Life cycle assessment

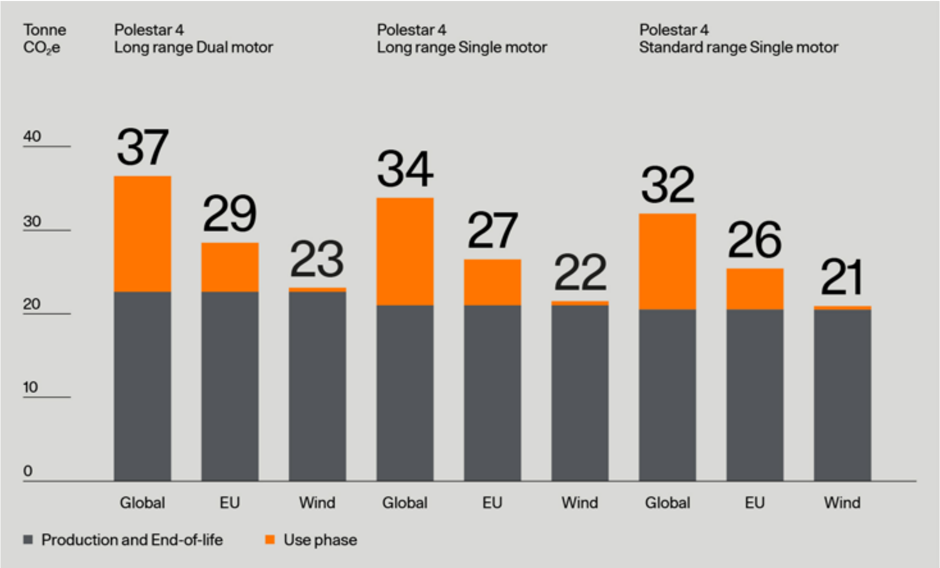
Carbon footprint of Polestar 4

Long range Dual motor
Long range Single motor
Standard range Single motor

Disclaimer

This report is for information only and (1) is based solely on an analysis of Polestar 4 (model year 24 and model year 25) “Long range Dual motor”, “Long range Single motor”, and “Standard range Single motor”, 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.

Content



← Figure 1

Carbon footprint for Polestar 4 variants, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit (200,000 km lifetime range)

The carbon footprint presented in this report is based on a Life Cycle Assessment (LCA), performed according to ISO LCA standards[1]. In addition, the "Product Life Cycle Accounting and Reporting Standard"[2] published by the Greenhouse Gas Protocol has been used for guidance in methodological choices. Given the great number of variables and possible methodological choices in LCA studies, these standards generally provide few strict requirements to be followed. Instead, they mostly provide guidelines for the practitioner. For this reason, care should be taken when comparing our results with results from other vehicle manufacturers' carbon footprints. In general, assumptions have been made in a conservative way, in order not to underestimate the impact from unknown data.

LCA is continuously used for assessing the carbon footprint of Polestar's cars. Major work has been put in to building the methodology, and it is continuously being developed. The assessment presented in this report was carried out by IVL Swedish Environmental Research Institute.

The carbon footprint includes emissions from upstream supplier activities, manufacturing, logistics, the use phase of the vehicles, and the end-of-life phase. The functional unit chosen is "The use of a specific Polestar vehicle driving 200,000 km".

As shown in Figure 1, the life cycle carbon footprints are 23-37 tonne CO_2e for "Long range Dual motor", 22-34 tonne CO_2e for "Long range Single motor", and 21-32 tonne CO_2e for "Standard range Single motor". The range in results is caused by differences in electricity mix scenarios, where the highest value reflects that a global electricity mix is used in the vehicle use phase, while the lowest value reflects that wind power is used.

1 ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines" and ISO 14040:2006 "Environmental management – Life cycle assessment – Principles and framework"

2 https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard-EReader_041613_0.pdf

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BEV
Battery Electric Vehicle. A BEV is a type of electric vehicle (EV) that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion.[3]

Characterisation
A calculation procedure in LCA where all emissions contributing to a certain impact category, e.g. GHGs that contribute to global warming, are characterised into a single 'currency'. For global warming, the carbon footprint is often expressed as mass unit of CO_2e, where e is short for equivalents.

Cradle-to-gate
An assessment that includes part of the product's life cycle, including material acquisition through the production of the studied product and excluding the use or end-of-life stages. However, for a component that is to be assembled in a product, a cradle-to-gate assessment can be carried out that covers the production of the component and parts of the logistics chain to the producer that assembles the component into a product.

Cradle-to-grave
A cradle-to-grave assessment considers impacts at each stage of the product's life cycle, from the time natural resources are extracted from the ground and processed through each subsequent stage of manufacturing, transportation, product use, recycling, and ultimately, disposal.[4]

Cut-off criteria
Specification of the amount of material or energy flow, or the level of environmental significance, associated with unit processes or product systems to be excluded from a study.[5]

Dataset (LCI or LCIA dataset)
A dataset containing life cycle information of a specified product or other reference (e.g. site, process), covering descriptive metadata and quantitative life cycle inventory and/or life cycle impact assessment data, respectively.[6]

End-of-life
End-of-life means the end of a product's life cycle. Traditionally it includes waste collection and waste treatment, e.g. reuse, recycling, incineration, landfill, etc.

Functional unit
Quantified performance of a product system for use as a reference unit.

GaBi
GaBi is LCA modelling software, provided by Sphera, which has been used for the modelling in this study.[7]

GHG
Greenhouse gases. Greenhouse gases are gases that contribute to global warming, e.g. carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2 O), as well as freons/CFCs. Greenhouse gases are often quantified as a mass unit of CO_2 e, where e is short for equivalents. See characterisation for further description.

ICE
Internal Combustion Engine. Sometimes used as a category when referring to a vehicle running with an ICE. An ICE vehicle uses exclusively chemical energy stored in a fuel, with no secondary source of propulsion.

3 Wikipedia, battery electric vehicle, https://en.wikipedia.org/wiki/Battery_electric_vehicle

4 "The Shonan guidelines", https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Global%20Guidance%20Principles.pdf

5 "The Shonan guidelines", https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Global%20Guidance%20Principles.pdf

6 GaBi, Sphera, https://sphera.com/product-sustainability-software/

7 GaBi, Sphera, https://sphera.com/product-sustainability-software/

Impact category
Class representing environmental aspects of concern to which life cycle inventory analysis results may be assigned.

Life cycle
Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment (LCA)
Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life.

LCA modelling software
LCA modelling software, e.g. GaBi, is used to perform LCA. It is used for modelling, managing internal databases, calculate LCA results etc, and contains databases from database providers.

Life Cycle Inventory analysis (LCI)
Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life Cycle Impact Assessment (LCIA)
Phase of life cycle assessment aiming to understand and evaluate the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life cycle interpretation
Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Offsetting
To counteract something by having and equal and opposite effect.
A climate offset broadly refers to a reduction in greenhouse gas emissions – or an increase in carbon storage (e.g., through land restoration or the planting of trees) – that is used to compensate for emissions that occur elsewhere.

Process
Set of interrelated or interacting activities that transforms inputs into outputs. Processes can be divided into categories, depending on the output of the process, e.g. material, energy, transport, or other service.

Raw material
Primary or secondary material that is used to produce a product.

System boundary
Set of criteria specifying which unit processes are part of a product system.

Scrap
1. A small piece or amount of something, especially one that is left over after the greater part has been used.
2. Discarded metal for reprocessing.

Waste
Substances or objects which the holder intends or is required to dispose of.

1

1.1 The products

Polestar has developed one plug-in hybrid electric vehicle (Polestar 1) and one battery electric vehicle (BEV) (Polestar 2). This study assesses the second BEV produced by Polestar, the Polestar 4. The study assesses three Polestar 4 variants: the “Long range Dual motor”, the “Long range Single motor”, and the “Standard range Single motor”. All variants have been developed in collaboration with Zhejiang Geely Holding Group (hereafter referred to as Geely), and are produced in Hangzhou Bay, China, with start of production week 44 2023. The variants are produced with different specifications. This study encompasses the specifications expected to have the largest sales volumes within the first year of production.

The studied vehicles are presented in table 1.

Table 1 →

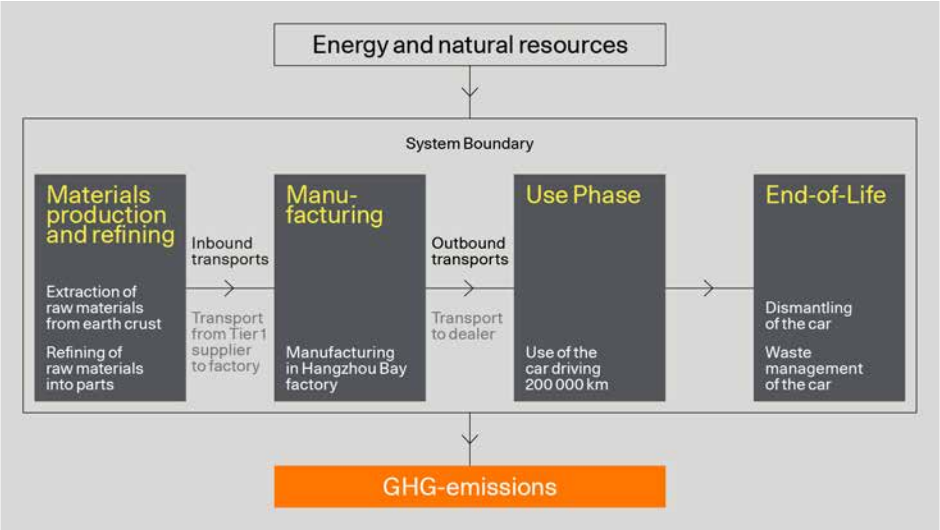
Studied vehicles.

Polestar 4 vehicle variant	Total weight (kg)	Li-ion battery modules weight (kg)	Battery cap. (kWh)
Long range Dual motor	2351	581	100
Long range Single motor	2229	581	100
Standard range Single motor	2171	523	86

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

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 three Polestar 4 variants. 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 our vehicles. The study was carried out to increase the knowledge about the carbon footprint of the Polestar 4 variants, and which underlying materials and processes that contribute the most. The aim is that this information can 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 the Polestar webpage at the start of vehicle production 2023. It contains the complete study, there is no additional separate documentation.



← Figure 2

System boundary of study.

1.3 Scope of study

The performed study is a Life Cycle Assessment (LCA), but it only considers GHG emissions, a so-called carbon footprint study. The study explores the global warming potential (GWP), using the CML2001 – Jan. 2016 method with characterisation factors for 100-year global warming potential (GWP) excluding biogenic carbon. By excluding biogenic carbon, up-front removal (and subsequent release) of biogenic carbon is automatically excluded from the accounting. All significant GHGs and removals from the processes included in the study (see “Main assumptions and exclusions”) are quantified. Carbon offsetting is not included. The study follows an attributional approach, i.e. it is not aimed at capturing systemic changes.

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

No cut-off criteria is 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 is not 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 LCA). For more information on how this is handled, see section 2.1 “Material production and refining”.

The time boundary of the study is manufacturing of the vehicle in 2023, and operating the vehicle over 15 years, from November 2023 to November 2038, after which end-of-life handling occurs.

The geographical boundary of the study is vehicle manufacturing in China, and use of the vehicle in Europe and the world, i.e. average figures for the electricity mix in Europe and the world are used for the use phase (as well as a scenario of using electricity generated from wind power). 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, if available. This is one step towards better data quality compared to the previous carbon footprint study on Polestar 2 which used global datasets for upstream processes as a first option. The methodology for choosing generic data is further described in the Polestar 2 carbon footprint report[8] “Appendix 1: General methodology when choosing datasets for complete vehicle carbon footprints”.

Another contrast to the Polestar 2 carbon footprint study is that this study considers use of recycled polymers, steel, and aluminium, as well as use of primary aluminium using hydropower electricity in the smelting step.

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

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

1.4 Function and functional unit

The functional unit defines precisely what is being studied. It defines and quantifies the main function of the product under study, provides a reference to which the inputs and outputs can be related, and is the basis for comparing/analysing alternative goods or services.

The functional unit of this study is:

- The use of a specific Polestar vehicle driving 200,000 km.
- The results are being presented as kg CO_2-equivalents per functional unit.

1.5 Allocation

When it comes to material sent to recycling, the emissions from producing this material is 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[9] 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 end-of-life of the vehicle.

In the manufacturing facilities, total number of completed cars 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 is applied in this study, i.e. no credits is given for materials being recycled and potentially avoiding other material production, or for energy generated in waste incineration potentially avoiding other energy production.

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

1.6 Main assumptions and exclusions

In general, assumptions are made in a conservative fashion following the precautionary principle, in order to not underestimate the impact from unknown data. For example, when no suitable dataset is available to represent the manufacturing process for a certain material (from raw material to finished vehicle component), the emissions from the raw material production is multiplied by two to compensate for the emissions from further processing. This is described in 2.6. "Minor material categories, production and refining".

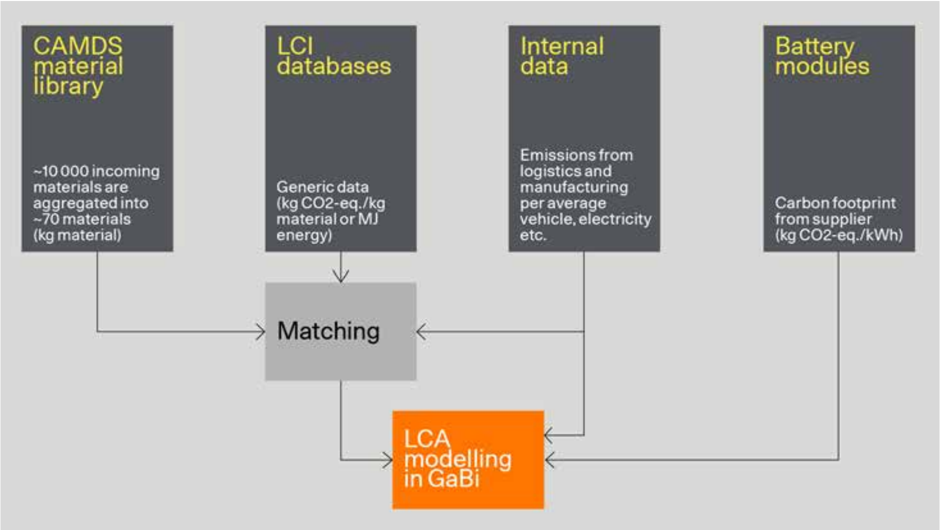
The use phase considers a lifespan of 15 years of the vehicle; probable changes in the electricity mix during this time is considered in the study based on the stated policies scenario (STEPS) from the International Energy Agency (IEA). This scenario is a slightly conservative benchmark for the future, 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 (the Worldwide Harmonized Light Vehicles Test Procedure) 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 lifetime mileage of the vehicle is assumed to be 200,000 km.
The battery is assumed to last the full lifetime mileage of the vehicle.

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 car manufacturing plant in Hangzhou Bay. However, when generic datasets are used, which is the case for energy generation, transportation means, and production of ingoing materials, manufacturing infrastructure is automatically included.
- Construction and maintenance of roads and charging infrastructure in the use phase.



← Figure 3

Overview of deriving the carbon footprint of vehicles.

1.7 Way of working overview

Figure 3 shows a high-level overview of how Polestar worked to derive the carbon footprints of the Polestar 4 variants.

There are four main ways that data needed for the final carbon footprint are retrieved. The input to the LCA comes from:

- CAMDS[10] (Chinese Automotive Material Data System) datasheets which contain information on material compositions of the components in a car. CAMDS is the Chinese version of IMDS[11] (International Material Data System).
- LCI databases from ecoinvent[12] (version 3.9.1) and Sphera[13]
- Data from operations controlled by Polestar, such as manufacturing plants and logistics.
- Carbon footprint of Li-ion battery modules, performed by the supplier with guidance and support from Polestar.

1.8 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 GaBi 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 CAMDS. A complete vehicle in CAMDS consists of about 10,000 different materials. To make the number of materials manageable in GaBi, they are aggregated to more than 70 defined material categories in a material library. The material library mapping logic is originally developed by Volvo Cars (IMDS ML) but was adjusted by Polestar to be used for CAMDS for this particular study. For the complete list of material categories, see Appendix 2.

10 DS, www.camds.org.cn

11 IMDS, www.mdsystem.com

12 Ecoinvent, www.ecoinvent.org

13 GaBi LCA databases http://www.gabi-software.com/databases/gabi-databases/

2

2.1 Material production and refining

Material production and refining is based on a Bill of Materials (BoM) containing material composition and material weight. The BoM used is specifically developed to be used for the LCA modelling and states the composition of the vehicle based on more than 70 material categories. The total weight of the vehicle is divided into these material categories.

Each material is 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 and ecoinvent 3.9.1. The datasets are chosen according to the Polestar methodology for choosing generic datasets (described in Appendix 1 in the Polestar 2 carbon footprint report[14]), with the deviation that 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, if available.

The material content corresponding to the entire weight of the vehicle is included in the LCA, but a small amount of materials is categorised as "undefined material" in the material library. The share of undefined material of the total vehicle weight (including battery modules) for all three Polestar 4 variants is below 1%. Since the undefined category seems to contain mostly undefined polymers, a dataset for Polyamide (Nylon 6) is used as approximation. This assumption is based on the fact that Polyamide is the polymer with the highest Carbon Footprint, out of the polymer data used in the LCA.

All filled polymers are 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 are 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 is not possible to modify the electricity, i.e. the built-in electricity has been used.

2.2 Aluminium production and refining

The share of aluminium that is cast aluminium and wrought aluminium is assumed to be 65% cast aluminium and 35% wrought aluminium. This is based on the report "Aluminium content in European passenger cars".[15] All wrought aluminium is assumed to go through the process of making aluminium sheets. The assumption of wrought aluminium being aluminium sheets is a conservative assumption since sheet production has a higher amount of scrap than most other wrought processes. The cast aluminium goes through a process for die-casting aluminium.

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

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

The scrap produced in the processes of making the aluminium parts for the car is included in the Carbon Footprint, and since a cut-off is applied at the point of scrap being produced in the factory, the total footprint of producing the scrap is allocated to the car even though the aluminium scrap is sent to recycling and used in other products. The material utilisation rate for the manufacturing processes of both cast aluminium and wrought aluminium can be seen in Appendix 3.

All aluminium is assumed to be produced in China. A share of the aluminium is identified to come from renewable electricity smelters. This share is modelled with an emission factor representing hydropower aluminium smelting in China. The emission factor was obtained through Polestar's own investigations. The Sphera dataset "RNA: Secondary aluminium ingot (95% recycled content)" is used for the recycled content ingot. Only post-industrial and post-consumer scrap is modelled as recycled content, no home scrap.

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 is then added to all steel. Which processing that is chosen depends on whether the steel is stamped in the factory or not. Hence, the steel categorised as unalloyed steel in the material library is divided into two sub-groups depending on the manufacturing process following the rolling and galvanising of the steel:

1. The steel that is processed and stamped in Geely controlled manufacturing. The Material Utilisation Degree is confidential.
2. The rest of the steel, which is distributed in various components of the car. The Material Utilisation Degree is according to the chosen database dataset, i.e. literature value.

The scrap produced in the processes of making the steel parts for the car, independent of processes, is included in the Carbon Footprint, and the same cut-off as for aluminium is applied. The material utilisation rate for the manufacturing processes of steel processed in Geely controlled manufacturing and steel processed at suppliers can be seen in Appendix 3.

The ecoinvent dataset "RoW: market for scrap steel" is used for the recycled content ingot. Only post-industrial and post-consumer scrap is modelled as recycled content, no home scrap.

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 are sorted into other categories, such as copper or different types of polymers.

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

2.5 Plastics production and refining

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

The Sphera dataset for mechanically recycled plastics "RER: Plastic granulate secondary (low metal contamination)" is used for the recycled content ingot. Only post-industrial and post-consumer scrap is modelled as recycled content, no home scrap.

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 is 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 GaBi databases where it is possible to add an electricity mix by choice, the electricity used is modelled as a 2023 Chinese electricity mix, based on the IEA STEPS scenario and Sphera data for electricity generation sources in China.

2.8 Battery modules

A BEV battery pack consists of a carrier, battery management system, cooling system, busbars, cell modules, thermal barriers, manual service disconnect and a lid. Polestar purchases cell modules from two different battery suppliers, who, in collaboration with IVL, Geely, and the report author, performed cradle-to-gate carbon footprint LCAs of their cell modules. The cell modules are therefore removed from the BoM based on CAMDS 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 CAMDS data.

2.9 Manufacturing and logistics

2.9.1 Logistics

Geely data has been used to calculate GHG emissions for transport from Tier 1 suppliers to the manufacturing site (inbound transport). Airbound transport was lacking from the data but was deemed by Geely to be used in very few cases. The inbound transport impact was increased by 20% to account for potential airbound transport.

For transport from manufacturing site to customer handover (outbound transport), IVL estimated the impact based on transporting the vehicles from China to Europe including three stages:

1. From the factory to the export port (CN): Truck, 30 ton, EU V, 1000 km
2. From the export port to the downstream selling port (CN-EU): Boat, Bulk commodity carrier, over 1000 to, 10,000km
3. From the selling port to the retailer (EU): Truck, 30 ton, EU V, 1000 km

2.9.2 Manufacturing

Geely data has been used to calculate GHG emissions from manufacturing. The data includes amounts of electricity, natural gas, diesel, and steam. For the electricity, the manufacturing factory uses two different sources. One is purchased from the national grid with green electricity certificate of I-REC hydro power. The other electricity source is photovoltaic panels on the roof of the manufacturing plant.

2.10 Use phase

To be able to calculate the emissions in the use phase of the car, the distance driven is needed together with the energy use, as well as emissions from electricity production. The vehicle lifetime driving distance for Polestar vehicles is set to 200,000 km, and energy use of the vehicle corresponds to driving according to the WLTP driving cycle. The WLTP values used in this study are preliminary data[16] based on tested CLTC (the Chinese Light-Duty Vehicle Test Cycle) values. The WLTP preliminary data are listed in Table 2.

Polestar 4 vehicle variant	Preliminary WLTP (kWh/100 km)
Long range Dual motor	17,8
Long range Single motor	16,5
Standard range Single motor	14,7

← Table 2

WLTP estimates.

Electricity production is modelled according to three cases: regional (global and EU28) grid mix and as a specific energy source (wind). Current and future global and EU28 electricity generation mixes are based on the World Energy Outlook 2022 Extended Dataset[17] from the International Energy Agency (IEA). Amounts of electricity from different energy sources are in this study paired with appropriate LCI datasets from the Sphera database (see Appendix 1) to determine the total impacts from different electricity generation mixes, both direct (at the site of electricity generation) and upstream. Because of lack of world average Sphera data, only European electricity generation sources are used for both the global and the EU28 cases.

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

2.11 End-of-life of the vehicle

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

The same methodology as described in Chapter 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.

The end-of-life is 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 gas, 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. The tyres are assumed to be incinerated, and 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 is assumed to be taken out of the car and sent to recycling. The recycling assumption is based on the foreseen increase in demand for battery metals, as electric vehicle production is expected to increase massively in the coming years[18]. The recycling assumption is also based on expected future regulation. For example, the new EU battery regulation imposes more stringent targets on waste collection, recycling efficiency and material recovery[19].

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 due to the fact that 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 in refining are outside the system boundaries set by the cut-off approach. More information about end-of-life is found in Appendix 4 – End-of-life assumptions and method.

16 Preliminary figures based on tested CLTC values. Subject to change pending final certification.

17 World Energy Outlook 2022 Extended Dataset - Data product - IEA

18 https://www.stenarecycling.com/siteassets/documents-and-downloads/documents/en/positionspapper_batteri_digital_en.pdf

19 https://www.europarl.europa.eu/news/en/press-room/20221205IPR60614/batteries-deal-on-new-eu-rules-for-design-production-and-waste-treatment

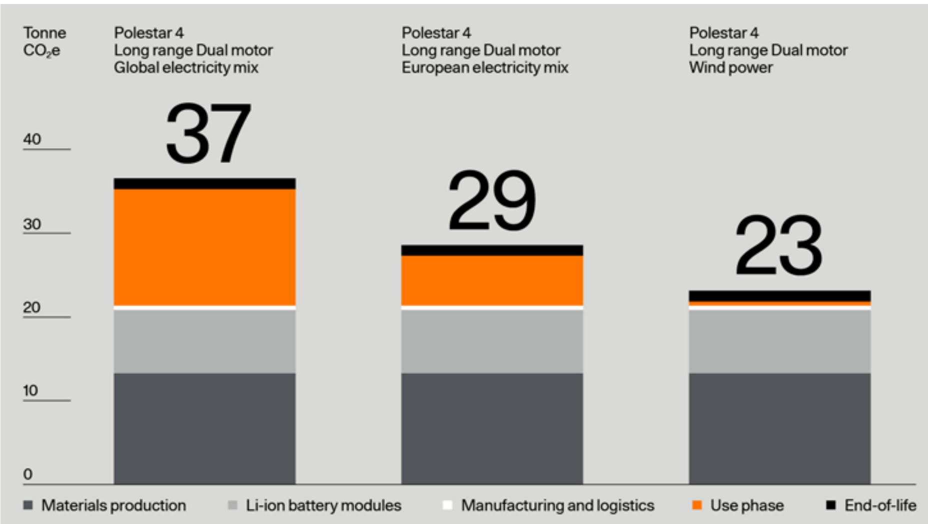
Figure 4-7 and Table 3-6 present the total carbon footprint of the three Polestar 4 variants, as well as the carbon footprint distributed onto life cycle phases. Depending on variant and electricity mix scenario, the life cycle carbon footprint varies between 21 and 37 tonne CO_2e. The largest variability in the results is due to the choice of electricity mix. In the case of global electricity mix, the use phase accounts for almost 40% of the life cycle carbon footprint, while in the case of wind power, the use phase accounts for only 2%.

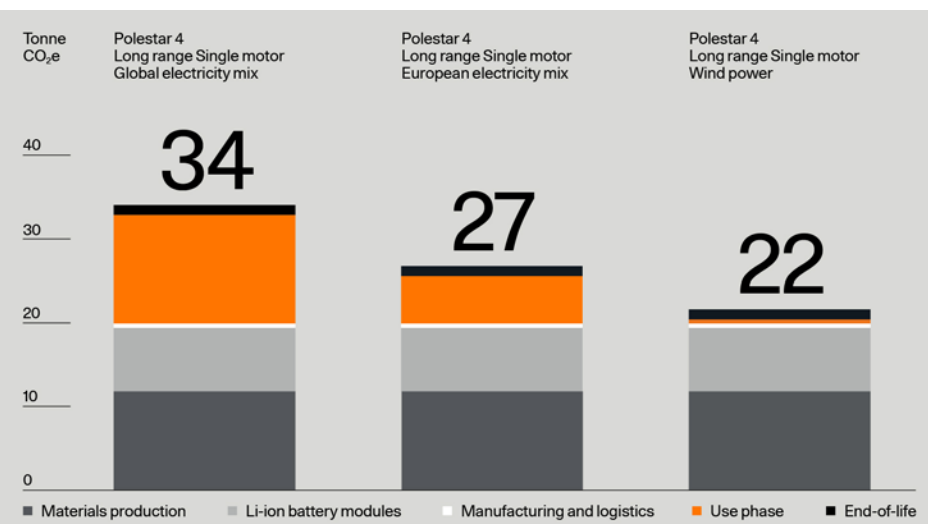
The single motor variants have a lower carbon footprint than the dual motor variant. This is due to that they

1. have one less motor and thereby require less materials, resulting in less impact from material extraction and manufacturing. The reduced battery capacity in the standard range single motor variant also leads to a lower weight (see Figure 1). The lower material volume also leads to
2. a lower total vehicle weight, that increases energy efficiency and lowers the use phase carbon footprint.

Figure 7-9 in Appendix 5 present the material breakdown of the three Polestar 4 variants. Battery modules represent the highest share of the carbon footprint of materials production and refining, with 36-39%. Aluminium represents 22-24% while steel and iron represent 20%. Compared to the original Polestar 2 carbon footprint report[20], where aluminium and battery modules represent the same share (29%), the emphasis has shifted towards the battery modules for Polestar 4. A reason for the shift is both a higher use of low carbon aluminium (from hydropower electricity driven smelters) and that the share of recycled aluminium was identified and included in the assessment for Polestar 4.

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





← Figure 4

Carbon footprint for Polestar 4 Long range Dual motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit (200,000 km lifetime range)

Table 3 →

Carbon footprint for Polestar 4 Long range Dual motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit.

	Polestar 4 LRDM Global electricity mix	Polestar 4 LRDM European electricity mix	Polestar 4 LRDM Wind power
Materials production	13,3	13,3	13,3
Li-on battery modules	7,6	7,6	7,6
Manufacturing and logistics	0,5	0,5	0,5
Use phase	13,9	5,9	0,5
End-of-Life	1,3	1,3	1,3
Total	37	29	23

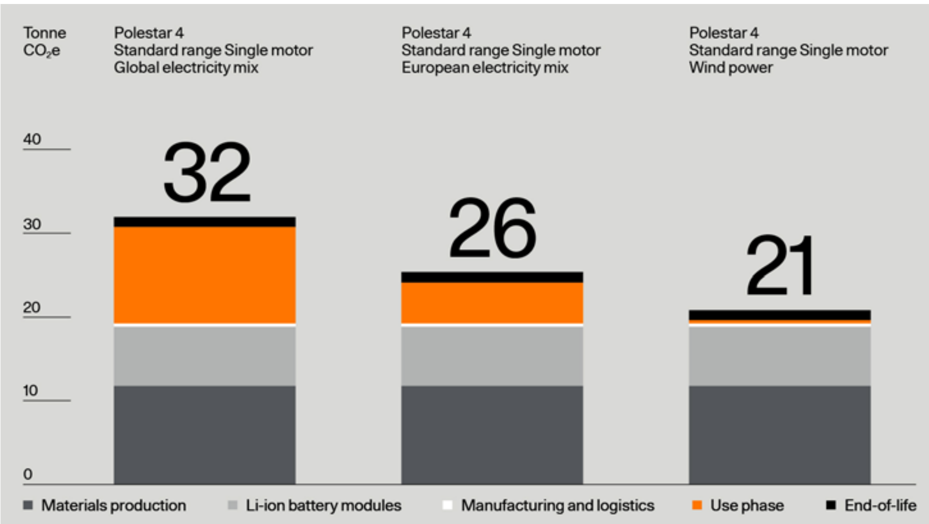
← Figure 5

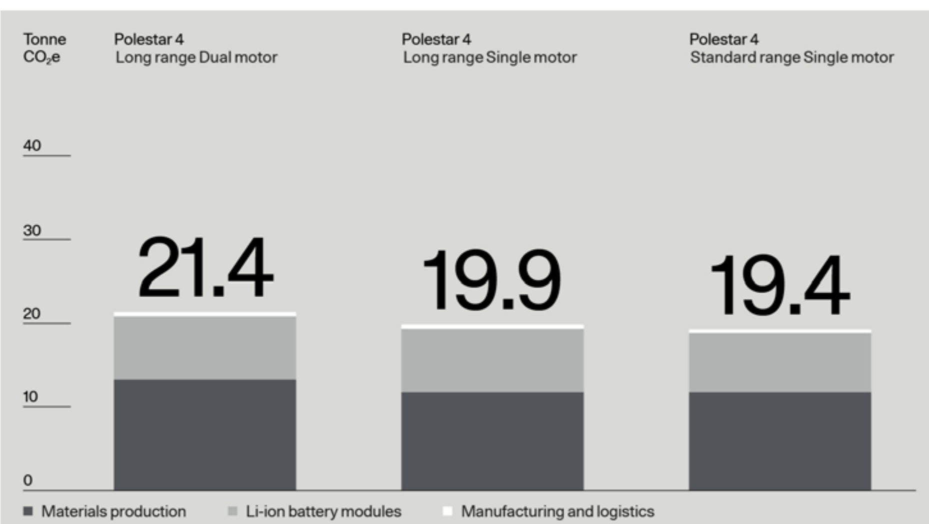
Carbon footprint for Polestar 4 Long range Single motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit (200,000 km lifetime range).

Table 4 →

Carbon footprint for Polestar 4 Long range Single motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit.

	Polestar 4 LRSM Global electricity mix	Polestar 4 LRSM European electricity mix	Polestar 4 LRSM Wind power
Materials production	11,8	11,8	11,8
Li-on battery modules	7,6	7,6	7,6
Manufacturing and logistics	0,5	0,5	0,5
Use phase	12,9	5,9	0,5
End-of-Life	1,2	1,2	1,2
Total	34	27	22





← Figure 6

Carbon footprint for Polestar 4 Standard range Single motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit (200,000 km lifetime range)

Table 5 →

Carbon footprint for Polestar 4 Standard range Single motor, with different electricity mixes in the use phase. Results are shown in tonne CO_2-equivalents per functional unit.

	Polestar 4 SRSM Global electricity mix	Polestar 4 SRSM European electricity mix	Polestar 4 SRSM Wind power
Materials production	11,8	11,8	11,8
Li-on battery modules	7,1	7,1	7,1
Manufacturing and logistics	0,4	0,4	0,4
Use phase	11,5	4,9	0,4
End-of-Life	1,2	1,2	1,2
Total	32	26	21

← Figure 7

Cradle-to-gate carbon footprint for the Polestar 4 variants, including Materials production, Li-ion battery modules, Manufacturing and Logistics.

Table 6 →

Cradle-to-gate carbon footprint for the Polestar 4 variants, including Materials production, Li-ion battery modules, Manufacturing and Logistics.

	Polestar 4 LRDM	Polestar 4 LRSM	Polestar 4 SRSM
Materials production	13,3	11,8	11,8
Li-on battery modules	7,6	7,6	7,1
Manufacturing and logistics	0,5	0,5	0,4
Total	21,4	19,9	19,4

4

LCA is continuously used for assessing the carbon footprint of Polestar's cars. Major work has been put in to building the methodology, and it is continuously being developed. In this study, some issues discussed in the previous Polestar 2 carbon footprint reports[21 22] have been addressed. One of the issues is that the development towards renewable and less carbon-intensive electricity generation sources should be reflected in LCAs of electric vehicles, to reflect their potential more realistically. IEA forecast data, coupled with Sphera data on electricity generation source emission intensity, was therefore used for the electricity scenarios in the Polestar 4 use phases. From 2023 to 2038, the carbon footprint development of global electricity will see a reduction of 40%. The European electricity mix decreases by 57% in the same time span. The IEA forecast data used is from the slightly conservative STEPS scenario, which does not take for granted that governments will reach their announced commitments, but instead only considers forecasted effects of decided policies.

Another issue which was highlighted in previous Polestar 2 carbon footprint reports was that the datasets that have been used for metal production are average data, and further investigation is needed to assess to what extent data differs from Polestar's actual supply network. In this study, the issue was addressed in two ways. Firstly, regional instead of global datasets were chosen for aluminium and steel. Secondly, Geely investigations identified volumes of recycled content for both aluminium, steel, and polymers. The fact that a share of the aluminium is coming from hydro power electricity smelters was also taken into account in the study. All these efforts lead to more realistic data and are improving Polestar's opportunities for using LCA to track improvement initiatives.

The continuous development of the carbon footprint methodology has many areas left to explore and improve. Examples include finding electronics data, which is more representative for specific applications, adding maintenance data to the use phase, increased collaboration with battery suppliers, and exploring additional environmental impact categories.

The primary goal of Polestar in disclosing detailed carbon footprint reports is to contribute to transparency. A powerful contribution to industry wide transparency would be standardisation of methodology for performing carbon footprints of personal vehicles, as it would make it possible to compare the results between different studies and manufacturers.

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

22 https://www.polestar.com/dato-assets/11286/1630409045-polestarlcarapportprintkorr11210831.pdf

5

In this study, the carbon footprints of the three Polestar 4 variants “Long range Dual motor”, “Long range Single motor”, and “Standard range Single motor” were calculated, including all life cycle phases, i.e. materials production and refining, manufacturing, use phase and end-of-life.

According to the methodology described in this report, the carbon footprints are 23-37 tonne CO_2e for “Long range Dual motor”, 22-34 tonne CO_2e for “Long range Single motor”, and 21-32 tonne CO_2e for “Standard range Single motor”. The range in results is caused by differences in electricity mix scenarios, where the highest value reflect that a global electricity mix is used in the vehicle use phase while the lowest value reflects that wind power is used.

Polestar will continue to improve the LCA methodology to create an even more robust methodology. To follow up more closely on how different sourcing decisions and material choices impact the results, Polestar also aims to increase the supplier-specific data used in the LCAs.

A1

← Table 7

Chosen datasets for materials

In the LCA a large number of generic datasets from databases are used. In this appendix the datasets used are listed. 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.

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 2015	agg	IAI/ Sphera
Aluminium, recycled	RNA	Secondary aluminium ingot (95% recycled content)	p-agg	AA/ Sphera
Aramid	DE	aramide fibre (para aramid)	agg	Sphera
ASA	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.9.1
Brake fluid	GLO	market for diethylene glycol	agg	ecoinvent 3.9.1
Carbon fibre	DE	Carbon Fibre (CF; from PAN; standard strength)	agg	Sphera
Cast iron	DE	cast iron part (automotive) - open energy inputs	p-agg	Sphera
Catalytic coating	ZA	market for platinum group metal concentrate	agg	ecoinvent 3.9.1
Ceramic	GLO	market for ceramic tile	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)	agg	Sphera
Copper alloys	GLO	market for zinc	agg	ecoinvent 3.9.1
Cotton	GLO	market for textile, woven cotton	agg	ecoinvent 3.9.1
Damper	RER	Polymethylmethacrylate sheet (PMMA)	agg	Plastics Europe
Damper	RoW	market for lime	agg	ecoinvent 3.9.1
E/P	GLO	polyethylene production, low density, granulate	agg	ecoinvent 3.9.1
Elastomer	RoW	market for calcium carbonate, precipitated	agg	ecoinvent 3.9.1
Elastomer	RoW	market for lime	agg	ecoinvent 3.9.1
Elastomer	GLO	market for carbon black	agg	ecoinvent 3.9.1
Elastomer	GLO	market for polyethylene terephthalate, granulate, amorphous	agg	ecoinvent 3.9.1
Elastomer	GLO	market for zinc oxide	agg	ecoinvent 3.9.1
Elastomer	GLO	market for synthetic rubber	agg	ecoinvent 3.9.1

Material	Location	Dataset name	Type	Source
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
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
Friction	DE	cast iron part (automotive) - open energy inputs	agg	Sphera
Friction	GLO	market for zirconium oxide	agg	ecoinvent 3.9.1
Friction	GLO	market for graphite, battery grade	agg	ecoinvent 3.9.1
Friction	GLO	barium sulphide production	agg	ecoinvent 3.9.1
Friction	GLO	market for barite	agg	ecoinvent 3.9.1
Friction	GLO	market for aluminium hydroxide	agg	ecoinvent 3.9.1
Friction	GLO	market for magnesium oxide	agg	ecoinvent 3.9.1
Friction	GLO	market for expanded vermiculite	agg	ecoinvent 3.9.1
Friction	EU-28	calcined petroleum coke	agg	Sphera
GF-fibre	GLO	market for glass fibre	agg	ecoinvent 3.9.1
Glycol	EU-28	ethylene glycol	agg	Plastics Europe
Lead, battery	DE	lead (99,995%)	agg	Sphera
Lubricants	EU-28	lubricants at refinery	agg	Sphera
Magnesium	CN	magnesium	agg	Sphera
Mineral	GLO	market for silica sand	agg	ecoinvent 3.9.1
Mineral	CN	aluminium oxide production	agg	ecoinvent 3.9.1
Mineral	GLO	market for potassium hydroxide	agg	ecoinvent 3.9.1
NdFeB	GLO	market for permanent magnet, electric passenger car motor	agg	ecoinvent 3.9.1

Material	Location	Dataset name	Type	Source
NR	DE	natural rubber (NR) (excl. LUC emissions)	agg	Sphera
PA	RoW	market for nylon 6	agg	ecoinvent 3.9.1
PBT	DE	polybutylene Terephthalate Granulate (PBT) Mix	agg	Sphera
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	Plastics Europe
Polymer, recycled	RER	Plastic granulate secondary (low metal contamination)	agg	Sphera
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	Plastics Europe
PP	RoW	market for polypropylene production, 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
PVC	GLO	Market for polyvinylchloride, suspension polymerisation	agg	ecoinvent 3.9.1
R-1234yf	DE	R-1234yf production (approximation)	agg	Sphera
SBR	DE	styrene-butadiene rubber (S-SBR) mix	agg	Sphera
Silicone rubber	DE	silicone rubber (RTV-2, condensation)	agg	Sphera
Steel, Sintered	Asia	steel hot dip galvanised	agg	world steel
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	agg	world steel
Steel, Recycled	RoW	market for scrap steel	agg	ecoinvent 3.9.1

Material	Location	Dataset name	Type	Source
Sulphuric acid	EU-28	sulphuric acid (96%)	agg	Sphera
Talc	RER	Talcum powder (filler)	agg	Sphera
Thermoplastic elastomers	DE	polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix	agg	Sphera
Thermoplastics	RoW	market for nylon 6	agg	ecoinvent 3.9.1
Tyre	DE	styrene-butadiene rubber (S-SBR) mix	agg	Sphera
Tyre	EU-28	water (deionised)	agg	Sphera
Tyre	GLO	vulcanisation of synthetic rubber (without additives)	u-so	Sphera
Undefined	RoW	market for nylon 6	agg	ecoinvent 3.9.1
Washer fluid	DE	Ethanol (96%) (hydrogenation with nitric acid)	agg	Sphera
Wood (paper, cellulose ...)	EU-28	Laminated veneer lumber (EN15804 A1-A3)	agg	Sphera
Zinc	GLO	Special high grade zinc	p-agg	IZA

Process	Location	Name	Type	Source
Aluminium manufacturing	DE	aluminium die-cast part	u-so	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
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

Electricity	Location	Name	Type	Source
Electricity from wind power	EU	Electricity from wind power	agg	Sphera
Electricity from wind power	CN	Electricity from wind power	agg	Sphera
Electricity from lignite	EU	Electricity from lignite	agg	Sphera
Electricity from coal	CN	Electricity from hard coal	agg	Sphera
Electricity from natural gas	EU	Electricity from natural gas	agg	Sphera
Electricity from natural gas	CN	Electricity from natural gas	agg	Sphera
Electricity from hydro power	EU	Electricity from hydro power	agg	Sphera
Electricity from hydro power	CN	Electricity from hydro power	agg	Sphera
Electricity from nuclear	EU	Electricity from nuclear	agg	Sphera
Electricity from nuclear	CN	Electricity from nuclear	agg	Sphera
Electricity from photovoltaic	EU	Electricity from photovoltaic	agg	Sphera
Electricity from photovoltaic	CN	Electricity from photovoltaic	agg	Sphera
Electricity from bioenergy	EU	Electricity from biomass (solid)	agg	Sphera
Electricity from bioenergy	CN	Electricity from biomass (solid)	agg	Sphera
Electricity from heavy fuel oil (HFO)	EU	Electricity from heavy fuel oil (HFO)	agg	Sphera
Electricity from heavy fuel oil (HFO)	CN	Electricity from heavy fuel oil (HFO)	agg	Sphera

↑ Table 9

Chosen datasets for electricity

← Table 8

Chosen datasets for manufacturing processes

A2

Appendix 2: Complete list of Material Library material categories

Table 10 →

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
Copper	Copper
Copper alloys	Copper
Magnesium	Other Metals
Zinc	Other Metals
Lead, battery	Other Metals
NdFeB	Other Metals
Ferrite magnet	Other Metals
ABS (filled)	Polymers
ASA (filled)*	Polymers
E/P (filled)	Polymers
EVAC (filled)	Polymers
PA (filled)	Polymers
PBT (filled)	Polymers
PC (filled)	Polymers
PC+ABS (filled)	Polymers
PE (filled)	Polymers
PET (filled)	Polymers
PMMA (filled)	Polymers
POM (filled)	Polymers
PP (filled)	Polymers
PVB (filled)*	Polymers
PVC (filled)	Polymers
ABS (unfilled)	Polymers
ASA (unfilled)*	Polymers

Material name	Material group
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
Epoxy*	Polymers
Polyurethane	Polymers
Damper	Polymers
Polyester	Polymers
Aramid	Polymers
Tyre	Polymers
Cotton	Natural Materials
Leather*	Natural Materials
Wood (paper, cellulose ...)	Natural Materials
Carbon fibre	Other

Material name	Material group
Friction	Other
Talc	Other
Mineral	Other
Catalytic coating	Ceramic/glass
Float glass	Ceramic/glass
GF-fibre	Ceramic/glass
Ceramic	Ceramic/glass
Anode*	
Cathode*	
Separator, Li battery*	
Electronics	Electronics
Lubricants	Fluids
Brake fluid	Fluids
Glycol	Fluids
R-1234yf	Fluids
R-134a*	Fluids
Sulphuric acid	Fluids
Washer fluid	Fluids
AdBlue*	Fluids
Undefined	Fluids
Diesel*	Fluids
Petrol*	Fluids

*Not used in the carbon footprint presented in this report.

A3

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

Table 11 →

Summary of data choices and assumptions for component manufacturing

Material	Assumption on component manufacturing	Comment	Material utilization rate in additional component manufacturing
Carbon fibre	No extra manufacturing processes	Assumed that processing after manufacturing into carbon fibre has negligible emissions and waste.	
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 have 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.	
Talc	No extra manufacturing processes	Assumed that processing after manufacturing into carbon fibre has negligible emissions and waste.	
Cast Aluminium	Die-casting process		96%
Wrought Aluminium	Rolling and Aluminium sheet deep drawing	Assumed to represent different types of wrought processes.	62%
Steel (in parts, processed at suppliers)	Steel sheet deep drawing	Sheet is assumed to adhere to the conservative approach.	63%
Steel (stamped in Geely controlled manufacturing)	Steel scrap generated at Geely controlled manufacturing	The steel scrap generated at stamping in the manufacturing plants, that is the steel in workstream "vehicle structures"	Confidential
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%

A4

Transport
Transportation of materials sent to material recycling is included and is conservatively assumed to be transported 1500 km by truck.

Disassembly
The disassembly stage is, globally, still a mostly manual process. The energy consumption 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 is included for the following disassembled components:

- Lead acid battery
- Li-ion batteries

For the lead acid batteries, the ecoinvent 3.9.1 dataset “RER: treatment of scrap lead acid battery, remelting” was used for the pre-treatment stage. The Li-ion battery is conservatively assumed to be transported 1500 km by truck to the recycling facility. 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. In order to estimate the amount of energy needed, the energy consumption per kg in the dataset “treatment of used glider”, passenger car, shredding from ecoinvent 3.9 is used. The electricity used for this process was modelled as a 2038 global electricity mix, based on the IEA STEPS scenario and Sphera data. Emissions of metals to water and air are 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 pre-treated components. Based on the choice of cut-off approach for end-of-life modelling, this stage is outside the boundaries of the life cycle and is not included in the inventory, except for the transportation to 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 Think step dataset of EU-28 incineration of mixed plastic.

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 Think step.

Transportation of materials which are separated in the shredding processes, and which are assumed to be recycled, is conservatively estimated to be 1500 km by truck.

Data collection
This section provides an overview of the data collection activities relating to each life cycle stage.

According to the cut-off methodology, the processes presented below are included in the data collection effort.

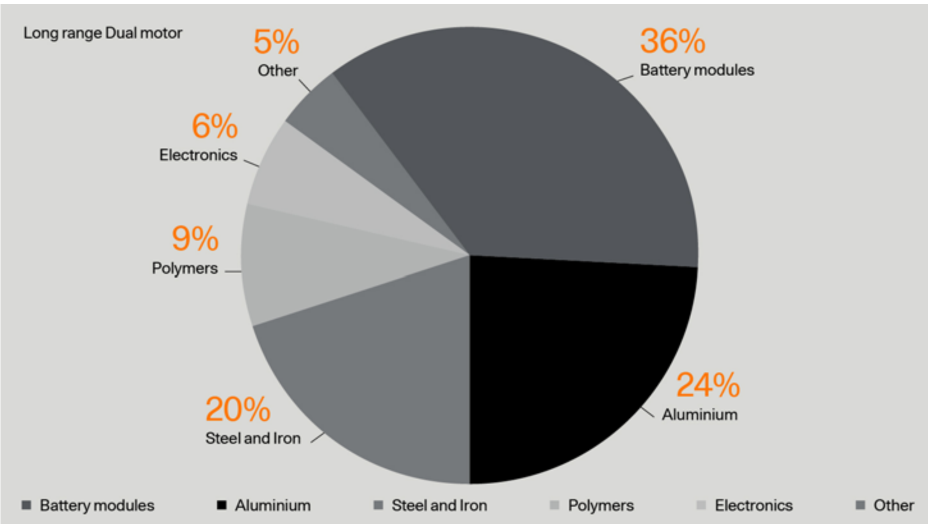
Table 12 →

Data collection activities relating to each life cycle stage.

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*
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*

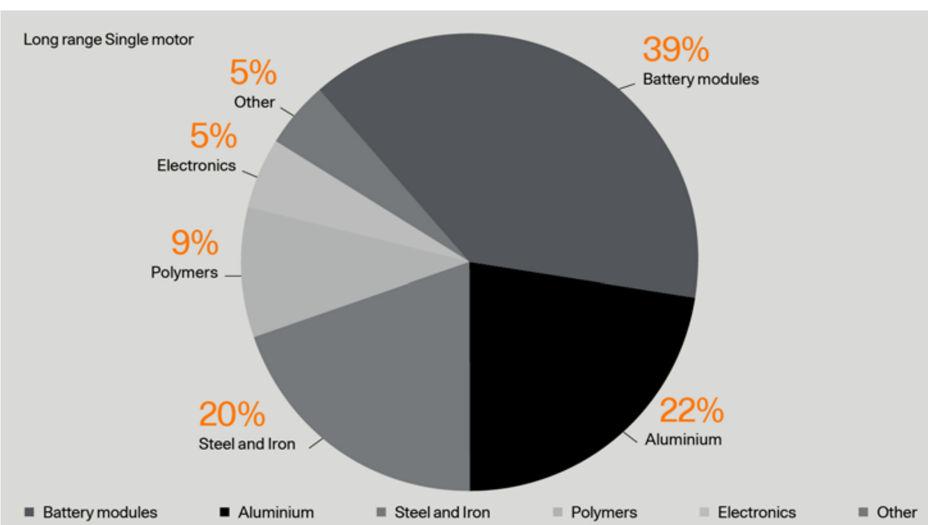
* Metals to material recycling, combustible materials to incineration (mainly plastics) and residue to landfill.

Figure 8-10 presents how the different material groups, including the battery modules, contribute to the carbon footprint from materials production and refining for the three Polestar 4 variants. The group "other" consists of all the material groups (see Table 10) that have a contribution of 1% or less.



← Figure 8

Contribution from different material groups, including battery modules, to the carbon footprint from materials production and refining for Polestar 4 Long range Dual motor.



← Figure 9

Contribution from different material groups, including battery modules, to the carbon footprint from materials production and refining for Polestar 4 Long range Single motor.

Figure 10 →

Contribution from different material groups, including battery modules, to the carbon footprint from materials production and refining for Polestar 4 Standard range Single motor.