses the first Polestar 5 variant that is introduced to the market: the Dual motor variant produced in Zhejiang Geely Holding Groups (hereafter referred to as Geely) factory in Chongqing, China in 2025. The variant is produced with several different alternative specifications/options. This study encompasses the specifications expected to have the largest sales volumes within the first year of production, based on Polestars internal predictions on how customers will specify their vehicles. The vehicle characteristics of the vehicle assessed in this study are presented in Table 1.

Table 1 →

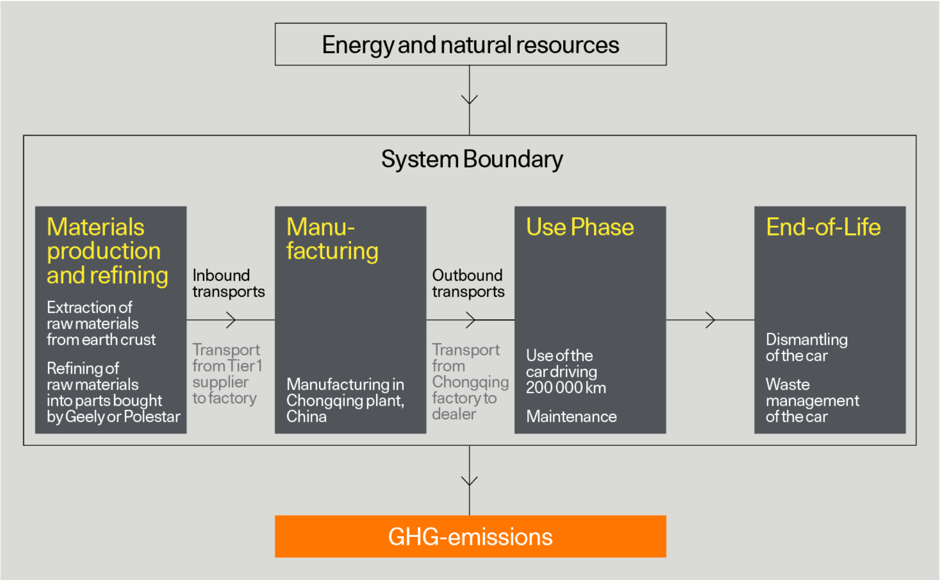
Polestar 5 vehicle characteristics.

Polestar 5	
Total weight vehicle	2 444 kg
Li-ion battery cathode type and capacity	NMC, 112 kWh
Battery modules weight	476 kg
Energy usage WLTP	17.6 kWh/100 km

The development of the methodology for this study was initiated jointly by Polestar and Volvo Cars Corporation when performing carbon footprint studies of Volvo XC40 Recharge and Polestar 2 in 2020. This methodology has been further developed by Polestar & Volvo Cars Corporation since then, notably in the 2024 Polestar 3 carbon footprint study, and now incorporates updates such as predicted future electricity mix in use phase, inclusion of emissions from maintenance and an updated functional unit. This will be further explained in the sections below.

1.2 Goal of study

Polestar has the ambition to become a climate neutral company by 2040 and strives to be transparent about the climate impact of Polestar vehicles. The goal of this study is to contribute to transparency by disclosing the carbon footprint of the Polestar 5. The purpose of the vehicle is to transport passengers and their belongings. The intended audience of this report are customers, employees at Polestar, investors, automotive OEMs (Original Equipment Manufacturers), and other stakeholders who are interested in the environmental performance of Polestar vehicles. The study was carried out to increase the knowledge about the carbon footprint of the Polestar 5, and which underlying materials and processes contribute the most to the climate impact. The aim is that this information will be utilised to make informed decisions, for example, on where to put effort in reducing greenhouse gas (GHG) emissions. The report is made public at Polestars website from September 2025.



← Figure 2

System boundary of study.

1.3 Scope of study

The study has been performed according to the carbon footprint standard ISO 14067 and explores the global warming potential (GWP), using characterisation factors for 100-year global warming potential (GWP) from the Intergovernmental Panel on Climate Change (IPCC, 2021), see Table 26 in Appendix 6. According to ISO 14067, emissions and removals in the following categories are included:

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

All significant GHGs emissions and removals from the processes included in the study (see "Main assumptions and exclusions") are quantified. No carbon offsetting is included. The study follows an attributional approach, i.e. it is not aimed at capturing systemic changes.

In the use phase, planned maintenance of the vehicle is considered, i.e. what is expected to be exchanged during the lifespan due to wear and tear of the vehicle is included, like change of tyres and windscreen wipers, but not changes due to accidents or other unexpected part failures which could affect only a very small percentage of vehicles. The datasets used to model the electricity consumption in the use phase include GHG emissions from electricity generation infrastructure, hence there is a climate impact associated with renewable electricity generation such as wind power.

The study includes the vehicle life cycle from cradle-to-grave, starting at extracting and refining of raw materials and ending at the End-of-Life (EoL) of the vehicle (see Figure 2).

No cut-off criteria have been applied for the mass of the product content or energy use. In other words, the intent is that the included inventory together gives rise to the full carbon footprint. Mass that has not been declared as a specific material by the suppliers is still included but approximated by modelling it as polyamide (the polymer with the highest carbon footprint out of the polymer data used in the study). For more information on how this has been handled, see section 2.1 "Material production and refining".

The time boundary of the study is manufacturing of the vehicle in 2026 and operating the vehicle over 15 years from 2026 to 2040, after which EoL handling occurs. There are developments within vehicle LCA standards currently still in draft in the EU which indicate that the average lifetime of passenger cars in the EU before scrappaging may have reached over 20 years. However, until such standards are finalised and in place, with the specific use period confirmed for these, Polestar will use a 15 year lifetime to retain comparability between Polestar vehicle carbon footprint studies.

The geographical boundary of the study is vehicle manufacturing in China, and use of the vehicle in the European Union (EU) and the world, i.e. average figures for the electricity mix in the EU and the world are used for the use phase (as well as a scenario of using electricity generated from wind power). The EoL geographical system boundary is set to global. For upstream processes, i.e. before the vehicle manufacturing, generic datasets for raw material production and refining in a specific country or region have been used when it is known or likely that production/refining takes place there. The methodology for choosing generic data is further described in the Polestar 2 carbon footprint report[1] "Appendix 1: General methodology when choosing datasets for complete vehicle carbon footprints".

The Polestar 5 is composed of higher quantities of aluminium compared to previous Polestar cars. Given this fact, Polestar has procured aluminium parts from suppliers which in turn procure aluminium from smelters utilizing renewable electricity. The share of aluminium originating from smelters utilizing renewable electricity in smelting has been incorporated into the present study. Use of recycled aluminium has been considered in the study, the shares of recycled aluminium per part has been given by aluminium parts suppliers directly to Polestar. The recycled aluminium share has been modelled separately to the primary aluminium share.

Use of recycled steel have not been considered in the modelling due to lack of data on the specific amounts in the vehicle. The dataset on steel production already contains a default percentage of 4.6% recycled content, which is not the case for the aluminium dataset.

The Polestar 5 contains recycled polymers which is incorporated into this study, for these parts data on recycled content has been obtained through IMDS. Some polymers in the Polestar 5 originate from biobased raw materials, however exact quantities are not known for the complete vehicle. Excluding biobased content means that the climate impact is slightly overestimated for polymers, but the effect on the overall result is estimated to be minor.

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

1.4 Function and functional unit

The functional unit is 1 vehicle kilometre (1 vkm). In the original Polestar 2 carbon footprint study, the vehicle lifetime mileage was used as the functional unit[1]. The functional unit has been changed since 1 vkm better captures the function of the vehicle – the mobility – and captures the effect of the lifetime mileage of the vehicle; the longer the lifetime mileage, the lower life cycle climate impact per 1 vkm. In practice, this means that the climate impact is calculated for the total life cycle and divided by the total km driven during the lifetime of the vehicle. The result will also be provided cradle-to-gate per produced vehicle and cradle-to-grave for a lifetime of 200 000 km distance driven. The reference flow in the study is the weight of the vehicle divided by the lifetime distance driven of 200 000 km. Table 1 shows the weight of the vehicle in the study.

1 https://www.polestar.com/dato-assets/11286/1600176185-20200915polestarlcafinala.pdf

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

1.5 Allocation

The total of assigned inputs and outputs for a unit process will match the inputs and outputs of the unit process prior to allocation. For all background processes, the same allocation method used in the LCI databases are adopted.

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

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

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

In the manufacturing facilities, total number of completed vehicles is used as the allocation basis, since there is a strong correlation between the use of resources and the total number of vehicles produced, irrespective of size of the vehicles.

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

1.6 Main assumptions and exclusions

In general, assumptions have been made in a conservative fashion following the precautionary principle, to not underestimate the climate impact from unknown data. For example, when no suitable dataset has been available to represent the manufacturing process for a certain material (from raw material to finished vehicle component), the emissions from the raw material production has been multiplied by two to compensate for the emissions from further processing. This is described in 2.7. "Minor material categories, production and refining".

Since the vehicle is manufactured in China it is assumed that materials originate from China, unless material origin from outside China is known. China or Asia specific material inventory datasets have been used as far as possible, based on availability within the Sphera professional and ecoinvent databases. See Appendix 1 for a detailed description of applied datasets.

Aspect	Description	Requirements in this study
Time-related coverage	Desired age of data.	General data should represent the current situation of the date of study (2025), or as close as possible. All data should be less than 10 years old.
Geographical coverage	Area from which data for unit processes should be collected.	Material production and refining should be representative of region where the material/component is produced, when known. Vehicle manufacturing should be representative of the manufacturing site location. The use phase data should be representative of European and global average. End-of-life data should be representative of global average.
Technology coverage	Type of technology (specific or average mix).	Data should be representative of the technology used in production processes.
Representativeness	Degree to which the data set reflects the true population of interest.	Primary data that is representative of the process should be used for processes under Polestar & Geely financial control. Secondary data may be used for upstream and downstream processes but fulfilling the requirements above on time-related, geographical and technology coverage.
Precision	Measure of the variability of the data values.	Data that is as representative as possible will be used. Data will be derived from credible sources, and references will be provided.
Completeness	Assessment of whether all relevant input and output data are included for each data set.	Generic data will be derived from credible sources, such as recognised LCI databases. Internal data should cover all relevant inputs and outputs. The data collected from battery module supplier should be verified in close collaboration with the supplier.
Reproducibility	Assessment of the method and data, and whether an independent practitioner will be able to reproduce the results.	Information about the method and data (reference source) should be provided.
Sources of the data	Assessment of the data sources used.	Data will be derived from credible sources, and references will be provided.
Uncertainty of the information	e.g. data, models, assumptions.	Data will be derived from credible sources, and references will be provided.

← Table 2

Data quality requirements used in the study.

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

The energy use of the vehicle corresponds to driving according to the WLTP driving cycle; it includes losses occurring during charging and in the drivetrain during driving, and only essential auxiliary systems are run while driving (excluding e.g. infotainment, air conditioning). The energy use in the use phase is explored in a sensitivity analysis.

The lifetime mileage of the vehicle is 200 000 km. As larger personal vehicles as the one studied here can be argued to have a longer lifetime distance driven[3], the effect of this is explored in a sensitivity analysis. The battery used in the Polestar 5 has been designed to last the life of the vehicle in typical use, thereby no change of battery modules is included in the study.

The study does not include:

- Non-manufacturing operations such as business travels, R&D activities or other indirect emissions
- Manufacturing infrastructure e.g., the production and maintenance of buildings, inventories or other equipment used in the vehicle manufacturing plant in Chongqing, China. However, when generic datasets are used, which is the case for energy generation, transportation means, and production of ingoing materials, impacts from manufacturing electricity generation infrastructure is automatically included.
- Construction and maintenance of roads and charging infrastructure in the use phase.

1.7 Data quality requirements

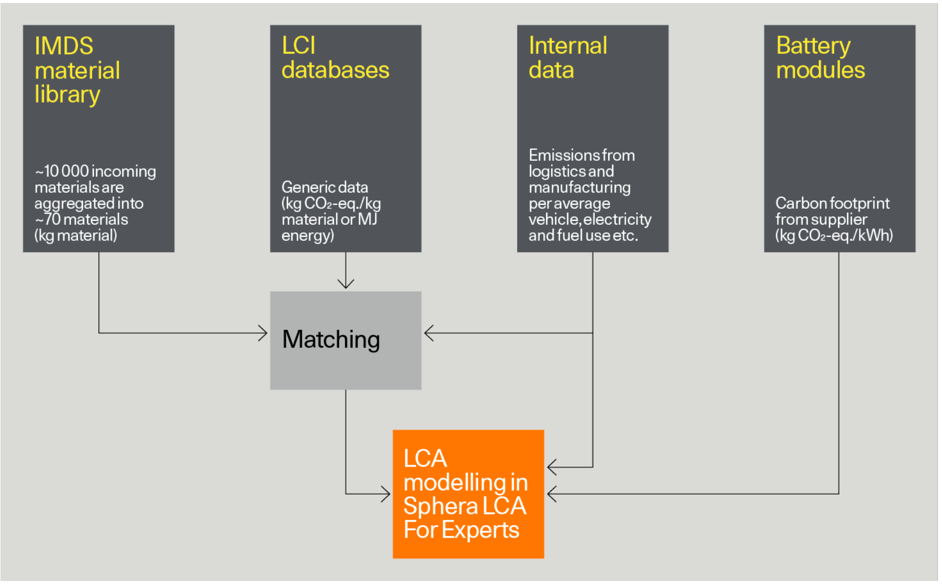
The data quality requirements used in the study are shown in Table 2. The data quality indicators used to assess the data used in the study can be found in Appendix 5, together with the quality assessment itself.

Considering the data quality requirements in Table 2, the data used in this study fulfil the requirements except that a considerable amount of the datasets used in the material production and refining are more than 10 years old and/or not representing the location of production, and that the technological coverage is insufficient for the EoL stage. This is due to both uncertainty of material origin, uncertainty of waste handling practises globally, and lack of geographical coverage in databases. For more details about the data quality assessment, see Appendix 5.

1.8 Critical review

In accordance with ISO 14067 this study has been critically reviewed by a third party, see Appendix 8.

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



Material type	Number of material categories	Share of total weight of the vehicle
Steel & iron	5	25%
Aluminium	4	43%
Other metals	3	< 1%
Polymers	35	18%
Natural materials	3	< 1%
Elastomers / elastomeric compounds (unspecified) (Tyres)	2	2%
Electronics	1	< 1%
Fluids & undefined	15	8%
Copper	2	2%

← Figure 3

A high-level overview of how Polestar works to derive data on which carbon footprints are calculated for vehicles.

← Table 3

Material categories defined in IMDS ML release 9. Note that Li-ion battery modules are treated separately and therefore not included in the table.

1.9 Way of working overview

Figure 3 shows a high-level overview of how Polestar works to derive carbon footprints of vehicles.

There are four main ways that data needed for the final carbon footprint are retrieved:

- IMDS[4] (International Material Data System) datasheets which contain information on material compositions of the components in a vehicle.
- LCI (Life Cycle Inventory) databases from ecoinvent[5] (version 3.9.1) and Sphera[6].
- Data from operations controlled by Polestar or a partner, such as manufacturing plants and logistics.
- Carbon footprint of Li-ion battery modules, performed by the supplier with guidance and support from Polestar.

1.10 Methodology to define vehicle material composition

The Bill of Materials (BoM) is an important component of the LCA and consists of the parts used in the vehicle and their respective weights and materials composition. The "part number vehicle BoM" is extracted from the product data management system. However, this BoM cannot be used as direct input to the LCA-model in LCA for Experts but must be processed and aggregated in several steps to a suitable "material BoM".

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

To have an efficient and systematic approach, this mapping is done in an automated way. The rules to categorise the materials are set up based on IMDS material category, material name and substance content. It is also possible to manually allocate materials in the IMDS ML, however, this is done in the most restrictive way possible. For this carbon footprint study, IMDS ML release 9 is used with the material categories listed in Table 3. For the complete list of material categories, see Appendix 2.

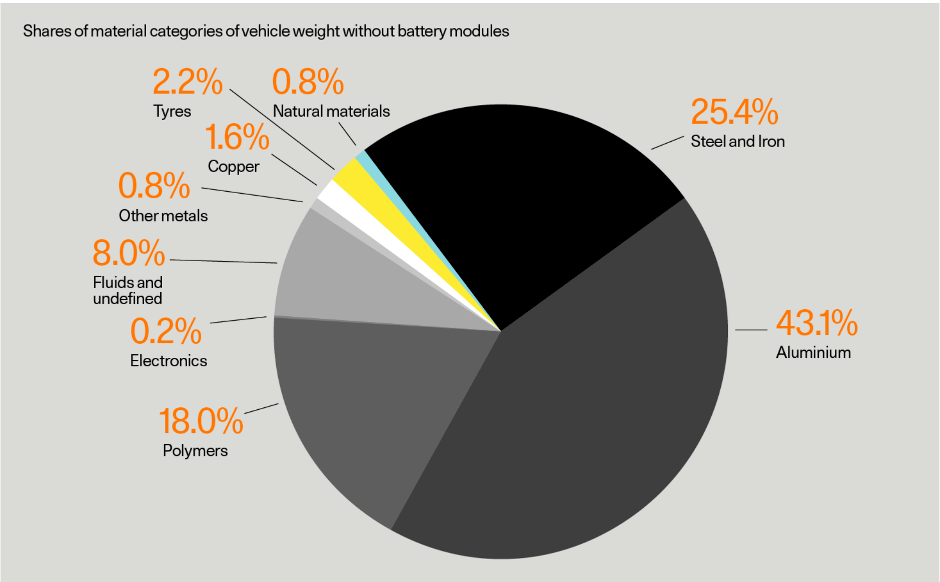
The "material BoM" has been modelled in LCA for Experts with relevant manufacturing process datasets. To follow the ISO 14067 standard, emission factors for the five impact categories have been calculated from the model in LCA for Experts for each material type including processes and refining and then extracted into a excel document. This is done for both cradle-to-grave emission factors and for EOL emission factors. After this is done, each components emission is calculated by its respective mass.

For the Li-ion battery modules, specific supplier carbon footprint data was used instead of IMDS data. The variety and accuracy of generic datasets for Li-ion batteries is limited, but through the collaboration with the battery module supplier the risk of inaccuracies has been minimised to the best of efforts.

4 IMDS, www.mdsystem.com

5 Ecoinvent, www.ecoinvent.org

6 Sphera LCA databases https://sphera.com/solutions/product-stewardship/life-cycle-assessment-software-and-data/



← Figure 4

Shares of material categories of vehicle weight without battery modules.

This chapter will describe the life cycle inventory of the study.

2.1 Material production and refining

Material production and refining is based on a BoM containing material composition and material weight. The BoM used for modelling in LCA for Experts is specifically developed to be used for the LCA modelling in LCA for Experts and states the composition of the vehicle based on more than 70 material categories. Each material category has an identified mass. The total weight of all material categories is then compared with the total weight of the vehicle. See Figure 4 for share of material categories for the vehicle.

In LCA for Experts each material has been coupled with one or several datasets (containing LCI-data) representing the production and refining of the material in each specific material category. See Appendix 1 – Chosen datasets.

The material production and refining are modelled using datasets from Sphera Professional database and ecoinvent 3.9.1 data. The datasets have been chosen according to the Polestar methodology for choosing generic datasets (described in Appendix 1 in the Polestar 2 carbon footprint report[7]).

The material content corresponding to the entire weight of the vehicle is included in the LCA, but a small number of materials has been categorised as "fluids & undefined material" in the material library. The share of fluids & undefined material of the total vehicle weight (excluding battery modules) for Polestar 5 is 8%. Since the undefined category seems to contain mostly undefined polymers, a dataset for Polyamide (Nylon 6) has been used as approximation. This assumption is made since polyamide is the polymer with the highest Carbon Footprint, out of the polymer data used in the LCA.

All filled polymers have been assumed to contain 78% polymer resin, 14% glass fibre and 8% talc representing an average of filled polymers as reported in IMDS.

In most cases, datasets that include both production of raw material as well as component manufacturing ready to be assembled in the vehicle are not available. Therefore, several datasets representing the refining and production of parts have been used for most material categories. The datasets used to represent further refining and manufacturing of parts are listed in Appendix 1.

For most database datasets representing materials production and refining processes it has not been possible to modify the electricity mix, i.e. the built-in electricity mix has been used. Some materials manufacturing processes from databases are country or region specific but specific to other regions than China. Thereby the exact manufacturing situation for Polestar 5 parts may not be accurately represented. These datasets do however give the possibility to apply country specific energy inputs. In these cases, Chinese energy inputs have been applied. These manufacturing processes are for steel, aluminium, tyres and polymers, displayed in Table 16 in Appendix 1.

When the materials have been categorised and then modelled in LCA for Experts, the emission factor for each material group has been multiplied by the weight corresponding to that material group. This has been done for all five impact categories according to ISO 14067, for manufacturing and for end-of-life treatment.

7 https://www.polestar.com/dato-assets/11286/1600176185-20200915polestarlcafinala.pdf

2.2 Aluminium production and refining

In previous Polestar vehicle carbon footprint reports the share of aluminium that is cast aluminium and wrought aluminium has been assumed to be 65% cast aluminium and 35% wrought aluminium, based on the report "Aluminium content in European passenger cars"[8]. However, as the Polestar 5 is produced from high quantities of aluminium compared to other vehicles a more in-depth analysis of the aluminium content is justified. Thereby the wrought aluminium share has been divided into "extrusions" and "pressings". Using IMDS-data and expert judgement from Polestar vehicle engineers the aluminium composition has been estimated to the numbers displayed in Table 4. These values exclude the weight of the aluminium in the battery modules as this aluminium content is accounted for in the carbon footprint report provided by the battery module supplier, more on this is described in Section 2.8.

Aluminium type	Aluminium type share of total aluminium
Castings	40%
Extrusions	38%
Pressings	22%

← Table 4

Shares of aluminium types, excluding battery modules.

All aluminium pressings have been assumed to go through the process of making aluminium sheets and all aluminium extrusions has been assumed to go through the process of aluminium extrusion. The cast aluminium goes through a process for die-casting aluminium.

The losses occurring in the processes of making the aluminium parts for the vehicle are included in the carbon footprint, and since a cut-off is applied at the point of losses occurring in the production in the factory, the total footprint of the losses is allocated to the vehicle even though the aluminium scrap is sent to recycling and used in other products. The material utilisation rate for the manufacturing processes of all three aluminium types can be seen in Appendix 3.

All aluminium is assumed to be produced in China. The assumption is based on an expert judgement by Polestar logistics specialists. As the Polestar 5 is manufactured from higher quantities of aluminium than previous Polestar vehicles, tough requirements on aluminium parts suppliers have been set by Polestar due to the high GHG emissions generally associated with aluminium production. Thereby aluminium used in parts of the vehicle comes from renewable electricity smelters. This share has been modelled with an emission factor representing aluminium smelting using electricity from hydropower plants in China. The emission factor was obtained through Polestar's own investigations and is a conservative assumption however the other emission factors were not provided (like biogenic emissions, aircraft emissions etc.).

Recycled aluminium is included in some parts of the Polestar 5. This share has been modelled using the disaggregated unit process "RNA: Aluminum, secondary, ingot, at plant USLCI" available in Sphera Professional Database and applying Chinese electricity mix and natural gas mix to the production of the aluminium ingot for the "Recycled aluminium" share of the recycled content and renewable electricity for the "Recycled aluminium produced using renewable electricity" share. The different aluminium categories and corresponding shares of total aluminium content is displayed in Table 5.

To determine the category of aluminium, as described in Table 5, first-hand information has been gathered from suppliers of aluminium parts to the Polestar 5. Through this supplier engagement process information on aluminium smelter location as well as recycled content has been gathered and assessed. Thereby Polestar has been able to retrieve information on electricity sources to these aluminium smelters to determine renewable electricity usage in smelting operations.

Table 5 →

Shares of different aluminium categories, excluding battery modules.

Aluminium category	Share of total aluminium
Aluminium from renewable electricity smelters	83%
Recycled aluminium	3%
Recycled aluminium produced using renewable electricity	10%
Standard Chinese aluminium	4%

2.3 Steel production and refining

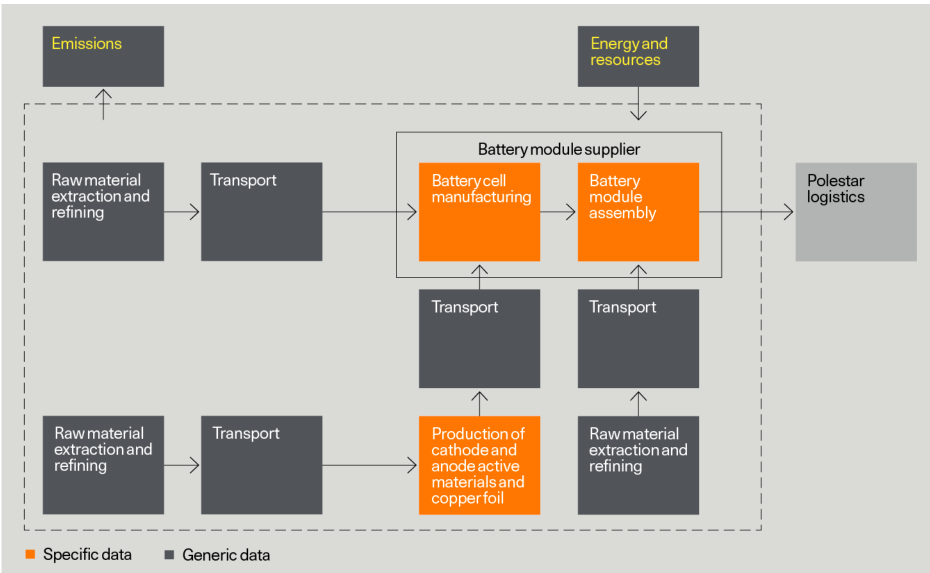
The raw material dataset used for the material category "unalloyed steel" has an output of rolled and galvanised steel. A processing process has then been added to all steel. No steel is processed and stamped in the Chongqing plant, contrary to previous Polestar vehicles for which part of the steel is being processed and stamped in the manufacturing plant. For all steel, which is distributed in various components of the vehicle, the material utilisation degree is according to the chosen database dataset, i.e. literature value. All steel is assumed to be going through the steel sheet deep drawing process, a conservative assumption as a lot of parts which in conventional vehicles are made from steel sheets, in the Polestar 5 are made from aluminium. The losses occurring in the processes of making the steel parts for the vehicle, independent of processes, are included in the carbon footprint, and the same cut-off as for aluminium is applied. The material utilisation degree for the manufacturing processes of steel can be seen in Appendix 3. All steel is assumed to be produced in China. The assumption is based on an expert judgement by Polestar logistics specialists.

2.4 Electronics production and refining

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

For the category "electronics" a generic data set from ecoinvent 3.9.1 has been used. This dataset represents the production of lead-free, mounted PCBs.

8 https://european-aluminium.eu/wp-content/uploads/2022/10/aluminum-content-in-european-cars_european-aluminium_public-summary_101019-1.pdf



← Figure 5

Flowchart for battery module manufacturing.

2.5 Plastics production and refining

For polymer materials, an injection moulding process has been used to represent the processing of plastic parts from a polymer raw material. The material utilisation degree for the manufacturing processes of plastics can be seen in Appendix 3.

Approximately 28 kg of the plastics in Polestar 5 are recycled plastics, as identified from the IMDS-data. This share has been modelled with a dataset for mechanically recycled plastics.

2.6 Minor material categories, production and refining

There are raw materials for which data on processing is missing in the LCA-databases. In those cases, the material weight was doubled as an estimation for the processing. This means that the processing process is assumed to have the same carbon footprint as the production of the raw material itself. This has been applied only for minor materials (by weight).

2.7 Electricity use in materials production and refining

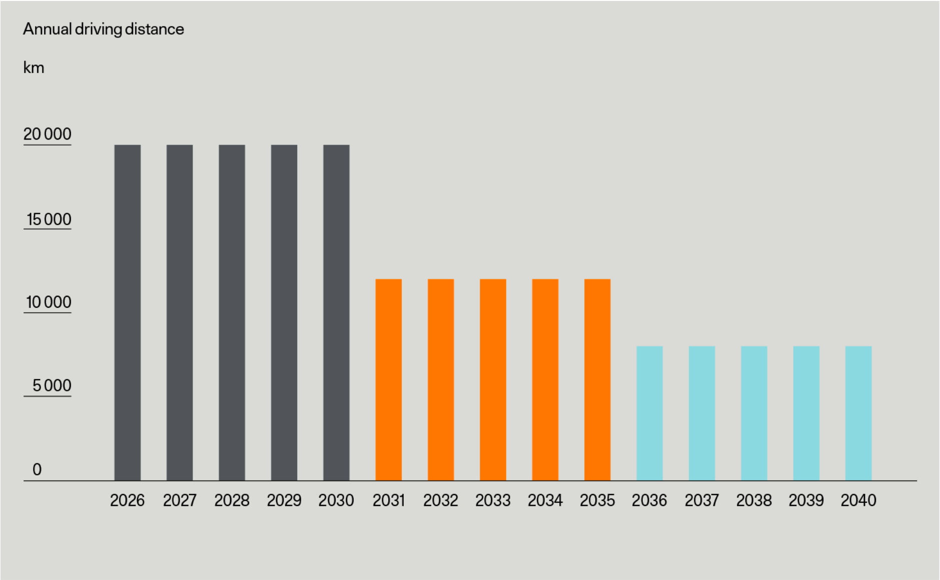
Most of the datasets used for materials production and refining have built-in electricity grid mix corresponding to the region the dataset is compiled for. In the few partially aggregated processes in the Sphera databases where it is possible to add an electricity mix by choice, a Chinese electricity grid mix is applied.

2.8 Battery modules

Polestar purchases Li-ion battery modules from a battery supplier who, in collaboration with Polestar, conducted a cradle-to-gate carbon footprint study of their battery module (up until Polestar logistics take over). See Figure 5 for the flowchart of battery manufacturing, representing system boundaries and primary activities. The battery modules have therefore been removed from the BoM based on IMDS data and are modelled separately in the complete vehicle LCA. All other parts of the battery pack are included in the materials BoM, based on IMDS data. The total weight for the battery pack is 679 kg with modules being 476 kg and other materials being 189 kg. The highest weight share for the battery pack, excluding the modules, are allocated to the aluminium tray, in which the modules sit, and high-voltage cables.

The carbon footprint study conducted by the battery supplier has not been third-party reviewed. Polestar follows developments in vehicle LCA standards closely and will seek to have battery carbon footprint reports third-party reviewed in future Polestar vehicle carbon footprint studies.

For cell and module production, the production of the anode- and cathode active material as well as the production of copper foil, the supplier purchases renewable electricity certificates to cover the complete Polestar production volume. These are in the form of Chinese Green Electricity Certificates (GECs). This will be going into effect before the end of 2025, after the start of production. However, since the batteries will be produced for many years, the estimated effect of this improvement has been included in this vehicle study. Therefore, most vehicles manufactured will incorporate battery modules produced through the acquisition of certificates for renewable energy sources.



← Figure 6

Assumed annual driving distances (km) during the lifetime of the vehicle.

The report from the battery supplier adheres to LCA standards such as ISO 14044:2006 and ISO 14040:2006, and the assessment's system boundary extends from cradle-to-gate. The impact categories considered include the Global Warming Potential (GWP) over 100 years, following the IPCC's 6th Assessment Report (AR6), with consideration given to all GHG, not just CO_2. The unit of measurement utilised is kg CO_2e. The functional units assessed in the report are the capacity of a finalized battery cell (measured in kWh) and the capacity of a finalised battery module (measured in kWh). The assessment's time boundary was set at 2026, capturing the environmental impact within that specific timeframe. The supplier has used the Sphera tool LCA For Experts to model the impacts of the battery modules. Supplier specific data has been used for energy input at the module supplier and at anode material, cathode material and copper foil suppliers. The cell manufacturing and module assembly uses renewable electricity through GECs, as previously stated, and natural gas for heating.

2.9 Logistics

Data required to calculate GHG emissions for transport from Tier 1 suppliers to the manufacturing site (inbound transport) has been gathered from suppliers by Polestar procurement and shared with the Polestar logistics team. Since the vehicle has not entered production at the time of writing this report and the Polestar 5 is the first vehicle to be produced in the pant, the underlying data for inbound transportation is based on estimations of transport distances and predictions on mode of transport.

Volvo Cars Corporation handles outbound logistics, hence data on GHG emissions has been provided by Volvo Cars Corpoation. Data has been provided in the form of estimated GHG emissions per vehicle transported from China to specific markets, this has been combined with predicted sales figures of Polestar 5 per market during the full year 2026 to calculate the average GHG emissions per transported Polestar 5 vehicle. Emission factors from the Network for Transport Measures (NTM)[9] has been used as a basis for calculations. The climate impact is not specified into emission categories, such as biogenic emission or fossil emissions and therefore has conservatively been assumed to only be associated with fossil emissions. The methodology to calculate emissions is developed in line with the ISO Standard 14083.

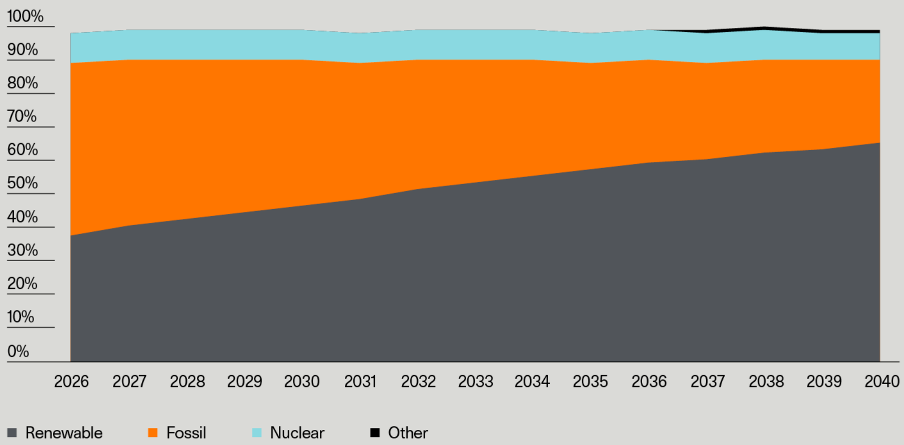
2.10 Manufacturing

The Chongqing plant operated by Geely is a new, fully electrified plant. Meaning no natural gas is used in the production of vehicles. The plant will run on 100% renewable electricity through the purchase of Chinese Green Energy Certificates. At the time of writing the exact electricity mix is unavailable, thereby data on Chinese renewable electricity distribution in 2023 from the IEA[10] has been used to estimate the sources of renewable electricity. This has been paired with appropriate LCI datasets from Sphera professional database. Since the Polestar 5 is the first vehicle to be manufactured in the plant, actual data on electricity consumption is unavailable. Predictions on electricity consumption based on the pre-production phase of the vehicle have been used to estimate the GHG emissions associated with the production of Polestar 5. There is other climate impacts associated with the manufacturing of the vehicle, such as emissions from water processing and chemicals. These are not included in the study due to these impacts being seen as negligible.

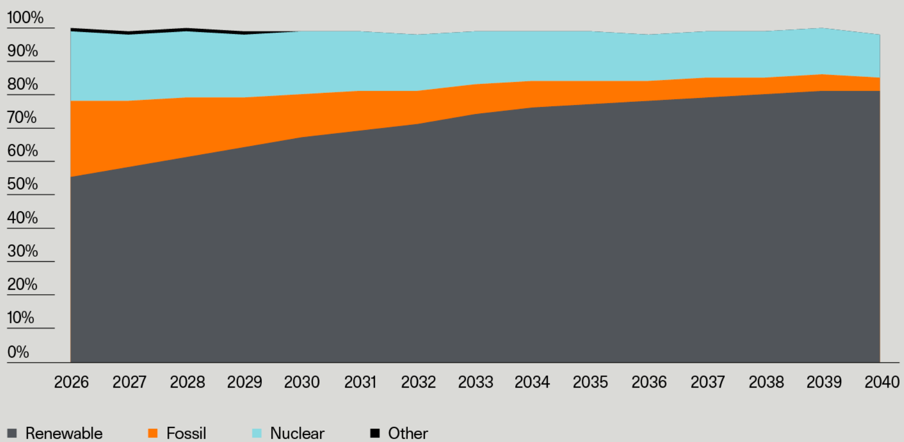
9 https://www.transportmeasures.org/en/

10 https://www.iea.org/countries/china/energy-mix

Global electricity mix 2026-2040 – IEA STEPS Scenario



EU electricy mix 2026-2040 – IEA STEPS Scenario



← Figure 7

Predicted share of energy production sectors in the Stated Policies Scenario STEPS for global energy mix.

← Figure 8

Predicted share of energy production sectors in the Stated Policies Scenario STEPS for European energy mix.

2.11 Use phase

To be able to calculate the emissions in the use phase of the vehicle, the distance driven is required, in combination with the energy use, as well as emissions from electricity production. The vehicle lifetime driving distance for Polestar vehicles has been set to 200 000 km, energy consumption is set to 17.6 kWh/100 km according to the WLTP driving cycle, the complete lifetime driving distance is covered in 15 years' time from 2026 to 2040. The consumption figure has not been certified at the time of writing this report and may be subject to change after vehicle certification.

Electricity production is modelled according to three cases: regional (global and EU) grid mix and as a specific energy source (wind). Current and future global and EU electricity generation mixes are based on the World Energy Outlook 2024 Extended Dataset[11] from IEA. Amounts of electricity from different energy sources have in this study been paired with appropriate LCI datasets from Sphera professional database (see Table 19 in Appendix 1) to determine the total climate impacts from different electricity generation mixes, both direct (at the site of electricity generation) and upstream. An additional specific electricity source in the form of solar power is available in Appendix 7.

The analysis assumes that 50% of a vehicle's total lifetime mileage is covered in the initial five years, equivalent to 20 000 kilometres per year, while 30% is driven in the subsequent five years, amounting to 12 000 kilometres annually. During the last five year of the vehicle's life, it is assumed that the yearly distance driven is 8 000 km, illustrated in Figure 6.

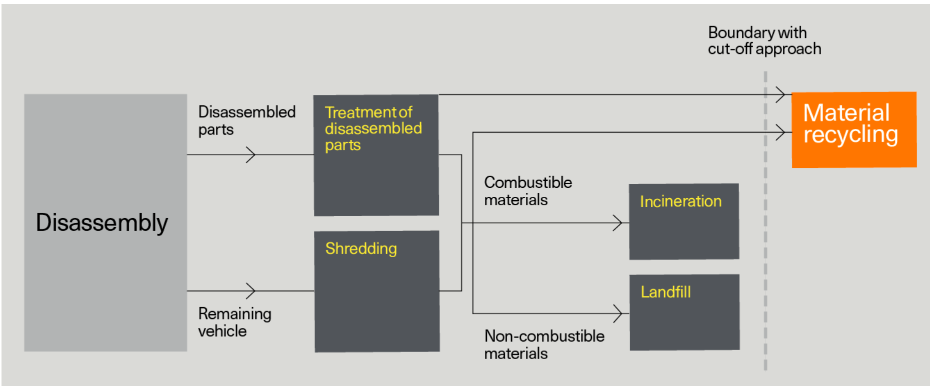
IEA uses the Global Energy and Climate (GEC) Model to explore possible future energy related scenarios based on different assumptions. For this study, STEPS has been used to determine the electricity generation mixes used to charge the vehicles in the use phase. STEPS reflects current policy settings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

Figure 7 and Figure 8 visually represent the development of electricity sources. It is evident that the production of electricity from fossil sources is expected to diminish, gradually being replaced by renewable sources based on the IEA STEPS data.

The well-to-wheel (WTW) emission data for the electricity usage for the vehicle is based on regulatory type-approval testing according to WLTP (Worldwide Harmonised Light Vehicle Test Procedure - used for certification of vehicles in the EU). Losses during charging, from charging infrastructure, are not included in the electricity use of the vehicle. The electricity use of the vehicles is 17.6 kWh/100 km.

The energy use in the use phase is modelled based on the WLTP test as that is a global standard. WLTP does not, however, take all driving conditions into account, and, for example, assumes a driving condition where heating or cooling is not necessary and no use of infotainment in use. This could, especially for certain markets, lead to an underestimated energy use figure.

11 World Energy Outlook 2024 Extended Dataset - Data product - IEA



← Figure 9

End-of-Life flow chart.

2.12 Maintenance

For the 15 years lifespan of the vehicle, it is assumed that some vehicle parts are required to be replaced. The data for maintenance of the vehicle is based on data for maintenance of a typical Polestar vehicle and not specific to the Polestar 5. The maintenance list is presented in Table 6. It is assumed that the number of items represents groups of items, e.g. one wiper blade represents the entire set of the two wiper blades. The vehicle tyres are designed to last 40 000 km. It is assumed that the tyres are not changed just before EoL, therefore 16 tyres need to be changed during the vehicle lifetime. For each part the corresponding item is found in the BoM and specific material data is used together with the corresponding dataset, in the same way as material production and refining. However, only standard Chinese aluminium is used for the parts which contain aluminium, meaning that no share of recycled aluminium or aluminium from smelters using renewable electricity is assumed to be part of any replacement components.

Table 6 →

Maintenance parts changed during the lifetime of the vehicle.

Vehicle part	Unit	
Wiper blades	number of sets	39
Tyres	number of items	16
Brake fluid	litres	2
Brake pads	number of items	24
Brake discs	number of items	4
Battery, 12 V	number of items	3
Steering joint	number of items	1
Link arm	number of items	2
Condenser	number of items	1
AC fluid	number of AC container volume	2
Cabin filter	number of items	12

2.13 End-of-life treatment

It is assumed that all vehicles, at their EoL, are collected and sent to EoL treatment. The same methodology as described in Section 1.5 Allocation is applied. Focusing on the point of lowest market value, according to the polluter pays principle, implies inclusion of steps like dismantling and pre-treatment (like shredding and specific component pre-treatment), but it does not include material separation, refining, or any credit for reuse in another product system, see Figure 9.

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

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

- batteries, wheels, tyres
- liquids: coolants, antifreeze, brake fluid, air-conditioning fluid, shock absorber fluid and windscreen wash
- airbags and seat belt pretensioners removed or set off

From a global perspective, the treatment of coolant generally implies incineration. 55% of the tires are assumed to be salvaged for rubber recovery[12], and the rest to be incinerated. The lead batteries are assumed to be salvaged for lead recovery. Airbags and seat belt pretensioners, which are disassembled for safety reasons rather than the potential recycling value, are assumed to be incinerated. The Li-ion battery modules are assumed to be taken out of the vehicle and sent to recycling. The assumption is that the Li-ion battery modules will be removed from the vehicle and sent to recycling due to the presence of valuable materials inside the modules. This is due to the resource-intensive and economically costly processes involved in extracting and refining these materials. Additionally, it is anticipated that recycling legislation will become more stringent, particularly as the vehicle approaches the end of its life.

All other parts of the vehicle are sent to shredding. In this process, the materials in the vehicle are shredded and then divided into fractions, depending on different physical and magnetic properties. Typical fractions are:

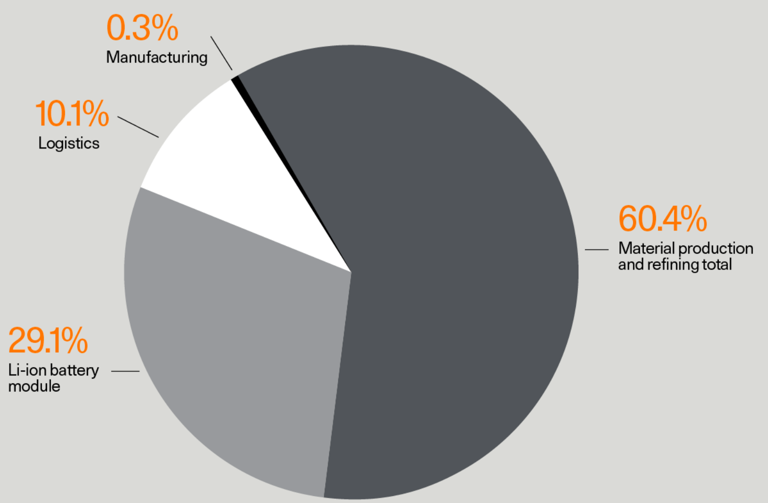
- ferrous metals (steel, cast iron, etc.)
- non-ferrous metals (aluminium, copper, etc.)
- shredder light fraction (plastics, ceramics, etc.)

The metal fractions can be sent for further refining and, in the end, material recycling. The combustible part of the light fraction can be incinerated for energy, or the entire fraction can end up in a landfill. For the purposes of this study, it is assumed the combustible streams of materials are incinerated, while the non-combustible materials are landfilled.

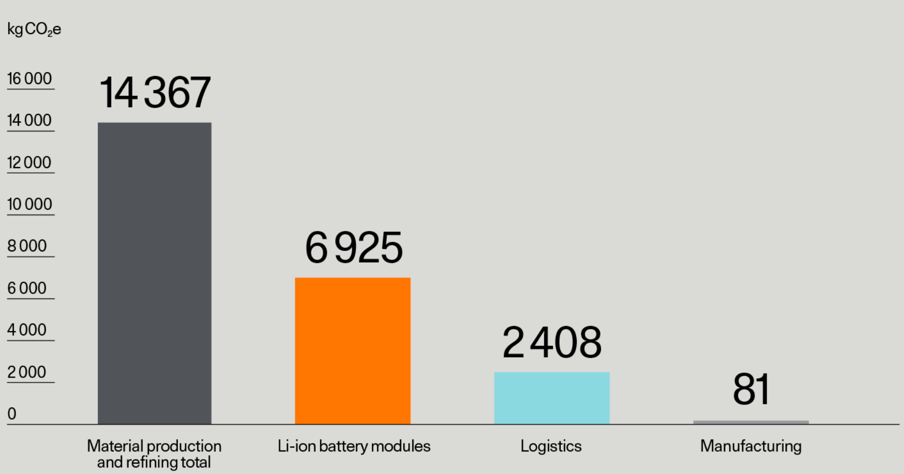
Due to the global focus of the study, no energy recovery is included for the incineration steps, even though in some Polestar markets, there is indeed energy recovery from incineration of waste. This somewhat conservative assumption has been made since there are many markets with no energy recovery, and data on how common the case with energy recovery is for the combustible streams is unknown. Assessment of material losses after shredding and refining are outside the system boundaries set by the cut-off approach. Further information on the EoL treatment is available in Appendix 4.

12 https://weibold.com/europe-collected-and-recycled-94-percent-of-endoflife-tires-in-2019#:~:text=According%20to%20ETRMA%2C%2094%25%20of,between%2092%25%20and%2095%25.

Share of cradle-to-gate emissions per life cycle step, for 1 vehicle



Cradle-to-gate total climate impact in kg CO_2e for the life cycle of the vehicle



← Figure 10

Share of cradle-to-gate emissions per life cycle step, for 1 vehicle.

In the subsequent sections, we present the findings of the study starting with cradle-to-gate results followed by cradle-to-grave results. A sensitivity analysis is also included. In accordance with ISO standards, the quantified results within this report have been rounded to three significant digits. This practice serves to improve clarity and maintain consistency throughout the report. Rounding the figures aids in enhancing readability and acknowledges the inherent uncertainties associated with the results.

3.1 Cradle-to-gate

The results showcased in Figure 10 displays the shares of total cradle-to-gate carbon footprint that are attributed per value chain step concerning the production of 1 vehicle with a weight of 2 444 kg. The largest share of impact, constituting 60% of the total, comes from the variety of materials utilised in the vehicle's production (excluding the battery modules). The battery modules contribute significantly as the next highest share, accounting for 29% of the cradle-to-gate climate impact, while 10% is associated with logistics and less than 1% stemming from the vehicle manufacturing processes occurring in the Chongqing plant in China, due to all energy used is renewable electricity.

Table 7 →

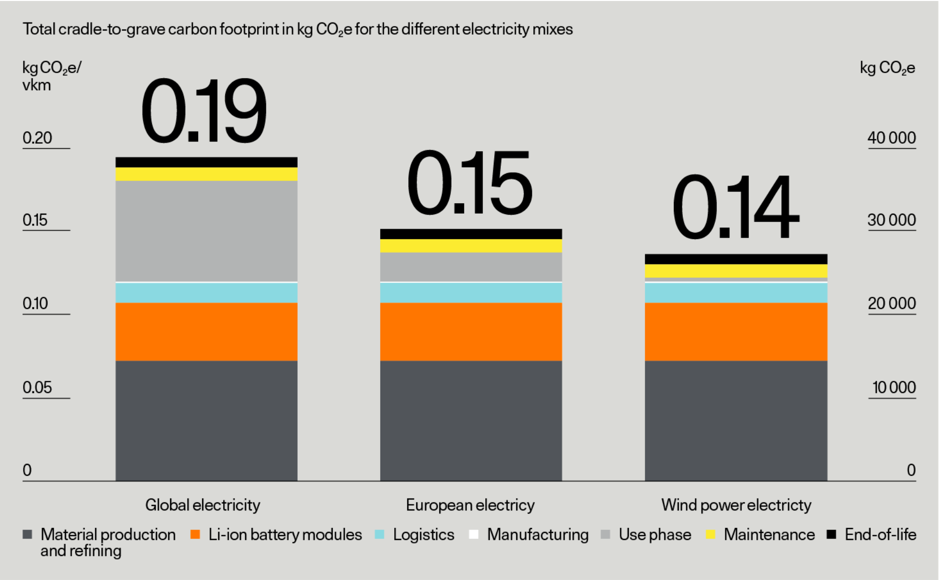
Cradle-to-gate total climate impact in tonne CO_2e for the life cycle of the vehicle.

Polestar 5	Tonnes CO_2e per vehicle
Materials production and refining	14.4
Li-ion battery modules	6.93
Logistics	2.41
Manufacturing	0.08
Total	23.8

← Figure 11

Cradle-to-gate total climate impact in kg CO_2e for the life cycle of the vehicle.

Table 7 presents the climate impact in tonnes CO_2e throughout the cradle-to-gate life cycle of the vehicle. The total climate impact amounts to 23.8 tonnes CO_2e for 1 vehicle, material production and refining is the category with the largest share of impact. See visualisation of results in Figure 11.



← Figure 12

Total carbon footprint cradle- to-grave kg CO_2e. The axis to the left presents the functional unit of 1 vkm and the axis to the right presents the vehicle's lifetime of 200 000 km.

3.2 Cradle-to-grave

The results of the comprehensive LCA for the vehicle, considering three distinct electricity mixes, are presented in Figure 12 for the cradle-to-grave study. Depending on the electricity mixes for the use phase, the climate impacts differ.

The life cycle stages with the most significant climate impact for the global electricity mix are materials production and refining and the use phase.

During the use phase, large variations are observed depending on the electricity sources employed for driving. Wind power electricity exhibits the least climate impact during the use phase, followed by EU electricity mix.

Table 8 presents the climate impact in tonnes CO_2e and gCO_2e / vkm throughout the life cycle of the vehicle, for different electricity mixes during use phase. The total climate impact amounts to 38.6 tonnes CO_2e for 1 entire vehicle with global electricity mix, with the material production and refining and use phase being the categories with the largest carbon footprint impact.

For EU electricity mix and for wind power electricity the highest climate impacts are seen in material production and refining and the Li-ion battery modules. Total climate impact accounts for 30.1 tonnes CO_2e and 27.0 tonnes CO_2e respectively, for entire vehicle.

	Global electricity		EU electricity		Wind power electricity	
	Tonnes CO_2-eq. per vehicle	g CO_2-eq. per vehicle-km	Tonnes CO_2-eq. per vehicle	g CO_2-eq. per vehicle-km	Tonnes CO_2-eq. per vehicle	g CO_2-eq. per vehicle-km
Materials production and refining	14.4	71.8	14.4	71.8	14.4	71.8
Li-ion battery modules	6.93	34.6	6.93	34.6	6.93	34.6
Logistics	2.41	12.0	2.41	12.0	2.41	12.0
Manufacturing	0.08	0.40	0.08	0.40	0.08	0.40
Use phase	12.0	60.2	3.48	17.4	0.45	2.27
Maintenance	1.58	7.88	1.58	7.88	1.58	7.88
End-of-Life	1.23	6.2	1.23	6.2	1.23	6.2
Total	38.6	193	30.1	150	27.0	135

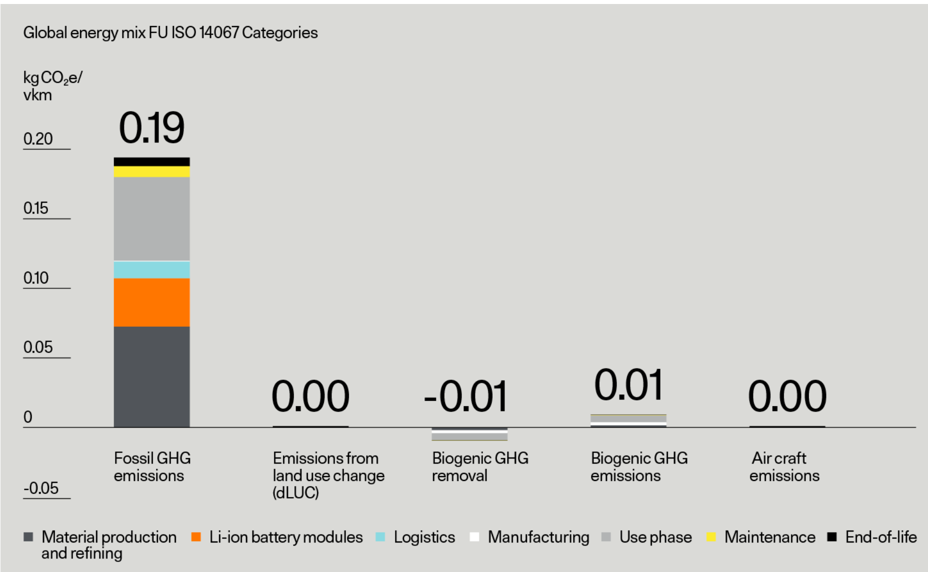
← Table 8

Cradle-to-grave climate impact with different energy mix during use phase for the functional unit 1 vkm measured in gCO_2e, and for the entire life cycle of 1 vehicle with driving distance 200 000 km measured in tonnes CO_2e.

3.2.1 Climate impact categories

According to ISO 14067 this study includes the five different climate impact categories: fossil GHG emissions, emissions from land use change, biogenic GHG emissions and removal, and aircraft emissions.

The five climate change impact categories are shown in Figure 13. Fossil GHG emissions account for the largest portion of the total climate impact, with 95.6% of total GHG emissions followed by biogenic carbon emissions of 4.37%. Land use change emissions together with aircraft emissions are reported negligible in contrast to the other emissions. Biogenic carbon removal is equal in magnitude to biogenic emissions. These percentages are based on the global energy mix, due to that mix being the most conservative for GWP. This is represented in Table 9. In Table 10 and Table 11 the two additional energy mixes are represented for each climate impact category.



← Figure 13

Results cradle-to-grave according to functional unit 1 vkm for the five climate impacts categories according to ISO 14067 with global energy mix in kg CO_2e.

← Table 9

Results according to functional unit 1 vkm for the five climate impacts categories according to ISO 14067 with global electricity mix in gCO_2e.

	Fossil GHG emissions g CO_2-eq.	Emissions from land use change (dLUC) g CO_2-eq.	Biogenic GHG removal g CO_2-eq.	Biogenic GHG emissions g CO_2-eq.	Air craft emissions g CO_2-eq.
Materials production and refining	72.2	0.03	-1.67	1.28	0.00
Li-ion battery modules	34.6	–	–	–	–
Manufacturing	0.36	0.05	-2.18	2.17	0.00
Logistics	12.0	–	–	–	–
Use phase	60.2	0.01	-5.03	5.05	0.00
Maintenance	7.86	0.00	-0.23	0.25	0.00
End-of-Life	6.15	0.01	-0.09	0.09	0.00
Total	193	0.09	-9.19	8.84	0.00

	Fossil GHG emissions g CO_2-eq.	Emissions from land use change (dLUC) g CO_2-eq.	Biogenic GHG removal g CO_2-eq.	Biogenic GHG emissions g CO_2-eq.	Air craft emissions g CO_2-eq.
Materials production and refining	72.2	0.03	-1.67	1.28	0.00
Li-ion battery modules	34.6	–	–	–	–
Manufacturing	0.36	0.05	-2.18	2.17	0.00
Logistics	12.0	–	–	–	–
Use phase	17.3	0.01	-10.9	10.9	0.00
Maintenance	7.86	0.00	-0.23	0.25	0.00
End-of-Life	6.15	0.01	-0.09	0.09	0.00
Total	151	0.09	-15.0	14.7	0.00

← Table 10

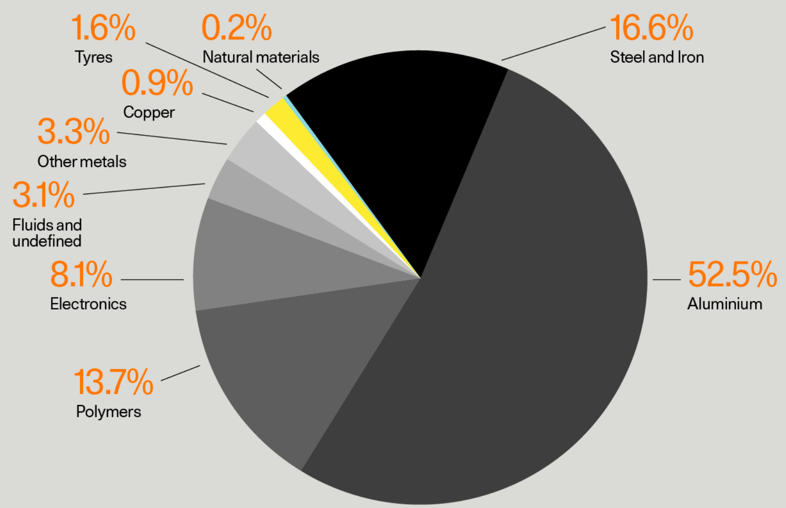
Results according to functional unit 1 vkm for the five climate impacts categories according to ISO 14067 with EU electricity mix in gCO_2e.

	Fossil GHG emissions g CO_2-eq.	Emissions from land use change (dLUC) g CO_2-eq.	Biogenic GHG removal g CO_2-eq.	Biogenic GHG emissions g CO_2-eq.	Air craft emissions g CO_2-eq.
Materials production and refining	72.2	0.03	-1.67	1.28	0.00
Li-ion battery modules	34.6	–	–	–	–
Manufacturing	0.36	0.05	-2.18	2.17	0.00
Logistics	12.0	–	–	–	–
Use phase	2.27	0.00	-0.16	0.16	0.00
Maintenance	7.86	0.00	-0.23	0.25	0.00
End-of-Life	6.15	0.01	-0.09	0.09	0.00
Total	136	0.09	-4.32	3.95	0.00

← Table 11

Results according to functional unit 1 vkm for the five climate impacts categories according to ISO 14067 with wind electricity in gCO_2e.

Share of GWP 100 results for different materials categories



← Figure 14

Share of GWP 100 results for different materials categories.

3.2.2 Climate impact materials production and refining

The primary contributors to GHG emissions within the category materials production and refining (excluding battery) are aluminium, accounting for 52% of the total climate impact, followed by steel and iron at 17%. Additionally, the climate impact from polymers 14% and electronics 8% used in the vehicle rank as the third and fourth most significant. Other categories such as fluids, copper, other metals, and tyres also contribute but to a lesser degree. Figure 14 displays the distribution of impacts per material category. Table 12 illustrate the results for GWP100 in tonnes CO_2e for the different materials used in the vehicle.

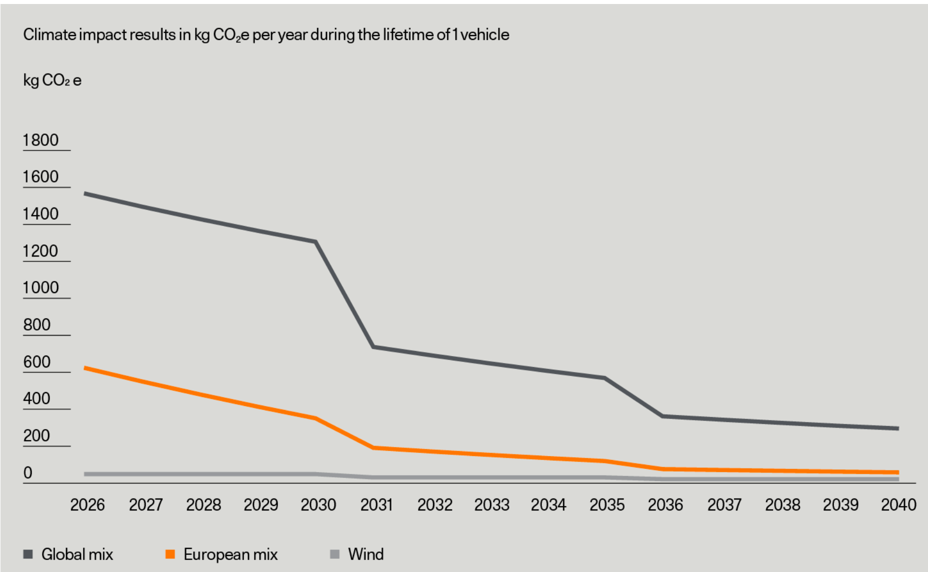
Table 12 →

GWP 100 results in tonnes CO_2e for different material categories.

Material category	Tonnes CO_2e per vehicle
Steel and Iron	2.39
Aluminium	7.55
Polymers	1.96
Electronics	1.16
Fluids and Undefined	0.45
Other Metals	0.47
Copper	0.13
Tyres	0.23
Natural Materials	0.03

3.2.3 Climate impact of battery

The results for the battery climate impact were provided by the supplier in a LCA report. The scope includes analysing processes from raw material extraction to the finalised product at the battery supplier gate. The impact categories focus on GWP over 100 years. Evaluation was based on two functional units: kWh capacity of battery cells, and modules, as explained in chapter 2.2. Data from primary processes managed by the reporting company are included, while specific data sources include manufacturing plants and contracted suppliers, energy used as electricity comes mainly from hydropower from purchase agreements, and thermal power generated from natural gas. Generic data was based on attributional modelling and represent the process's geographical region and extracted from LCI databases such as ecoinvent and Sphera. The results reveal that the primary sources of greenhouse gas emissions are production of the anode and cathode of the cell, along with the aluminium casing. Additionally, thermal energy from natural gas plays a significant role as a major contributor in the production process.



← Figure 15

Climate impact results in kg CO_2e per year during the lifetime of 1 vehicle and 200 000 km driving distance with different electricity mixes during use phase.

3.2.4 Climate impact of use phase

One of the stages in the vehicle's life cycle with the greatest emissions is the use phase, encompassing the vehicle's entire operational lifespan and the associated electricity usage. The climate impact within this category depends on the origin of electricity production. Notably, for the different scenarios in the use phase electricity sourced from wind power has the least environmental impact during the use phase, followed by the average EU electricity mix scenario.

Considering the anticipated changes in electricity production—specifically, the reduction in fossil fuel-based electricity and the concurrent increase in renewable electricity forecasted from 2024, it is expected that yearly emissions will decline. The distances driven are then multiplied by the emission factors corresponding to each year, reflecting the changes in global and European electricity. This process yields the graphical representation showcased in Figure 15. On average, the emissions throughout the entire lifespan amount to 0.34 kg CO_2e/kWh for the global electricity mix scenario and 0.10 kg CO_2e/kWh for the EU electricity mix scenario.

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

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

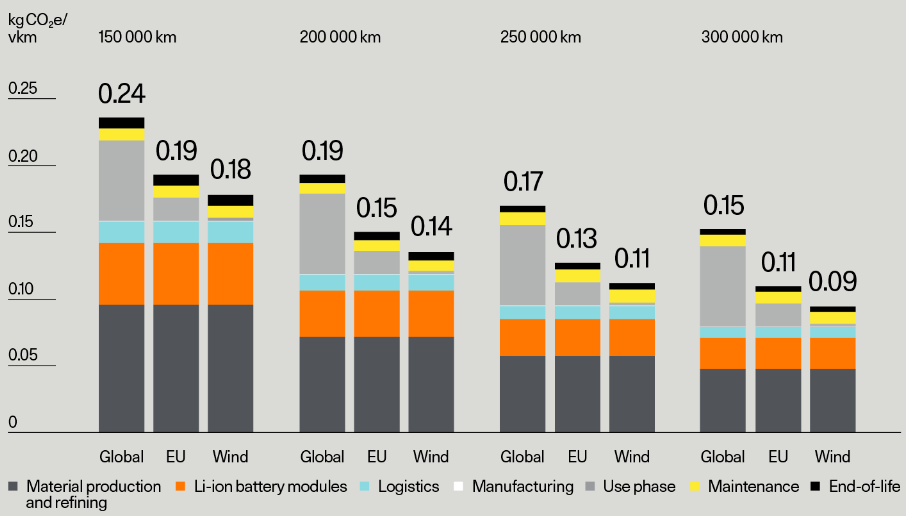
Electricity production is modelled according to three cases: regional (global and EU) grid mixes and a specific energy source (wind). Current and future global and EU electricity generation mixes are based on the World Energy Outlook 2024 Extended Dataset[13] from IEA. Amounts of electricity from different energy sources have in this study been paired with appropriate LCI datasets from Sphera Database (see Appendix 1) to determine the total climate impacts from different electricity generation mixes, both direct (at the site of electricity generation) and upstream.

3.2.5 Climate impact of maintenance

The result from the cradle-to-grave study shows that the expected maintenance of the vehicle contributes approximately 1.6 tonnes of CO_2e to the total climate impact of the Polestar 5. The replacement of tyres is the largest contributor at 5% followed by the break discs at 26%, the exchange of 12 V batteries at 9% and brake pads at 6%. The rest of the components together account for 9% of the total climate impact arising because of vehicle maintenance.

13 World Energy Outlook 2024 Extended Dataset - Data product - IEA

Sensitivity analysis lifetime driving distance per 1 vkm



← Figure 16

Sensitivity analysis lifetime driving distance per 1 vkm (functional unit) for driving distance 150 000 km, 200 000 km, 250 000 km and 300 000 km with different electricity mix scenarios.

Vehicle part	Unit	150 000 km	200 000 km	250 000 km	300 000 km
Wiper blades	number of sets	39	39	39	39
Tyres	number of items	12	16	24	28
Brake fluid	litres	2	2	2	2
Brake pads	number of items	16	24	32	40
Brake discs	number of items	4	4	8	8
Lead, battery 12 V	number of items	3	3	3	3
Steering joint	number of items	1	1	1	1
Link arm	number of items	2	2	2	2
Condenser	number of items	1	1	1	1
AC fluid	number of AC container volume	2	2	3	3
Cabin filter	number of items	9	12	15	18

← Table 13

Parts changed during maintenance for different driving distances of the vehicle.

3.3 Sensitivity analysis

Given the fact that the results from this study are dependent on data which may differ during real world usage of the vehicle, exploring the climate impact of the vehicle when varying certain key parameters is interesting. A sensitivity analysis was carried out to examine the climate impact of lifetime driving distance, the electricity source during the use phase as well as use phase electricity consumption.

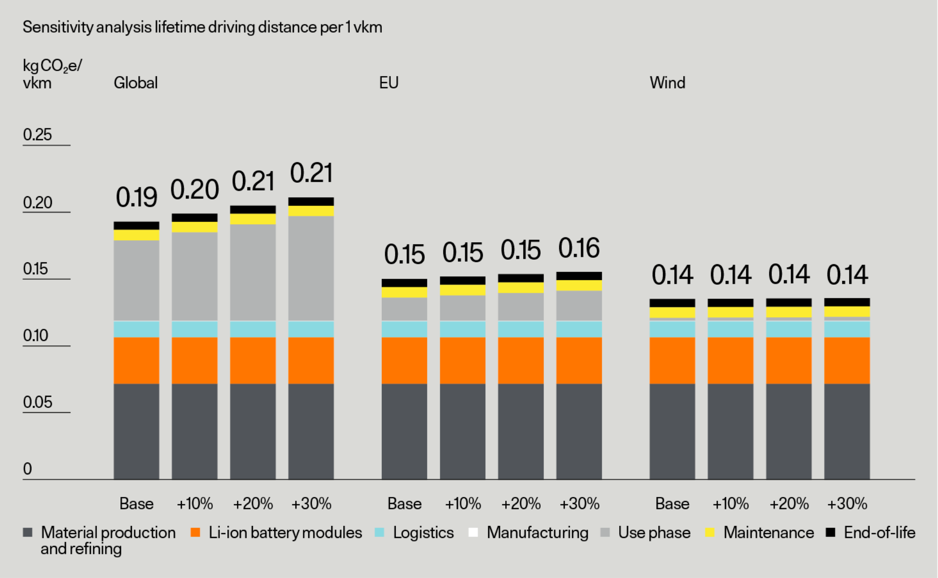
3.3.1 Lifetime driving distance

The current study assumes a lifetime distance driven of 200 000 km, as that is a common distance to use in personal vehicle LCA studies. Larger personal vehicles, such as SUVs, can be argued to have a longer lifetime distance driven[14]. the Polestar 5 is not an SUV but a premium grand tourer vehicle of similar road footprint and weight as an electric SUV. For that reason, a sensitivity analysis with 250 000 km and 300 000 km lifetime distances driven was carried out. And to explore the effects of a shorter lifetime distance driven, a sensitivity analysis of 150 000 km was also carried out. Figure 16 presents the results of the cradle-to-grave life cycle for the different driving distances together with different electricity scenarios.

3.3.2 Maintenance scenario

Lifetime affects maintenance of the vehicle and Table 13 describes the maintenance for lifetimes included in the sensitivity analysis above.

14 Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA - Publications Office of the EU



← Figure 17

Sensitivity analysis of electricity consumption in use phase per vkm (functional unit) for driving distance 200 000 km with different electricity mix scenarios and increases in baseline WLTP electricity consumption.

3.3.3 Use phase electricity consumption

Electricity consumption is calculated based on the WLTP standard. However, this method does not account for factors such as individual driving behavior, traffic conditions, weather conditions, road gradient, or vehicle load—each of which can significantly influence actual electricity use. To account for potential underestimations in certain markets, an evaluation of the impact of 10%, 20% and 30% increases in electricity consumption is included in this sensitivity analysis. These effects are reflected in the results given in Figure 17 and Table 14.

Electricity consumption scenario	Tonnes CO_2e per vehicle	Kg CO_2e per vehicle km
Global base	38.6	0.19
Global +10%	39.8	0.20
Global +20%	41.0	0.21
Global +30%	42.2	0.21
EU base	30.1	0.15
EU +10%	30.4	0.15
EU +20%	30.8	0.15
EU +30%	31.1	0.16
Wind base	27.0	0.14
Wind +10%	27.1	0.14
Wind +20%	27.1	0.14
Wind +30%	27.2	0.14

← Table 14

Sensitivity analysis of electricity consumption in use phase per 1 vehicle (functional unit) and per vkm (functional unit) for driving distance 200 000 km with different electricity mix scenarios and increases in baseline WLTP electricity consumption.

4

In conclusion the climate impact of the cradle-to-gate study reveals that 60% is caused by material production and refining of which aluminium represents 52% of the emissions, iron and steel contributing with 17% and polymers 14%. Following is the production of battery modules which emerge as a significant factor, constituting 29% of the cradle-to-gate impact. Logistics and manufacturing together contribute 11%.

The cradle-to-grave study reveals a total carbon footprint for the complete Polestar 5 life cycle of 38.6 tonnes CO_2e with global electricity mix in the use phase. 37% of the total climate impact is caused by the material production and refining (excluding battery modules). Following is the use phase (global electricity mix) contributing 31% of the vehicle's total climate impact, and then the battery modules, constituting 18% of the overall climate impact.

The study categorises the environmental impact into five climate change impact categories, as depicted in Figure 13. Fossil GHG emissions emerge as the predominant contributor, accounting for 95.6% of the total climate impact. Biogenic carbon emission contributes the second most with 4.37%, which is low in comparison to the fossil emission.

Due to the use phase contributing a large share of the emissions for the lifetime of the vehicle the emissions connected to the electricity production during this phase is of importance. One can see in Figure 12 that renewable electricity production such as wind power reduces the overall lifetime climate impact. The same goes for EU electricity mix and solar power (available in Appendix 7), however not contributing to the same extent. This is due to the larger share of electricity production stemming from renewable sources in the EU electricity mix, as seen in Figure 8.

When considering emissions linked to battery manufacturing, the emissions might appear relatively low. However, in cell manufacturing 100% renewable electricity is used. For the cathode, anode and copper foil production 100% renewable electricity will be implemented at the end of 2025. With electricity use in production being one of the major contributors to emissions in battery module production, this correlates to the presented result.

The results of the sensitivity analysis for three different driven lifetime km scenarios, 150 000 km, 250 000 km and 300 000 km, demonstrate that the longer distance driven by the vehicle over the lifetime the lower the emissions per vehicle km. This suggests that whilst total emissions will be higher, on a per-kilometre basis, the climate impact of the vehicle is lower when covering a longer lifetime distance (i.e. fewer vehicles are required to provide the same utility in terms of km driven). As transportation solutions with a lower climate impact is a necessity to reach globally set targets for climate neutrality, these results emphasize the potential benefits of optimizing vehicle usage over its entire lifespan for reduced climate impact.

The sensitivity analysis of increased electricity consumption in the use phase suggests that increased consumption has an impact on the per vehicle km climate impact, but not to a very high extent. The largest increase of climate impact per vehicle km is observed in the +30% global electricity mix scenario where the impact increased from 0.19 kg CO_2e / vkm in the baseline scenario to 0.21 kg CO_2e / vkm. On per vehicle km basis this may not seem as much but in absolute numbers this increase amounts to 3.6 tonnes CO_2e over the 200 000 km lifetime. The absolute figure of the increase for the +30% EU electricity and wind power electricity scenarios are 1.0 and 0.1 tonnes CO_2e, respectively. Thereby it can be concluded that driving behaviour, weather conditions and other factors which influence vehicle electricity consumption has an impact on the use phase climate impact.

The EU regulation[15] regarding batteries and waste batteries from 2023 outlines the importance for future end-of-life handling of lithium-ion batteries. The framework emphasizes various crucial elements such as recycled content, collection rates, and end-of-life considerations.

The regulation places a strong emphasis on harmonising product and marketing requirements across the life cycle of batteries. To enhance future reports, environmental implications associated with the disposal and recycling of batteries utilised in vehicles would be beneficial. This would give a more comprehensive picture of the impacts and challenges linked to the end-of-life management of batteries in the context of electric vehicles.

Environmental sustainability involves a multifaceted perspective. While the focus of the study has been on carbon emissions following ISO 14067, future assessments should also aim to broaden the scope by incorporating other significant environmental impact categories such as water consumption, resource depletion, and impact on biodiversity. Expanding the analysis will yield a more holistic evaluation of the vehicle's environmental performance, allowing the possibility to make more informed decisions about its overall sustainability. It could be also interesting to assess alternative future energy scenarios in addition to IEAs STEPS scenarios.

Material extraction and refining and Li-ion battery module production is identified as two hot spots, just as in previous Polestar carbon footprint reports. Further efforts in reducing the climate impact from these categories is needed to reduce the carbon footprint of battery electric vehicles and reach globally set targets for climate neutrality. As this is the part of the vehicle life cycle of which Polestar holds the most influence, these parts of the life cycle should remain the focus of decarbonization efforts.

15 REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENTAND OF THE COUNCIL of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC

A1

Appendix 1: Chosen datasets

In the LCA a large number of generic datasets from databases are used. In this appendix the datasets used are listed, see Table 15. Some materials are listed multiple times with different datasets. The reason is that the material carbon footprint is modelled based on a mix of the different datasets corresponding to the material composition.

Table 15 →

Chosen datasets for materials.

Material	Location	Dataset name	Type	Source
ABS	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.9.1
Aluminium	CN	aluminium ingot mix IAI 2019	agg	IAI/Sphera professional database
Aluminium, recycled	RNA	Aluminum, secondary, ingot, at plant USLCI – open energy inputs	p-agg	USLCI/Sphera professional database
Aramid	DE	aramide fiber (para-aramid)	agg	Sphera professional database
Brake fluid	GLO	market for diethylene glycol	agg	ecoinvent 3.9.1
Cast iron	DE	cast iron part (automotive) - open energy inputs	p-agg	Sphera professional database
Catalytic coating	ZA	market for platinum group metal concentrate	agg	ecoinvent 3.9.1
Copper	EU-28	copper Wire Mix (Europe 2015)	agg	DKI/ECI
Copper alloys	GLO	copper mix (99.999% from electrolysis) (65%)	agg	Sphera professional database
Copper alloys	GLO	market for zinc (35%)	agg	ecoinvent 3.9.1
Cotton	GLO	market for textile, woven cotton	agg	ecoinvent 3.9.1
Damper	RER	Polymethylmethacrylate sheet (PMMA) (60%)	agg	PlasticsEurope
Damper	RoW	market for lime (40%)	agg	ecoinvent 3.9.1
E/P	GLO	polyethylene production, low density, granulate	agg	ecoinvent 3.9.1
Electronics	GLO	market for printed wiring board, surface mounted, unspecified, Pb containing	agg	ecoinvent 3.9.1
EPDM	DE	ethylene Propylene Diene Elastomer (EPDM)	agg	Sphera professional database
Epoxy	GLO	market for epoxy resin, liquid	agg	ecoinvent 3.9.1
EVAC	GLO	market for ethylene vinyl acetate copolymer	agg	ecoinvent 3.9.1
Ferrite magnet	GLO	market for ferrite	agg	ecoinvent 3.9.1
Float glass	EU-28	float flat glass	agg	Sphera professional database

Material	Location	Dataset name	Type	Source
Friction	DE	cast iron part (automotive) - open energy inputs (48%)	agg	Sphera professional database
Friction	GLO	market for zirconium oxide (12%)	agg	ecoinvent 3.9.1
Friction	GLO	market for graphite (11%)	agg	ecoinvent 3.9.1
Friction	GLO	market for barium sulfide (10%)	agg	ecoinvent 3.9.1
Friction	GLO	market for barite (7%)	agg	ecoinvent 3.9.1
Friction	GLO	market for aluminium hydroxide (5%)	agg	ecoinvent 3.9.1
Friction	GLO	market for magnesium oxide (4%)	agg	ecoinvent 3.9.1
Friction	GLO	market for expanded vermiculite (2%)	agg	ecoinvent 3.9.1
Friction	EU-28	calcined petroleum (2%)	agg	Sphera professional database
GF-fibre	GLO	market for glass fibre	agg	ecoinvent 3.9.1
Glycol	EU-28	ethylene glycol	agg	PlasticsEurope
Lead, battery	DE	lead (99.995%)	agg	Sphera professional database
Leather	CN	Polestar Chromium-free leather	agg	Bridge of Weir
Lubricants	EU-28	lubricants at refinery	agg	Sphera professional database
Magnesium	CN	magnesium	agg	Sphera professional database
NdFeB	GLO	market for permanent magnet, electric passenger car motor	agg	ecoinvent 3.9.1
NR	DE	natural rubber (NR)	agg	Sphera professional database
PA	GLO	market for nylon 6	agg	ecoinvent 3.9.1
PBT	DE	polybutylene Terephthalate Granulate (PBT) Mix	agg	Sphera professional database
PC	GLO	market for polycarbonate	agg	ecoinvent 3.9.1
PE	RoW	polyethylene production, low density, granulate	agg	ecoinvent 3.9.1
PET	GLO	market for polyethylene terephthalate, granulate, amorphous	agg	ecoinvent 3.9.1
PMMA	RER	polymethylmethacrylate sheet (PMMA)	agg	PlasticsEurope
Polymer, recycled	EU-28	Plastic granulate secondary (low metal contamination)	agg	Sphera professional database

Material	Location	Dataset name	Type	Source
Polyester	GLO	market for fibre, polyester	agg	ecoinvent 3.9.1
Polyurethane	RoW	market for polyurethane, rigid foam	agg	ecoinvent 3.9.1
POM	EU-28	polyoxymethylene (POM)	agg	PlasticsEurope
PP	GLO	market for polypropylene, granulate	agg	ecoinvent 3.9.1
PS	GLO	market for polystyrene, general purpose	agg	ecoinvent 3.9.1
PVB	DE	polyvinyl butyral granulate (PVB) by-product ethyl acetate	agg	Sphera professional database
PVC	GLO	polyvinylchloride production, suspension polymerisation	agg	ecoinvent 3.9.1
R-1234yf	DE	R-1234yf production (approximation)	agg	Sphera professional database
SBR	DE	styrene-butadiene rubber (S-SBR) mix	agg	Sphera professional database
Silicone rubber	DE	silicone rubber (RTV-2, condensation)	agg	Sphera professional database
Steel, Sintered	Asia	steel hot dip galvanised (1%)	agg	Worldsteel
Steel, Stainless, Austenitic	EU-28	stainless steel cold rolled coil (304)	p-agg	Eurofer
Steel, Stainless, Ferritic	EU-28	stainless steel cold rolled coil (430)	p-agg	Eurofer
Steel, Unalloyed	Asia	steel hot dip galvanised (99%)	agg	Worldsteel
Sulphuric acid	EU-28	sulphuric acid (96%)	agg	Sphera professional database
Thermoplastic elastomers	DE	polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix	agg	Sphera professional database
Thermoplastics	GLO	market for nylon 6	agg	ecoinvent 3.9.1
Tyre	DE	styrene-butadiene rubber (S-SBR) mix (21%)	agg	Sphera professional database
Tyre	EU-28	water (deionised) (79%)	agg	Sphera professional database
Undefined	GLO	market for nylon 6	agg	ecoinvent 3.9.1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)	agg	Sphera professional database
Wood (paper, cellulose ...)	EU-28	Laminated veneer lumber (EN15804 A1-A3)	agg	Sphera professional database
Zinc	GLO	Special high-grade zinc	p-agg	IZA

Process	Location	Name	Type[16]	Source
Aluminium manufacturing	DE	aluminium die-cast part	u-so	ts
aluminium die-cast part	u-so	ts	p-agg	ts
Aluminium manufacturing	EU-28	aluminium sheet – open input aluminium rolling ingot	p-agg	ts
Aluminium manufacturing	DE	aluminium sheet deep drawing	u-so	ts
Aluminium manufacturing	RNA	Extrusion of aluminum billet, AEC	p-agg	ts
Polymers (all categories) manufacturing	DE	Plastic injection moulding part (unspecific)	u-so	ts
Stainless (all categories) manufacturing	DE	Steel sheet deep drawing (multi-level)	u-so	ts
Tyre	GLO	vulcanisation of synthetic rubber (without additives)	u-so	Sphera professional database

Electricity	Location	Name	Year	Type	Source
Chinese electricity grid mix	CN	Electricity grid mix 1kV-60kV	2020	agg	Sphera professional database
Renewable electricity mix for aluminium parts "Recycled aluminium produced using renewable electricity"	GLO	Green electricity grid mix (production mix)	2020	agg	Sphera professional database
Thermal energy from natural gas	CN	CN Thermal energy from natural gas	2020	agg	Sphera professional database
Natural gas	CN	CN Natural gas mix	2020	agg	Sphera professional database

Electricity	Location	Name of LCI dataset	Year	Type	Share	Source
Electricity from hydro power	CN	Electricity from hydro power	2020	agg	43%	Sphera professional database
Electricity from wind power	CN	Electricity from wind power	2020	agg	30%	Sphera professional database
Electricity from photovoltaic	CN	Electricity from photovoltaic	2020	agg	20%	Sphera professional database
Electricity from biomass	CN	Electricity from biomass	2020	agg	7%	Sphera professional database

← Table 16

Chosen datasets for material manufacturing processes.

↓ Table 19

Chosen data sets for electricity for use phase.

Material category Use phase	Location	Name of LCI dataset	Year	Type	LCI database
Electricity from solar power	RER	Electricity from photovoltaic	2020	agg	Sphera professional database
Electricity from wind power	RER	Electricity from wind power	2020	agg	Sphera professional database
Electricity from geothermal	RER	Electricity from geothermal	2020	agg	Sphera professional database
Electricity from hydro power	RER	Electricity from hydro power	2020	agg	Sphera professional database
Electricity from bioenergy	RER	Electricity from biomass (solid)	2020	agg	Sphera professional database
Electricity from nuclear power	RER	Electricity from nuclear	2020	agg	Sphera professional database
Electricity from unabated coal	RER	Electricity from lignite	2020	agg	Sphera professional database
Electricity from unabated gas	RER	Electricity from natural gas	2020	agg	Sphera professional database
Electricity from oil	RER	Electricity from heavy fuel oil (HFO)	2020	agg	Sphera professional database

← Table 17

Chosen datasets for energy and electricity for material manufacturing processes.

← Table 18

Chosen datasets for electricity used in vehicle manufacturing at Geely Chongqing plant.

16 U-so datasets have been adapted to use the "Chinese electricity grid mix", "Thermal energy from natural gas" and "Natural gas" from Table 17.

A2

Appendix 2: Complete list of IMDS Material Library Material

Table 20 →

IMDS Material Library material categories.

Material name	Material group
Steel, sintered	Steel and iron
Steel, unalloyed	Steel and iron
Steel, stainless, austenitic	Steel and iron
Steel, stainless, ferritic	Steel and iron
Cast iron	Steel and iron
Aluminium	Aluminium
Low carbon aluminium	Aluminium
Recycled aluminium	Aluminium
Recycled aluminium produced with renewable electricity	Aluminium
Copper alloys	Copper
Magnesium	Other Metals
Zinc	Other Metals
NdFeB	Other Metals
ABS (filled)	Polymers
ASA (filled)	Polymers
E/P (filled)	Polymers
EVAC (filled)	Polymers
PA (filled)	Polymers
PBT (filled)	Polymers
PC (filled)	Polymers
PC+ABS (filled)	Polymers
PE (filled)	Polymers
PET (filled)	Polymers
PMMA (filled)	Polymers
POM (filled)	Polymers

Material name	Material group
PP (filled)	Polymers
PVB (filled)	Polymers
PVC (filled)	Polymers
ABS (unfilled)	Polymers
ASA (unfilled)	Polymers
E/P (unfilled)	Polymers
EVAC (unfilled)	Polymers
PA (unfilled)	Polymers
PBT (unfilled)	Polymers
PC (unfilled)	Polymers
PC+ABS (unfilled)	Polymers
PE (unfilled)	Polymers
PET (unfilled)	Polymers
PMMA (unfilled)	Polymers
POM (unfilled)	Polymers
PP (unfilled)	Polymers
PVB (unfilled)	Polymers
PVC (unfilled)	Polymers
Thermoplastics	Polymers
Thermoplastic elastomers	Polymers
Elastomer	Polymers
EPDM	Polymers
NR	Polymers
SBR	Polymers
Silicone rubber	Polymers

Material name	Material group
Epoxy	Polymers
Polyurethane	Polymers
Damper	Polymers
Polyester	Polymers
Aramid	Polymers
Tyre	Tyres
Lubricants (matcat)	Fluids & Undefined
Brake fluid	Fluids & Undefined
Catalytic coating	Fluids & Undefined
Ceramic	Fluids & Undefined
Damper	Fluids & Undefined
Ferrite magnet	Fluids & Undefined
Float glass	Fluids & Undefined
Friction	Fluids & Undefined
GF-Fibre	Fluids & Undefined
Glycol	Fluids & Undefined
Lead, battery	Fluids & Undefined
Sulphuric acid	Fluids & Undefined
Cotton	Natural Materials
Wood (paper, cellulose ...)	Natural Materials
Washer fluid	Fluids & Undefined
Undefined	Fluids & Undefined
R-1234yf	Fluids & Undefined
NR	Natural Materials
Leather	Natural Materials

A3

Appendix 3: Summary of data choices and assumptions for component manufacturing

Table 21 →

Summary of data choices and assumptions for component manufacturing.

Material	Assumption on component manufacturing	Comment	Material utilisation rate in additional component manufacturing
Cast iron	No extra manufacturing processes	The chosen dataset already includes the production of a finished part to be used in automotive applications.	
Fluids	No extra manufacturing processes	Assumed that fluids do not need further refining after production of the raw material (the fluid itself).	
Tyres	No extra manufacturing processes	Assumed that the processes after vulcanisation only has minor GHG-emissions	
Copper (wire)	No extra manufacturing processes	Assumed that processing after manufacturing into copper wire has negligible emissions and waste.	
NdFeB magnets	No extra manufacturing processes	The chosen dataset already includes the production of a finished magnet to be used in electric motors for automotive applications	
Electronics (PCBs)	No extra manufacturing processes	The chosen dataset already includes the production of a finished printed circuit board.	
Cast Aluminium	Die-casting process	Assumed to represent different types of casting processes. MUD according to dataset	96%
Pressing Aluminium	Rolling and Aluminium sheet deep drawing	Assumed to represent different types of pressing processes. MUD according to dataset	62%
Extrusion Aluminium	Extrusion process	Assumed to represent different types of extrusion processes. MUD according to article "Reducing the environmental impacts of aluminum extrusion"[17]	82%
Steel (in parts, processed at suppliers)	Steel sheet deep drawing	Sheet is assumed to adhere to the conservative approach.	63%
Stainless steel	Steel sheet deep drawing	Sheet is assumed to adhere to the conservative approach	63%
Polymers	Injection moulding process	Assumed to represent different types of processes	98%
Other materials	Raw material weight x2	Emissions from raw material production has been multiplied by two, to compensate for further refining and processing.	50%

17 Reducing the environmental impacts of aluminum extrusion - ScienceDirect

A4

Transport
Transportation of materials sent to material recycling is included and is conservatively assumed to be transported 100 km by truck.

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

Pre-treatment
Pre-treatment was included for the following disassembled components:

- Lead acid battery
- Tyres
- Li-ion batteries

For the lead acid batteries and tyres, ecoinvent datasets were used for the pre-treatment stage. The Li-ion battery is conservatively assumed to be transported 1 500 km by truck to the recycling facility according to Polestar logistics specialist. For the remaining disassembled parts, no inventory was made since their disassembly is mainly done as a safety precaution. After this stage, they will be handled similarly to the rest of the vehicle. The fluids that are incinerated likewise do not go through any pre-treatment.

Shredding
In the shredding process, the vehicles are milled to smaller fractions. This process uses electricity. To estimate the amount of energy needed, the energy usage per kg in the dataset "treatment of used glider", passenger car, shredding from ecoinvent 3.9.1 was used. The electricity used for this process was modelled as a 2039 global electricity mix, based on the IEA STEPS scenario and Sphera professional database data. Emissions of metals to water and air have been omitted due to the focus on climate change. 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
This is the fate of the flows of metals from the shredding, as well as for the materials in the pretreated components. Based on the choice of cut-off approach for end-of-life modelling, this stage is outside the boundaries of the life cycle and is not included in the inventory, except for the transportation to material recycling, as mentioned above.

Final disposal – incineration and landfill
The disassembled fluids as well as the combustible part of the shredder light fraction, are modelled to be incinerated without energy recovery. The choice to not include energy recovery relates to the global scope of the study.

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

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

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

← Table 22

Data collection activities.

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

Transportation of materials which are separated in the shredding processes, and which are assumed to be recycled is conservatively estimated to be 100 km by truck.

Data collection

This section provides an overview of the data collection activities relating to each life cycle stage, see Table 22. According to the cut-off methodology, the processes presented below are included in the data collection effort.

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

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← Table 23

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

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

For the temporal and geographical correlation, the scores vary widely. The datasets from ecoinvent are often more than 10 years old, while Sphera professional database datasets tend to be less than three years old. The most important reason why the geographical correlation varies widely is that the origin of many materials is unknown. The origin of the materials that are used in the largest quantity and with the largest overall climate impact, however, score 1-2 on geographical coverage: aluminium, steel and battery modules. Another material group with high climate impact is electronics. Electronics scores poorly on both geographical and technological correlation, which should be considered when interpreting the results. Overall, technological correlation also has a large variation in scores, however, most of the data has 2 as score. Representativeness and precision have good scores, as the data is from databases or supplier specific.

Car manufacturing and logistics receive overall good scores as the data is collected from partner production facilities and controlled or overseed processes. The use phase also scores well, as electricity usage data is based on vehicle specific measurements, and climate impact calculations are based on fairly new emission factors from the Sphera professional database (2020) and current and forecasted electricity mix data from IEA (2024). The End-of-Life treatment receives fewer good scores as data from the current state is used, and it is highly uncertain how well it correlates to the conditions in 15 years. It is also highly uncertain how the waste handling will be (and in some cases currently is) performed in different markets.

Based on the comprehensive assessment of data quality, it is indicated that the data quality requirements outlined in section 1.7 are met.

← Table 24

Quality assessment of data used for materials and processes in the study.

					Correlation score				
Material/process	Location	Dataset name	Year	Source	Temporal	Geographical	Technological	Representative	Precision
ABS	GLO	market for acrylonitrile-butadiene-styrene copolymer	2022	ecoinvent 3.9.1	1	4	2	1	1
Aluminium	CN	aluminium ingot mix IAI 2019	2019	IAI/Sphera professional database	2	1	2	1	1
Aluminium from hydropower	CN	Low carbon aluminium	2022	Polestar's own investigations	1	1	1	1	2
Aluminium, recycled	RNA	RNA: Aluminum, secondary, ingot, at plant USLCI – open energy inputs	2003	Sphera professional database / USLC	5	5	2	1	1
Aramid	DE	aramide fiber (para aramid)	2021	Sphera professional database	2	5	2	1	1
Battery modules	CN	Polestar 5 battery modules	2025	Battery module supplier	1	1	1	1	2
Brake fluid	GLO	market for diethylene glycol	2023	Ecoinvent 3.9.1	1	4	2	1	1
Cast iron	DE	cast iron part (automotive) - open energy inputs	2023	Sphera professional database	1	5	2	1	1
Catalytic coating	ZA	market for platinum group metal concentrate	2015	ecoinvent 3.9.1	3	5	2	1	1
Copper	EU-28	copper Wire Mix (Europe 2015)	2015	DKI/ECI	3	5	3	1	1
Copper alloys	GLO	copper mix (99.999% from electrolysis)	2023	Sphera professional database	1	4	2	1	1
Copper alloys	GLO	market for zinc	2011	ecoinvent 3.9.1	4	4	2	1	1
Copper alloys	GLO	tin	2021	Sphera professional database	2	4	2	1	1
Cotton	GLO	market for textile, woven cotton	2011	ecoinvent 3.9.1	4	4	2	1	1
Damper	RER	Polymethylmeth-acrylate sheet (PMMA)	2010	PlasticsEurope	4	5	2	1	1
Damper	RoW	market for lime	2011	Ecoinvent 3.9.1	5	5	2	1	1
E/P	GLO	polyethylene production, low density, granulate	2011-2016	ecoinvent 3.9.1	3	4	3	1	1
Electronics	GLO	market for printed wiring board, surface mounted, unspecified, Pb containing	2023	Ecoinvent 3.9.1	1	4	3	1	1
EPDM	DE	ethylene Propylene Diene Elastomer (EPDM)	2023	Sphera professional database	1	5	2	1	1
Epoxy	GLO	market for epoxy resin, liquid	2011	ecoinvent 3.9.1	4	4	2	1	1
EVAC	GLO	market for ethylene vinyl acetate copolymer	2011	Ecoinvent 3.9.1	4	4	2	1	1
Ferrite magnet	GLO	market for ferrite	2011	ecoinvent 3.9.1	4	4	3	1	1
Float glass	EU-28	float flat glass	2023	Sphera professional database	3	5	2	1	1
Friction	DE	cast iron part (automotive) - open energy inputs	2023	Sphera professional database	1	5	4	1	1
Friction	GLO	market for zirconium oxide	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	market for graphite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	market for barium sulfide	2015-2020	ecoinvent 3.9.1	2	4	4	1	1
Friction	GLO	market for barite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	market for aluminium hydroxide	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	market for magnesium oxide	2011	Ecoinvent 3.9.1	4	4	4	1	1
Friction	GLO	market for expanded vermiculite	2011	ecoinvent 3.9.1	4	4	4	1	1
Friction	EU-28	calcined petroleum	2021	Sphera professional database	2	5	4	1	1

Material/process	Location	Dataset name	Year	Source	Correlation score: Temporal	Geographical	Technological	Representative	Precision
GF-fibre	GLO	market for glass fibre	2011	ecoinvent 3.9.1	4	4	2	1	1
Glycol	RER	ethylene glycol	2008	PlasticsEurope	4	5	2	1	1
Lead, battery	DE	lead (99.995%)	2023	Sphera professional database	1	5	2	1	1
Leather	CN	Polestar chromium-free leather	2022	Bridge of Weir	1	1	1	1	2
Lubricants	EU-28	lubricants at refinery	2018	Sphera Professional database	3	5	2	1	1
Magnesium	CN	magnesium	2023	Sphera Professional database	1	5	2	1	1
NdFeB	GLO	market for permanent magnet, electric passenger car motor	2022	Ecoinvent 3.9.1	1	4	2	1	1
NR	DE	natural rubber (NR)	2023	Sphera professional database	1	5	2	1	1
PA	RoW	Market for nylon 6	2011	ecoinvent 3.9.1	4	4	2	1	1
PBT	DE	Polybutylene Terephthalate Granulate (PBT) Mix	2023	Sphera professional database	1	5	2	1	1
PC	GLO	Market for polycarbonate	2011	ecoinvent 3.9.1	4	4	2	1	1
PE	RoW	Polyethylene production, low density, granulate	2011-2022	ecoinvent 3.9.1	3	5	2	1	1
PET	GLO	Market for polyethylene terephthalate, granulate, amorphous	2011-2022	Ecoinvent 3.9.1	4	4	2	1	1
PMMA	RER	Polymethylmeth-acrylate sheet (PMMA)	2005	PlasticsEurope	5	5	2	1	1
Polymer, recycled	EU-28	Plastic granulate secondary (low metal contamination)	2023	Sphera Professional database	1	5	3	1	1
Polyester	GLO	market for fibre, polyester	2022	Ecoinvent 3.9.1	2	4	2	1	1
Polyurethane	RoW	market for polyurethane, rigid foam	2011	Ecoinvent 3.9.1	4	5	2	1	1
POM	EU-28	polyoxymethylene (POM)	2010	PlasticsEurope	4	5	2	1	1
PP	GLO	Market for polypropylene, granulate	2022	ecoinvent 3.9.1	1	4	2	1	1
PS	GLO	market for polystyrene, general purpose	2011	Ecoinvent 3.9.1	4	4	2	1	1
PVB	DE	polyvinyl butyral granulate (PVB) by-product ethyl acetate	2022	Sphera Professional database	1	5	2	1	1
PVC	GLO	polyvinylchloride production, suspension polymerisation	2013-2018	Ecoinvent 3.9.1	3	4	2	1	1
R-1234yf	DE	R-1234yf production (approximation)	2021	Sphera Professional database	2	5	3	1	1
SBR	DE	styrene-butadiene rubber (S-SBR) mix	2023	Sphera Professional database	1	5	2	1	1
Silicone rubber	DE	silicone rubber (RTV-2, condensation)	2023	Sphera Professional database	1	5	2	1	1
Steel, Sintered	Asia	steel hot dip galvanised	2022	Worldsteel	1	2	3	1	1
Steel, Stainless, Austenitic	EU-28	stainless steel cold rolled coil (304)	2014	Eurofer	3	5	2	1	1
Steel, Stainless, Ferritic	EU-28	stainless steel cold rolled coil (430)	2014	Eurofer	3	5	2	1	1
Sulphuric acid	EU-28	sulphuric acid (96%)	2023	Sphera professional database	1	5	2	1	1
Sulphuric acid	EU-28	sulphuric acid (96%)	2023	Sphera professional database	1	5	2	1	1

Material/process	Location	Dataset name	Year	Source	Correlation score: Temporal	Geographical	Technological	Representative	Precision
Thermoplastic elastomers	DE	polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/ EPDM, TPE-O) Mix	2023	Sphera Professional database	1	5	3	1	1
Thermoplastics	GLO	market for nylon 6	2022	Ecoinvent 3.9.1	1	4	3	1	1
Tyre	DE	styrene-butadiene rubber (S-SBR) mix	2021	Sphera professional database	2	5	2	1	1
Tyre	EU-28	water (deionised)	2021	Sphera professional database	2	5	2	1	1
Tyre	GLO	vulcanisation of synthetic rubber (without additives)	2021	Sphera professional database	2	4	2	1	1
Undefined	RoW	market for nylon 6	2022	ecoinvent 3.9.1	1	4	5	1	1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)	2021	Sphera professional database	2	5	3	1	1
Wood (paper, cellulose ...)	EU-28	Laminated veneer lumber (EN15804 A1-A3)	2023	Sphera Professional database	1	5	3	1	1
Zinc	GLO	Special high grade zinc	2022	IZA	1	4	3	1	1
Aluminium manufacturing	DE	aluminium die-cast part	2023	ts	1	5	3	1	1
Aluminium manufacturing	EU-28	aluminium sheet – open input aluminium rolling ingot	2023	ts	1	5	3	1	1
Aluminium manufacturing	DE	aluminium sheet deep drawing	2021	ts	2	5	3	1	1
Aluminium manufacturing	RNA	Extrusion of aluminum billet, AEC	2015	ts	4	5	3	1	1
Polymers (all categories) manufacturing	DE	Plastic injection moulding part (unspecific)	2021	ts	2	5	2	1	1
Steel (all categories) manufacturing	DE	Steel sheet deep drawing (multi-level)	2021	ts	2	5	3	1	1

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

↑ Table 25

Summarised quality assessment of data used in the study (based on matrix in table).

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Table 26 →

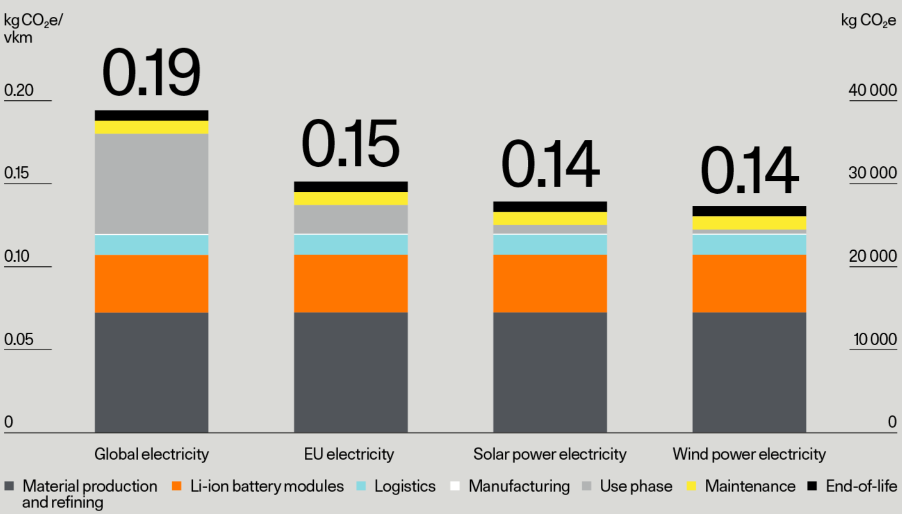
Characterisation factors according to IPCC Intergovernmental Panel on Climate Change by the United Nations[18].

Species	GWP-100	Unit
Carbon dioxide	1	CO_2-eq
Nitrous oxide (laughing gas)	273	CO_2-eq
R 116 (hexafluoroethane)	12400	CO_2-eq
Tetrafluoromethane	7380	CO_2-eq
Sulphur hexafluoride	25200	CO_2-eq
Methane	29	CO_2-eq
Carbon dioxide, fossil	1	CO_2-eq
R 23 (trifluoromethane)	14600	CO_2-eq
R 113 (trichlorotrifluoroethane)	6520	CO_2-eq
Carbon tetrachloride (tetrachloromethane)	2200	CO_2-eq
R 22 (chlorodifluoromethane)	1960	CO_2-eq
R 12 (dichlorodifluoromethane)	11200	CO_2-eq
R 134a (tetrafluoroethane)	1530	CO_2-eq
Ethane	0,437	CO_2-eq
Halon (1301)	7200	CO_2-eq
R 152a (difluoroethane)	164	CO_2-eq
R 124 (chlorotetrafluoroethane)	597	CO_2-eq
Trichloromethane (chloroform)	20,6	CO_2-eq
Dichloromethane (methylene chloride)	11,2	CO_2-eq
R 11 (trichlorofluoromethane)	5560	CO_2-eq
Propane	0,02	CO_2-eq
Methyl bromide	2,43	CO_2-eq
Dichloroethane (ethylene dichloride)	1,3	CO_2-eq
R 245fa (1,1,1,3,3-Pentafluoropropane)	962	CO_2-eq

18 https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf

Species	GWP-100	Unit
Halon (1211)	1930	CO_2-eq
1,1,1-Trichloroethane	161	CO_2-eq
R 125 (pentafluoroethane)	3740	CO_2-eq
Butane (n-butane)	0,006	CO_2-eq
Nitrogentriflouride	17400	CO_2-eq
R 21 (Dichlorofluoromethane)	160	CO_2-eq
R 141b (dichloro-1-fluoroethane)	860	CO_2-eq
R 143 (trifluoroethane)	364	CO_2-eq
Ethyl chloride	0,481	CO_2-eq
R 32 (difluoromethane)	771	CO_2-eq
R E245fa2 (2-(Difluoromethoxy)-1,1,1-trifluoroethane)	878	CO_2-eq
Trichloroethene (isomers)	0,044	CO_2-eq
R 142b (chlorodifluoroethane)	2300	CO_2-eq
Tetrachloroethene (perchloroethylene)	6,34	CO_2-eq
Chloromethane (methyl chloride)	5,54	CO_2-eq
Perfluoropentane	9220	CO_2-eq
Bromoform	0,25	CO_2-eq
1,2-Dibromoethane	1,02	CO_2-eq
R 143a (trifluoroethane)	5810	CO_2-eq

Cradle-to-grave climate impact per use phase electricity mix scenario, including solar power in in GWP100



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← Figure 18

Cradle-to-grave climate impact per use phase electricity mix scenario, including solar power in in GWP100.

The increasing adoption of solar power around the world justifies an additional specific electricity source to be examined. However, just as wind power, the climate impact per produced kWh of electricity from solar systems depend on weather conditions. A solar panel installed in a region with many annual hours of sunlight will generate more electricity over its lifetime than one installed in a region with fewer hours of sunlight. Thus, the climate impact associated with the production and installation of the system will be distributed across a higher electricity output (kWh) in regions with greater solar exposure compared to regions with lower solar exposure. Several other factors can also influence the average climate impact per kWh. In this study, the dataset 'RER: Electricity from photovoltaic' from the Sphera professional database has been used, which represents the average climate impact of producing and delivering 1 kWh of solar power in Europe. Consequently, it does not aim to represent a typical rooftop solar installation but rather the European average of solar power installations.

Table 27 →

Cradle-to-grave climate impact per use phase electricity mix scenario, including solar power in GWP100.

Electricity mix	Tonnes CO_2e per vehicle	Kg CO_2e per vehicle km
Global	38.6	0.19
EU	30.1	0.15
Solar Power	27.7	0.14
Wind power	27.0	0.14

Figure 18 and Table 27 display that the carbon footprint per vehicle kilometre are comparable. However, in absolute numbers (over the 200 000 km lifetime driving distance) the solar power electricity scenario in the use phase is 0.7 tonnes CO_2e higher than the wind power electricity scenario. Even though there is a slight increase, solar power proves to be a good alternative to the EU and global average electricity mix to reduce the climate impact from the use phase of the Polestar 5.

POLESTAR 5 LCA - INDEPENDENT CRITICAL REVIEW STATEMENT

Ricardo confirms that a critical review was performed of the following carbon footprint study of the Polestar 5.

Table 1: Details of Carbon Footprint Study

Aspect	Details
Title of study	Critical review of the carbon footprint assessment prepared by Polestar to calculate the potential carbon footprint of the new battery electric vehicle (BEV) Polestar 5.
Standard the study was conducted to	Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification (ISO 14067:2018)
Commissioner of the LCA study	Polestar
Practitioner of the LCA study	Polestar
Version of report to which the critical review belongs	Version 1.0 / 26th August 2025
Assurance type	Third party assurance via critical review panel based on UNI CEN ISO/TS 14071:2016 (ref. par. 4.2). Additional requirements and guideline to ISO 14044:2006), verifying the conformity of the carbon footprint study with the requirement of ISO 14067:2018 All reviewers are employed by Ricardo-AEA Ltd and are independent of the CFP study.
Critical review date	July 2025 to August 2025

The review panel included:

Nikolas Hill – Nikolas is a Technical Director and the Head of Vehicle Technologies and Fuels in Ricardo's Sustainable Transport team of the Policy, Strategy and Economics (PSE) practice area. Nik has over 25 years experience, in environmental analysis and is the lead on vehicle LCA for the sustainable transport team.

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

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

1.1 CONCLUSIONS

The independent critical review process focused on the Carbon Footprint assessment of the Polestar 5 vehicle. it is considered that the critically reviewed CFP study, as documented:

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

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

1.2 DISCLAIMER

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