Carbon footprint report

Volvo C40 Recharge

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Executive summary

Volvo Cars has committed to only sell fully electric cars by 2030. This is the most ambitious transformation into electrification from any established car manufacturer and it is a key step for Volvo Cars to reach full climate neutrality across its entire value chain by 2040. In the short-term Volvo Cars is working towards reducing its life cycle carbon footprint per average vehicle by 40 per cent between 2018 and 2025. This plan, one of the most ambitious in the industry, is validated by the Science Based Target Initiative to be in line with the Paris Agreement[1] of 2015, which seeks to limit global temperature rise to 1.5C above pre-industrial levels. Volvo Cars has also committed to communicating improvements from concrete short-term actions in a trustworthy way, including the disclosure of the carbon footprint of all new models.

The Volvo C40 Recharge is Volvo Cars' second fully electric car, and the first model Volvo Cars launches that is only available as a fully electric version. The carbon footprint shows a great reduction in greenhouse gas emissions compared to that of an internal combustion engine (ICE) vehicle, especially if the car is charged with renewable electricity. The carbon footprint is also lower than that of the XC40 Recharge, mainly thanks to improved aerodynamics.

This report presents the carbon footprint of the new fully electric Volvo C40 Recharge with production start in autumn 2021, in comparisons with the fully electric Volvo XC40 Recharge and Volvo XC40 ICE, both launched in 2020. The carbon footprints for these XC40 models were published in 2020 but are now updated.

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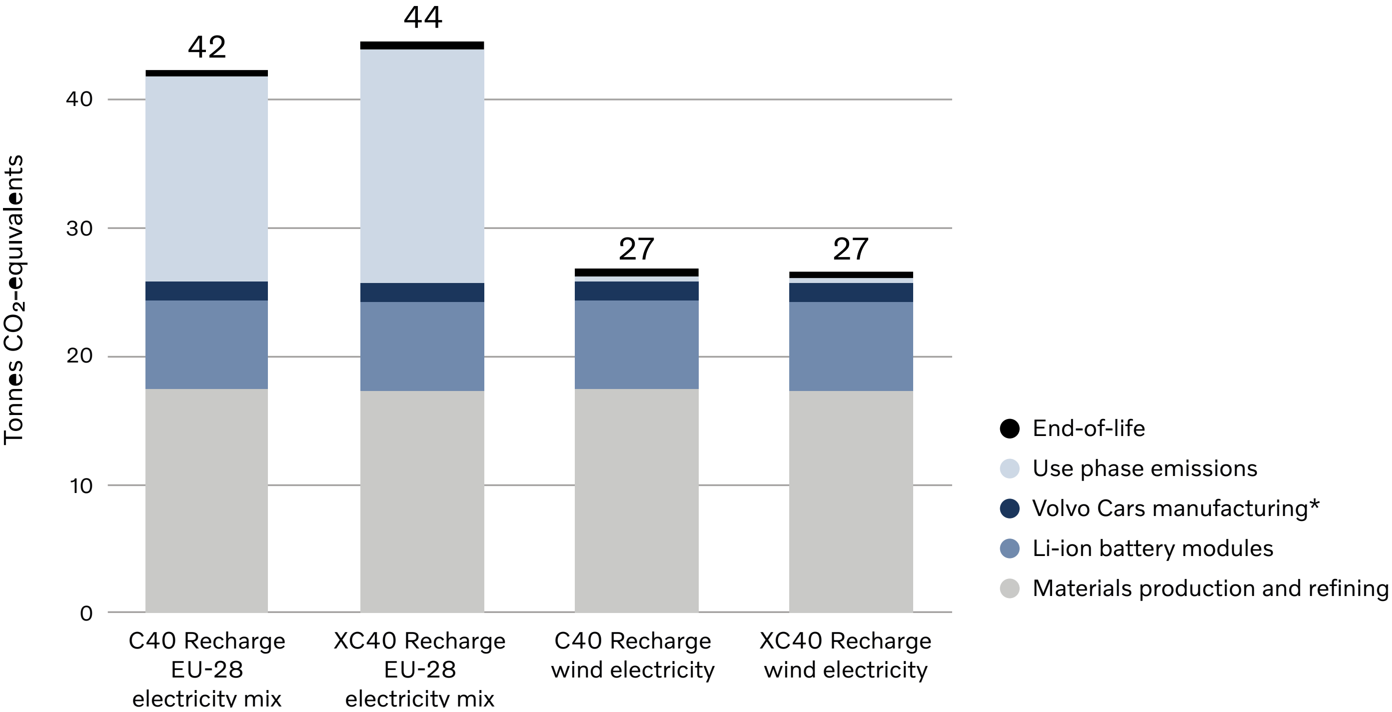
[1] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

The methodology is based on life cycle assessment (LCA) according to ISO LCA standards[2]. Driving distance is assumed to be 200,000km. In general, assumptions are made in a conservative way in this study, to not underestimate the impact from uncertain data. Therefore care should be taken when comparing these results with those from other vehicle manufacturers.

The carbon footprints of C40 Recharge, XC40 Recharge, both charged with EU-28 electricity mix, and XC40 ICE fuelled with petrol containing 5 per cent ethanol (E5), are approximately 42, 44 and 59 tonnes CO_2-equivalents respectively. See ***figures i*** (for the Recharge models) and ***ii*** (for XC40 ICE result compared with C40 Recharge). Thus, C40 Recharge has a roughly 5 per cent lower carbon footprint than XC40 Recharge over its life cycle when charged with EU-28 electricity mix and slightly more than 10 per cent lower carbon footprint in its use phase. The reason for the lower carbon footprint of C40 Recharge compared with XC40 Recharge is mainly because of better aerodynamic properties of the C40 Recharge.

Figure ii shows a breakdown of the carbon footprint for the C40 Recharge with different electricity mixes in the use phase. The carbon footprint becomes approximately 50, 42 and 27 tonnes CO_2-equivalents when charging C40 Recharge with global electricity mix, EU-28 electricity mix or wind power respectively. Thus, the choice of electricity mix is crucial for the carbon footprint.

Furthermore, the results assume a constant carbon intensity throughout the vehicle lifetime. The effect of a more realistic trend of future reduction of carbon intensity in EU-28 electricity mix is tested in a sensitivity analysis and the life cycle carbon footprint is reduced as expected, but not as much as in the case of nearly 100 per cent renewable electricity, such as wind power.



** Volvo Cars manufacturing includes both factories as well as inbound and outbound logistics.*

Figure i. Carbon footprint for C40 Recharge and XC40 Recharge, with different electricity mixes.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

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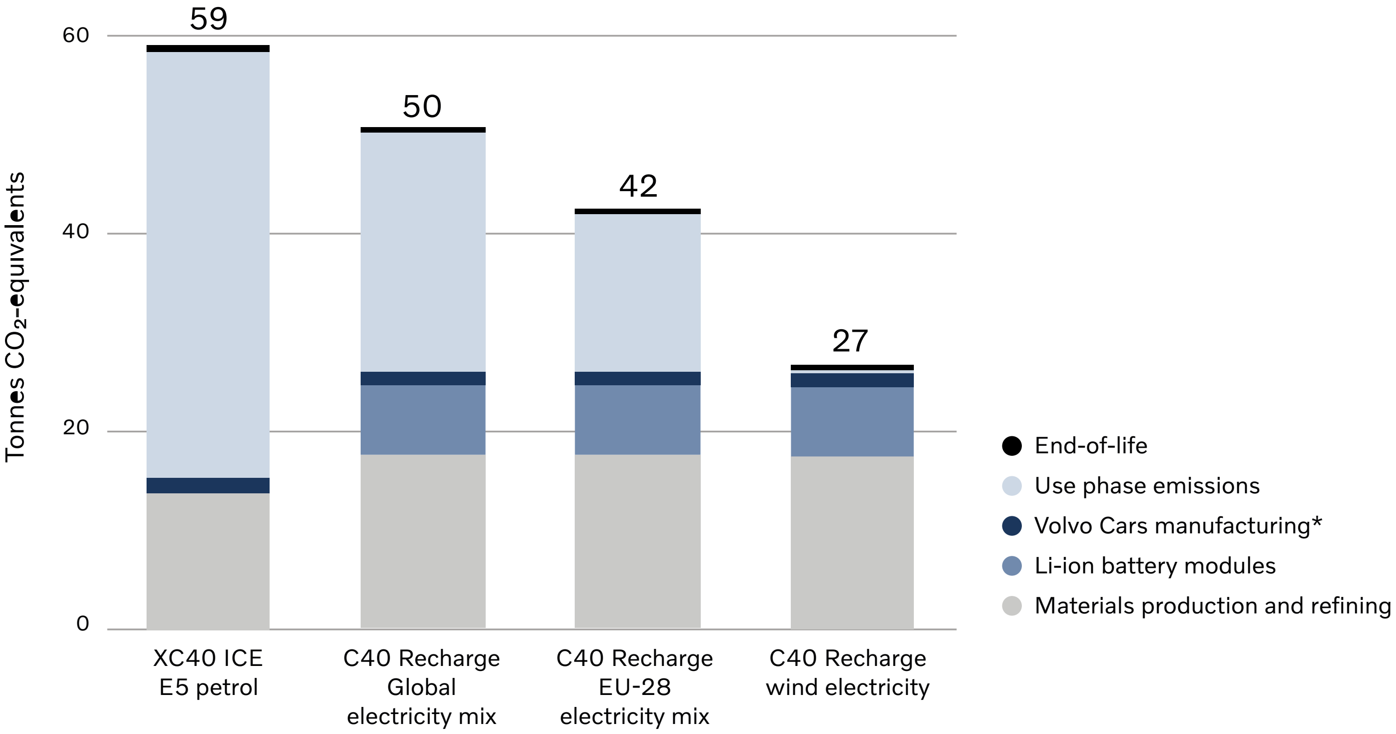
[2] ISO 14044:2006 “Environmental management – Life cycle assessment – Requirements and guidelines” and ISO 14040:2006 “Environmental management – Life cycle assessment – Principles and framework”



** Volvo Cars manufacturing includes both factories as well as inbound and outbound logistics.*

Figure ii. Carbon footprint for C40 Recharge and XC40 ICE, with different electricity mixes.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

The accumulated emissions from the Materials production and refining, Li-ion battery modules and Volvo Cars manufacturing phases of C40 Recharge are nearly 70 per cent higher than for XC40 ICE. However, the use phase emissions for a battery electric vehicle (BEV) per distance driven are lower than for an ICE. This is illustrated in ***figure iii***, where it is also possible to read out, depending on the electricity mix used to charge the BEV, the distance at which the total carbon footprint of C40 becomes lower than the footprint of the XC40.

Electrification of cars causes a shift of focus from the use phase to the materials production and refining phase. Volvo Cars has a strategy of working towards reducing the greenhouse gas (GHG) emissions from this phase by 25 per cent per average vehicle from 2018 to 2025 which is an ambitious start towards achieving climate neutrality by 2040. Production of aluminium, the Li-ion battery modules and steel are the main emission contributors. Hence Volvo Cars is actively striving to reduce carbon footprint of materials and parts e.g., through increase of the degree of recycled content in the materials. Li-ion battery technology is relatively young implying a relatively high potential for improvements. It is hoped that conclusions from this study will provide further guidance on how to prioritise the efforts.

It should be noted that the carbon footprint calculations are performed to represent a globally sourced version of the models. The results of using data for regional sourcing in EU for some materials are tested in a sensitivity analysis and indicate that the effect of more regional data can be significant. Another methodological choice that has a large impact on the result is the choice of allocation method for production scrap. This study accredits the GHG emissions for the scrapped materials to the car, although a lot of the material will be used in other products through materials recycling.

Although this report is relative transparent, it is important for future improvements to have even more transparency and traceability of data from the supply chains and in carbon footprint reports.

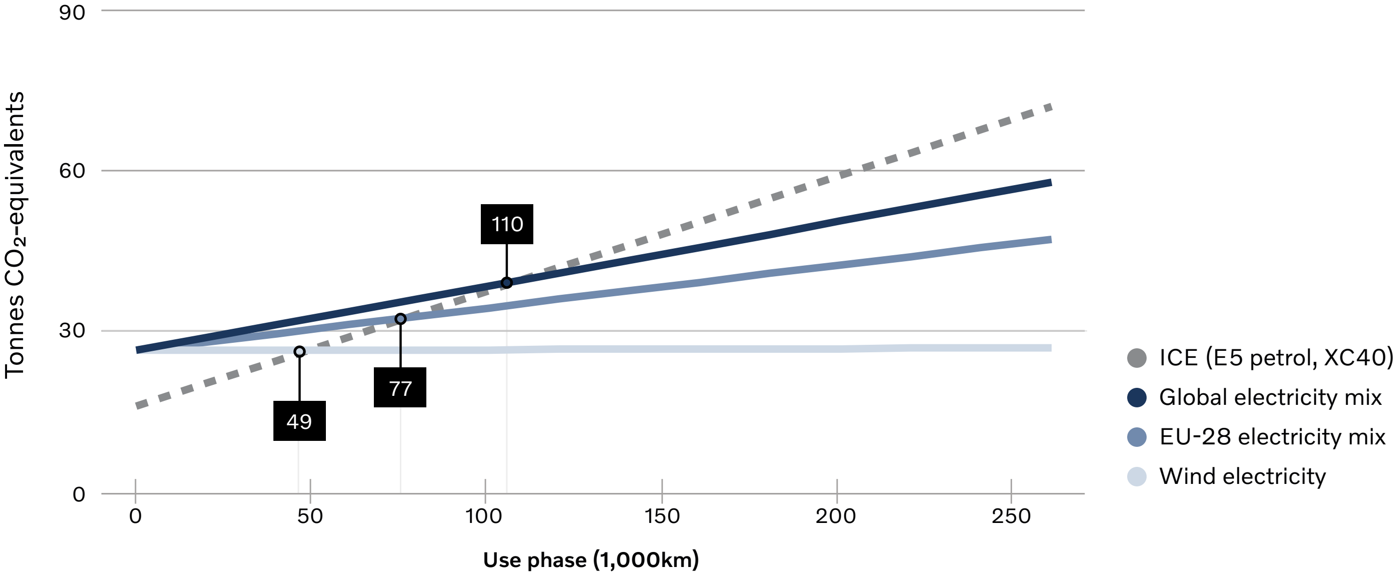


Figure iii. Break-even diagram: *Total amount of GHG emissions, depending on total kilometres driven, from XC40 ICE (dashed line) and C40 Recharge (with different electricity mixes in the use phase). Where the lines cross, break-even between the two vehicles occurs. All life cycle phases except use phase are summarized and set as the starting point for each line at zero distance.*

Key Findings

- The C40 Recharge has approximately 5 per cent lower total carbon footprint than XC40 Recharge when charged with EU-28 electricity mix in the use phase, which is mainly because of better aerodynamic properties.
- The C40 Recharge has a lower total carbon footprint than the XC40 ICE (E5 petrol) for all the analysed sources of electricity for the use phase.
- Materials production and refining, battery module production and manufacturing at Volvo Cars for a C40 Recharge results in nearly 70 per cent higher GHG emissions compared to an XC40 ICE (E5 petrol).
- The highly probable future reduction of carbon intensity of the EU-28 electricity mix will reduce the carbon footprint of C40 Recharge when using this mix for driving. However, a significantly lower carbon footprint is achieved when charging the car with renewable electricity, such as wind power.
- Production of aluminium and the Li-ion battery modules have relative high carbon footprints, with a contribution of approximately 30 per cent each to the total footprint of all materials and components in the C40 Recharge.
- Choice of methodology has a significant impact on the total carbon footprint. Therefore, care should be taken when comparing results from this report with those from other vehicle manufacturers.

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Terms and definitions

Attributional approach
An attributional approach to an LCA means that it estimates what share of the global environmental burdens belongs to a product. This in contrary to a consequential approach that gives an estimate of how the global environmental burdens are affected by the production and use of the product[3].

BEV
Battery electric vehicle. A BEV is a type of electric vehicle that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion.

Carbon footprint
The total greenhouse gas (GHG) emissions caused by e.g., a product expressed as CO_2-equivalents, usually calculated with life cycle assessment (LCA) methodology.

Characterisation
A calculation procedure in LCA where all emissions contributing to a certain impact category, e.g., greenhouse gases (GHGs) that contribute to climate change, are characterised into a single 'currency'. For climate change, the carbon footprint is often expressed as mass unit of CO_2-equivalents.

Cradle-to-gate
A cradle-to-gate assessment includes parts of the product's life cycle, i.e., from the cradle to the factory gate. It includes primary production of materials and the production of the studied product, but it excludes the use and end-of-life phases of the product. A supplier can provide a component, part or sub-assembly cradle-to-gate LCA to an OEM, for the OEM to include in the LCA of the OEM's product.

Cradle-to-grave
A cradle-to-grave assessment, compared to a cradle-to-gate assessment, also includes the use and end-of-life phases of the product, i.e., it covers the full life cycle of the product.

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.[4]

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.

EU-28 and EU-28 electricity mix
Data used in the LCA comes from the GaBi Professional and ecoinvent databases. The term EU-28 is used to describe the geographic region of the generic data and include all 27 member states in EU plus United Kingdom. The electricity mix for the use phase of the BEVs can be chosen either as country grid mix or for a specific energy source. The most recent electricity grid mix in GaBi, with reference year 2017, is used.

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

GaBi
GaBi is an LCA modelling software, provided by Sphera, and has been used for the modelling in this study.[5]

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[3] Ekvall T., 2019. Attributional and Consequential Life Cycle Assessment | IntechOpen

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

[5] GaBi, Sphera, http://www.gabi-software.com/sweden/index/

GHGs
Greenhouse gases. Greenhouse gases are gases that contribute to global warming (climate change), e.g., carbon dioxide (CO_2), methane (CH_4), nitrous oxide/laughing gas (N_2O), but also freons/CFCs. Greenhouse gases are often quantified as mass unit of CO_2-equivalents. See characterisation for further description.

ICE vehicle
Internal combustion engine vehicle. An ICE vehicle uses exclusively chemical energy stored in a fuel, with no secondary source of propulsion.

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

Li-ion battery
Lithium-ion battery, a type of rechargeable battery in which lithium ions move from the negative electrode through an electrolyte to the positive electrode during discharge, and back when charging.

Life cycle
Consecutive and interlinked phases 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 cycle.

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

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.

Material utilisation degree, MUD
The share of utilised material of the total amount needed for producing a part. For example, if 100kg of steel is needed to produce a steel part of 70kg due to that scrap is generated in the manufacturing, the MUD is 0.7.

PCB
Printed circuit board.

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.

Simple cut-off
The simple cut-off is a method for modelling recycling. It implies that each product is assigned the environmental burdens of the processes in the life cycle of that product. It means that using recycled material comes with the burdens from the collection and recycling of the material, which often are less than for production of primary material. At the same time no credits are given for recycling or creating recycled material.
It is also called the recycled content approach and the 100/0 method.

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

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

1. General description of life cycle assessment (LCA)

1.1 Principles of LCA

The life cycle assessment (LCA) methodology is used to determine what impact a product or a service has on the environment, and according to the European Commission life cycle assessments provide the best framework for assessing the potential environmental impacts for products that are currently available.[6] The methodology was developed because there was a need to consider the whole life cycle of a product when examining environmental impacts, instead of just looking into one process at a time. A peril with focusing only on one process at a time is that a decrease in environmental impact in one area can lead to increased environmental impact in another. To prevent this phenomenon, otherwise known as sub-optimisation, an LCA aims to include all processes from cradle to grave. However, an LCA is always a study of the environmental impacts for the processes within the system boundary, defined in the goal and scope of the LCA. Therefore, it is important to remember that all environmental impacts, from a product or service, can never be considered.

In ***Figure 1*** the different phases of LCA are shown. First, the goal and scope of the LCA should be defined. The system boundaries must be clearly stated since it has a direct impact on the result of the LCA. When the goal and scope are defined the inventory analysis can start. This is where data regarding all processes inside the system boundaries are gathered; these data can be presented in a report and are then called LCI (life cycle inventory). In addition, the data from the inventory analysis are further processed in the impact assessment phase, where different emissions (e.g., CO_2, SO_2, NO_x etc.) are sorted into different categories depending on what environmental impact they contribute to. These categories can be, for example, climate change, acidification and eutrophication. Through the impact assessment the total environmental impact of the studied system can be quantified. LCA is an iterative process where, for example, interpretation of results may necessitate refining the goal and scope definition, inventory analysis or impact assessment, in order to create a final assessment that in the best way addresses the question that one wants to answer.

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[6] Communication on Integrated Product Policy (COM (2003)302)

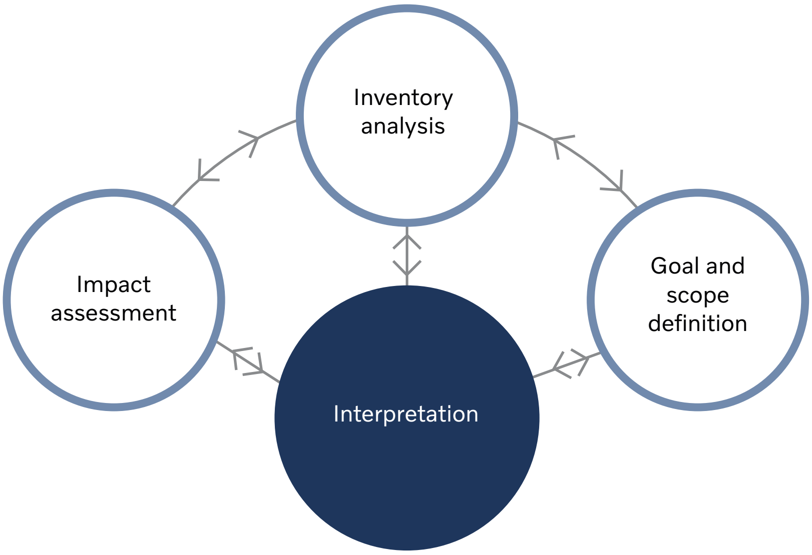

Figure 1. *Illustration of the general phases of a life cycle assessment, as defined in ISO 14040.*

A fourth step, called weighting, may also be included in LCA. In this step, results are further aggregated. The different environmental impacts are weighed against each other based on, for example, political goals, economical goals or the critical load of different substances in the environment. The LCA methodology undertaken for this study does not include weighting since only one environmental impact category (climate change) is studied.

1.2 LCA standards

The methodology follows the standards set by ISO 14044:2006 "Environmental management — Life cycle assessment — Requirements and guidelines" and ISO 14040:2006 "Environmental management – Life cycle assessment – Principles and framework". These standards differ from other standards that are commonly used by the vehicle industry, e.g. for testing or certification of the products, since they contain very few strict requirements. Instead, they mostly provide guidelines for LCA including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA functional phases and conditions for use of value choices and optional elements. The standards are valid for LCAs of all products and services and do not provide details enough to make LCAs of vehicles from different OEMs comparable.

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In addition to ISO 14044, the "Product Life Cycle Accounting and Reporting Standard[7]" which is part of the GHG protocol framework, has been used for guidance in methodological choices.

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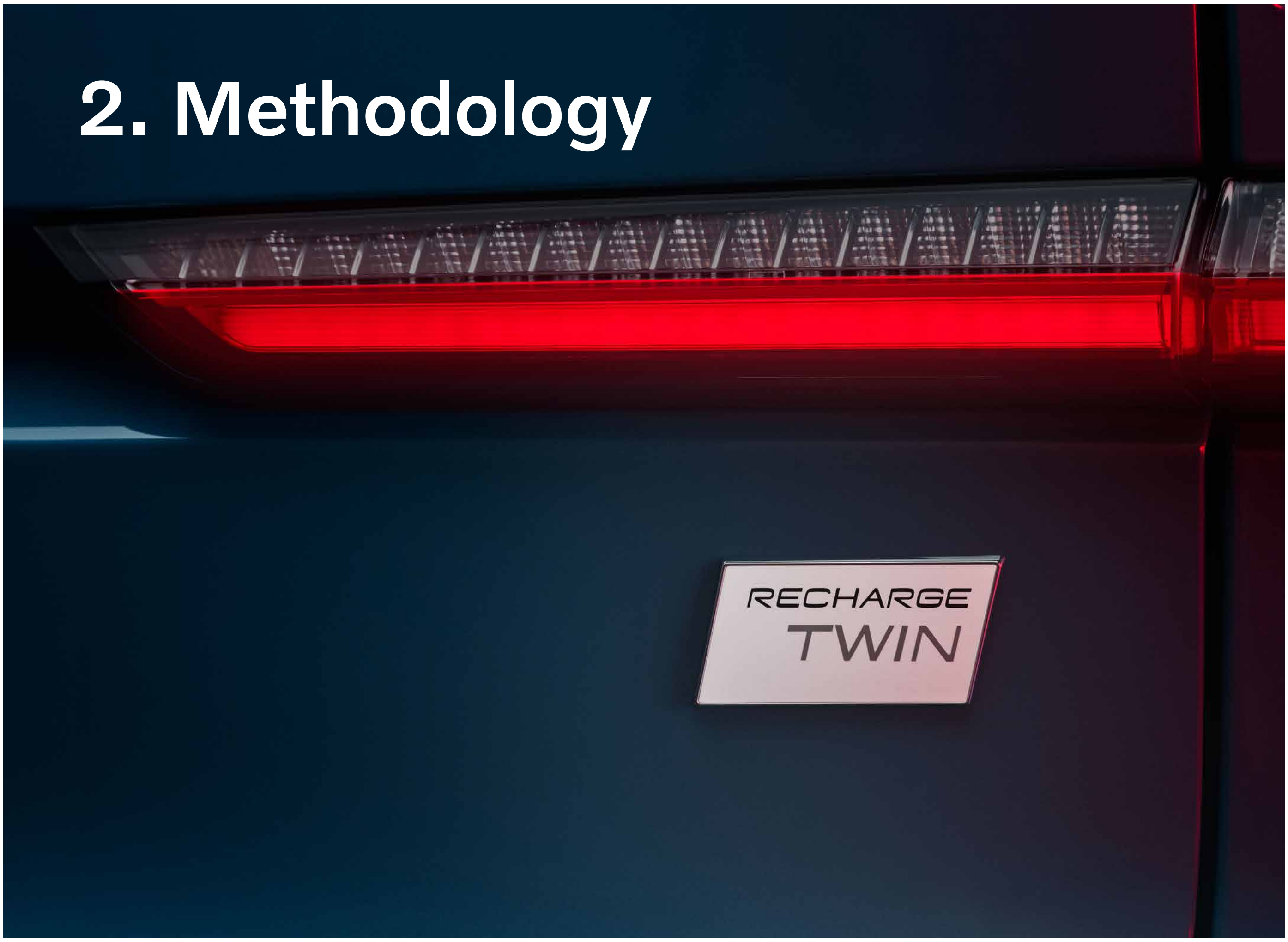
[7] Product Life Cycle Accounting Reporting Standard. Published by World Resources Institute and World Business Council for Sustainable Development. Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

2. Methodology



2.1 The products

The Volvo Cars vehicles in this study can be categorised as:

- **BEV** – battery electric vehicle
- **ICE vehicle** – internal combustion engine vehicle

The methodology in this study is the same as was used in 2020 when performing LCAs of the vehicles XC40 Recharge and XC40 ICE (E5 petrol).

The studied vehicles are presented in ***Table 1***. The total pack energy for C40 Recharge and XC40 Recharge is 71–78 kWh.

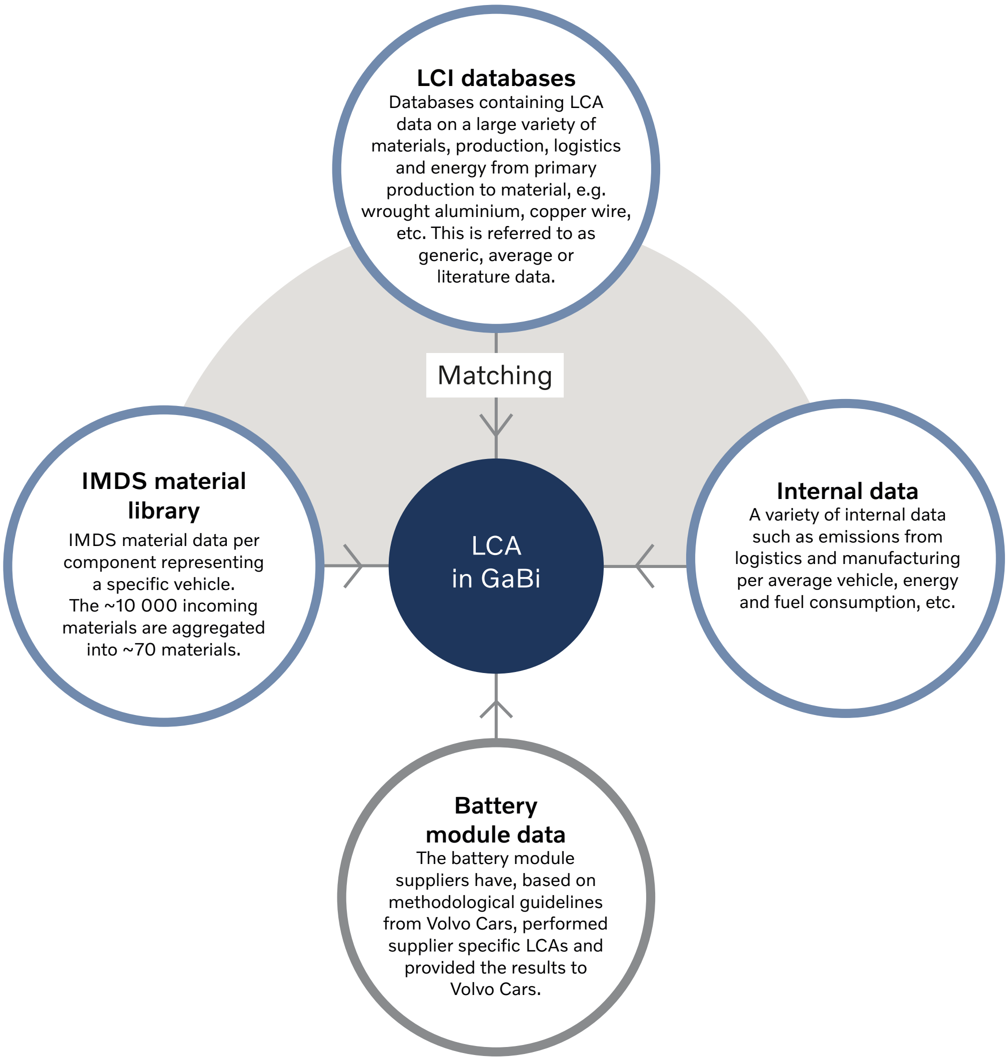
Vehicle	Total weight (kg)
C40 Recharge	2180
XC40 Recharge	2170
XC40 ICE	1690

Table 1. *Studied vehicles and their corresponding weight in kg.*

2.2 Way of working overview

Figure 2 provides a high-level overview of how the work to obtain the carbon footprints of the vehicles is carried out according to the methodology at Volvo Cars. Four main ways are used to retrieve the data needed for the final LCA. The import to GaBi (see *Terms and definitions*) is made in a specific mapping tool, provided by Sphera, called GaBi-DFX[8]. The input to GaBi comes from:

- IMDS[9] (International Material Data System) datasheets which contain information on material compositions of the components
- The LCI databases ecoinvent[10] 3.7.1 and GaBi LCA database 2021.1 version (GaBi Professional)[11]
- Data from operations run by Volvo Cars, such as factories and logistics
- LCA of battery modules, performed by our battery suppliers with guidance and support by Volvo Cars and Polestar



LCI databases
Databases containing LCA data on a large variety of materials, production, logistics and energy from primary production to material, e.g. wrought aluminium, copper wire, etc. This is referred to as generic, average or literature data.

IMDS material library
IMDS material data per component representing a specific vehicle. The ~10 000 incoming materials are aggregated into ~70 materials.

Internal data
A variety of internal data such as emissions from logistics and manufacturing per average vehicle, energy and fuel consumption, etc.

Battery module data
The battery module suppliers have, based on methodological guidelines from Volvo Cars, performed supplier specific LCAs and provided the results to Volvo Cars.

Figure 2. *Overview of LCA way of working.*

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[8] GaBi DfX, http://www.gabi-software.com/international/software/gabi-dfx/

[9] IMDS, www.mdsystem.com

[10] ecoinvent, www.ecoinvent.org

[11] GaBi LCI databases, http://www.gabi-software.com/databases/gabi-databases/

2.3 Methodology to define vehicle material composition

The bill of materials (BOM) is an important input to 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 Volvo Cars' product data management system KDP. However, this BOM cannot be used as direct input to the LCA model in GaBi but must be developed and aggregated in several steps into 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 GaBi, they are aggregated into approximately 70 material categories defined by Volvo Cars in a materials library developed by Volvo Cars, Volvo IMDS ML.

The part number BOM from KDP is uploaded to Volvo Cars IMDS in-house system iPoint Compliance Agent (iPCA). In iPCA a materials BOM is generated and imported into Volvo IMDS ML where all materials are mapped into the by Volvo Cars defined material categories.

In order to have an effective and systematic approach, this mapping is automated. The rules for categorising the materials are determined by IMDS material category, material name and substance content. It is also possible to manually allocate materials in the Volvo IMDS ML, however, this is done as restrictively as possible. For these LCAs, Volvo IMDS ML release 8 is used with the material categories listed in ***Table 2***. For the complete list of material categories see "*Appendix 3 – Complete list of Volvo Cars' material library material categories*".

The BOM from Volvo IMDS ML must then be formatted further order to allow import into GaBi. A formatting tool is used to apply the format required by GaBi and this step is also automated.

The import to GaBi is made in a specific mapping tool, provided by Sphera, called GaBi DfX. In the mapping, each material is connected to a specific life cycle inventory dataset and, if relevant, a manufacturing process dataset.

For the Li-ion battery modules, supplier specific carbon footprint data were used instead of IMDS data. The production of the Li-ion battery modules consists of complex manufacturing steps and has therefore high impact on the result. Also, the variety and accuracy of datasets available is limited for Li-ion batteries.

Material type	Number of material categories
Steel and iron	5
Aluminium	1
Magnesium	1
Copper	2
Zinc	1
Lead, battery	1
Magnet	2
Polymers	About 40*
Natural materials	4
Glass	3
Electronics	1
Fluids	11
Undefined	1

** Including filled/unfilled.*

Table 2. *Material categories defined by Volvo Cars in Volvo IMDS ML release 8. Note that Li-ion battery modules are treated separately and therefore not included in the table.*

2.4 Goal and scope definition

The main goal of the methodology in this study is to evaluate the carbon footprint of C40 Recharge and compare with the carbon footprints of XC40 Recharge and XC40 ICE (petrol containing 5 per cent ethanol (E5 petrol)). Another goal is to be able to use the complete vehicle carbon footprint of C40 Recharge to examine the effects of changes in electricity mix used for charging the battery and data choice for production of materials.

This methodology follows an attributional approach and is developed considering exclusively the environmental impact category climate change with its characterisation factor global warming potential (GWP)[12] and on the detail level of a complete vehicle.

2.4.1 Intended audience

The intended audience is decision makers, car customers, researchers, public and internal R&D.

2.4.2 System boundaries

The study performed is a life cycle assessment (LCA) for greenhouse gas emissions only: a so-called carbon footprint.

Regarding the tail-pipe emissions from the ICE vehicles, only carbon dioxide emissions are included whereas methane and nitrous oxide emissions (CH4 and N_2O) are excluded. CH_4 and N_2O contribute a minor fraction of total tailpipe GHG emissions from a petrol vehicle and exclusion of these emissions has no influence on the conclusions of this study.[13]

The study includes the vehicle life cycle from cradle-to-grave, starting at extracting and refining of raw materials and ending with the end-of-life of the vehicle, see ***Figure 3***. Major assumptions, uncertainties and cut-offs are described under "*2.4.6 Assumptions and limitations*".

The emissions from the life cycles of infrastructure are included when they are available in the LCA databases. No active data collection or modelling of infrastructure has been carried out in this study.

Generic data, as opposed to supplier specific data, are used for most of the upstream processes, such as raw materials production and manufacturing processes. Thus, there are steps in some of the manufacturing value chains, specific to vehicle components, that might not be included.

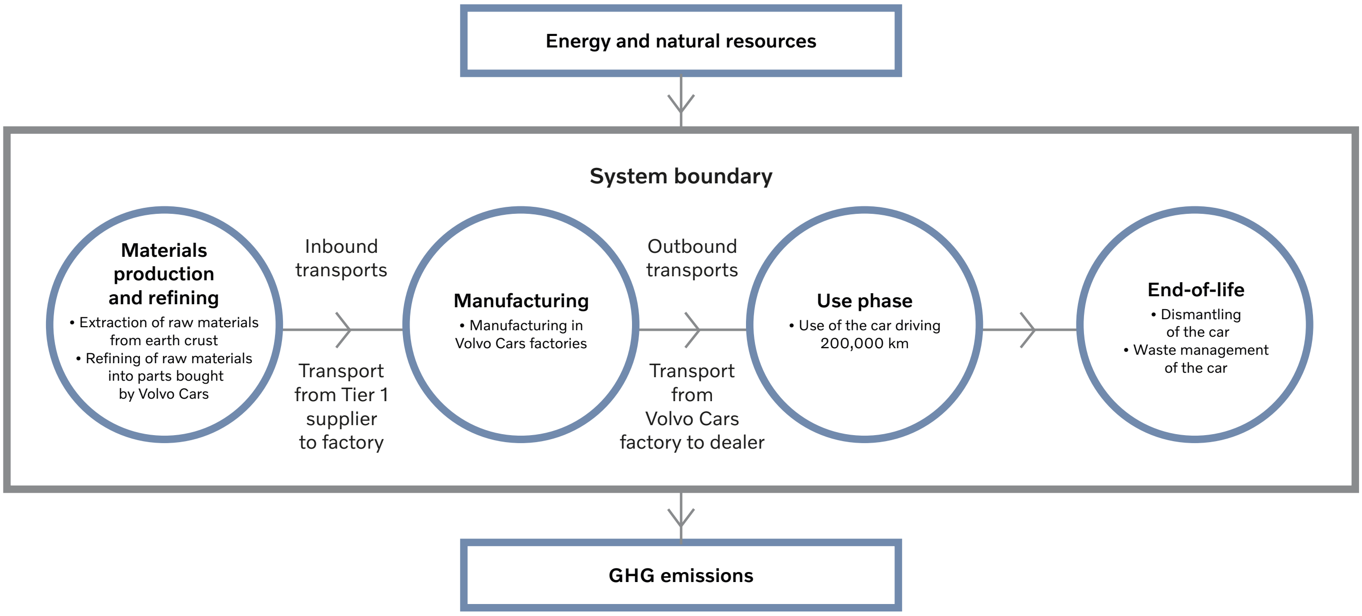

Figure 3. *Schematic description of the studied system and its different life cycle phases.*

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[12] CML2001-Aug.2016, global warming potential (GWP 100 years, thus calculated for 100 years of impact from the day of emissions) excluding biogenic carbon

[13] Analysis of GaBi data for passenger car, EURO 6

It is likely that these processes are assembly processes at the tier 1 suppliers of Volvo Cars and the contribution to the total carbon footprint from these processes are likely to be very small.

The production data are for the current situation, which means that the carbon intensity of the electricity mix for driving is also recent, although it will probably change during the car's estimated lifetime of 15 years. The effect of this approach was tested in the sensitivity analysis, see page 30.

The study was carried out with a global approach, which means that the generic datasets used for raw materials production and refining are not specific for any region. As far as possible global averages have been applied. How this principle for data choice may affect the results is tested in the sensitivity analysis, see page 31.

2.4.3 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 Volvo vehicle driving 200,000km

The results are being presented as kg CO_2-equivalents per functional unit.

2.4.4 Allocations

100 per cent of total emissions from scrap has been allocated to the vehicles. Thus, for example, the produced amount of steel and aluminium included in the carbon footprint calculation does not only include the amount of material in the vehicle, but also the scrap generated in the whole manufacturing chain. More specifically, the methodology uses the cut-off approach, which is the recommended method according to the EPD[14] system. This method follows the "polluters pay principle" meaning that if there are several product systems sharing the same material, the product causing the waste shall carry the environmental impact. In other words the system boundary is specified to occur at the point of "lowest market value". Also, if the material does not go to a new product system, the final disposal is included within the life cycle of the vehicle.

2.4.5 System expansion

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

2.4.6 Assumptions and limitations

In general, assumptions have been made in a conservative fashion following the precautionary principle, in order not to underestimate the impact from uncertain data. Additional processes have been added to the model when judged needed to represent actual emissions more accurately.

The inventory does not include:

- Processes at Volvo Cars such as business travels, R&D activities or other indirect emissions
- Volvo Cars infrastructure e.g., the production and maintenance of buildings, inventories or other equipment used in the production
- Construction and maintenance of roads in the use phase
- Emissions from tyres and road wear in the use phase
- Maintenance of the vehicles in the use phase

This study does not investigate changes, i.e., it is not consequential[15], nor takes rebound effects[16] into consideration.

Carbon footprints developed using this methodology should not be broken down to lower levels, e.g., system or component level, without reassuring that an acceptable level of detail is also reached on the studied subsystem.

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[14] https://environdec.com/resources/documentation#generalprogrammeinstructions

[15] Consequential LCA, https://consequential-lca.org/clca/why-and-when/

[16] https://esrc.ukri.org/about-us/50-years-of-esrc/50-achievements/the-rebound-effect/

3. Life cycle inventory analysis (LCI)

In this chapter all input data and methodological choices concerning the inventory are presented.

3.1 Material production and refining

Material production and refining (see ***figure 3***) are based on a BOM containing material composition and material weight. The BOM used for modelling in GaBi is specifically developed for LCA modelling in GaBi and reports the composition of the vehicle based on about 70 material categories. The total weight of the vehicle is divided into these material categories.

In GaBi, each material has been coupled with one or several datasets (containing LCI data) representing the production and refining of the material in each specific material category. See *Appendix 4 – Chosen datasets*. Material production and refining are modelled using datasets from GaBi Professional database 2021.1 and ecoinvent 3.7.1 database, system model cut-off. The datasets have been chosen according to the Volvo Cars methodology for choosing generic datasets. For some raw materials there were no datasets for the exact materials. In those cases, data sets for similar materials have been used.

The material content corresponding to the entire weight of the vehicle is included in the LCA, but for the different vehicles a small amount of materials have been categorised as undefined material in Volvo IMDS ML. ***Table 3*** shows the share of undefined material of the total vehicle weight (including battery modules) for each vehicle.

Vehicle model	Share of undefined material
C40 Recharge	1.6%
XC40 Recharge	1.0%
XC40 ICE	0.9%

Table 3. *Share of undefined material in the different vehicles.*

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 per cent polymer, 14 per cent glass fibre and 8 per cent 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 2 – Summary of data-choices and assumptions for component manufacturing*.

For most database datasets representing materials production and refining processes it has not been possible to modify the electricity, thus the built-in electricity mix has been used.

3.1.1 Aluminium production and refining

The share of aluminium that is cast aluminium and wrought aluminium was assumed to be 65 per cent and 35 per cent respectively. This is based on the report "Aluminium content in European passenger cars"[17]. All wrought aluminium was 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 generates a higher amount of scrap than most other wrought processes. The cast aluminium goes through a process for die casting aluminium.

The scrap generated in the processes of making the aluminium parts for the vehicle is included in the carbon footprint, and since a cut-off is applied at the point of scrap being generated in the factory, the total footprint of generating the scrap is allocated to the vehicle even though the aluminium scrap is sent to recycling and used in other products. The material utilisation rate (MUD, the degree of utilised material of the total amount needed for producing a part) for the manufacturing processes of both cast aluminium and wrought aluminium can be seen in *Appendix 2 – Summary of data-choices and assumptions for component manufacturing*. All aluminium is assumed to be produced as primary, thus produced from bauxite ore.

3.1.2 Steel production and refining

The raw material dataset used for the material category "unalloyed steel" is rolled and galvanised steel. A manufacturing process was added to all steel. Which manufacturing process was chosen depends on whether the steel is stamped by Volvo Cars or not. Hence, the steel categorised as unalloyed steel in the material library has been divided into two sub-groups depending on the manufacturing process following the rolling and galvanising of the steel:

1. The steel that is processed and stamped in Volvo Cars factories. The MUD is according to data at Volvo Cars.

2. The rest of the steel, which is distributed in various components of the car. The MUD is according to the chosen database dataset, i.e., literature value.

The scrap generated 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 MUD for the manufacturing processes of steel can be seen in *Appendix 2 – Summary of data-choices and assumptions for component manufacturing*.

3.1.3 Electronics production and refining

The material category "Electronics" includes printed circuit boards (PCBs) and the components mounted on them. It does not include chassis, cables or other parts that are present in electronic components. All materials that are used in electronic devices that are not PCBs have been sorted into other categories, such as copper or different types of polymers. For the category "Electronics" a generic dataset from ecoinvent 3.7.1 has been used. This dataset represents the production of lead-free, mounted PCBs.

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[17] https://www.european-aluminium.eu/media/2714/aluminum-content-in-european-cars_european-aluminium_public-summary_101019-1.pdf

3.1.4 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 rate for the manufacturing processes of plastics can be seen in *Appendix 2 – Summary of data-choices and assumptions for component manufacturing*.

3.1.5 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 manufacturing process is assumed to have the same carbon footprint as the production of the raw material itself. This has been applied only for minor materials (by weight).

3.1.6 Electricity use in materials production and refining

A global average electricity mix has been applied for materials production and refining. This was modelled using statistics from the International Energy Agency (IEA)[18] and electricity datasets in GaBi, since there is no existing dataset for global electricity mix in the GaBi database. This electricity mix is used for a few[19] partially aggregated processes in the GaBi databases where it is possible to add an electricity mix by choice as well as the use phase of the BEVs.

3.1.7 Differences in materials production data compared to the previous LCA report

Since re-calculations with updated production data have been performed to make the car models comparable, improvements have also been implemented. There is now a higher degree of defined materials and an adjustment has been made regarding ratio between wrought and cast aluminium. The average composition of filled polymers is adjusted and data in the databases are generally updated. Logistics and Volvo Cars production site data have also been updated.

3.2 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. Volvo Cars purchases modules from CATL and LG Chem, who, in collaboration with the report authors, performed cradle-to-gate (up until Volvo Cars logistics take over the part) carbon footprint LCAs of their modules. The modules have therefore been removed from the BOM based on IMDS data and modelled separately in the complete vehicle LCA. All other parts of the battery pack are included in the materials BOM, based on IMDS data.

3.3 Manufacturing and logistics at Volvo Cars

3.3.1 Logistics

For GHG emissions from transports from Tier 1 suppliers to Volvo Cars manufacturing sites (inbound transport), Volvo Cars' total emissions from inbound transports divided by the total number of cars produced during the same year has been applied. In the same way, emissions from transports from Volvo Cars manufacturing sites to the dealer (outbound transport), have been compiled based on Volvo Cars' total emissions from outbound transports per the total number of cars sold during the same year. Network for Transport Measures (NTM)[20] has been used as a basis for the calculations.

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[18] https://www.iea.org/data-and-statistics/charts/world-gross-electricity-production-by-source-2019

[19] The processes that use the electricity mix are cast iron production, rubber vulcanization and five additional manufacturing processes.

[20] https://www.transportmeasures.org/en/

3.3.2 Volvo Cars factories

GHG emissions from electricity usage, heat usage and use of different fuels in each of the factories were calculated using site-specific input data. The GHG emissions per vehicle were then calculated by dividing the total GHG emissions from the factory by the total amount of vehicles or engines produced in that factory during the same year.

The C40 Recharge will initially be produced in Ghent in Belgium. XC40 ICE and XC40 Recharge are produced in both Luqiao in China and Ghent in Belgium. The emissions from the Volvo Cars manufacturing have been calculated in proportion to the number of cars produced in the car factories between May 2020 and April 2021. For engine factories, data from 2019 were used. This was done to avoid the months of March-April 2020 during the corona pandemic which had a significant impact on the production.

3.4 Use phase

The calculation of the emissions in the use phase of the car is based on the distance driven, tailpipe emissions per driven kilometre, and the well-to-tank emissions from fuel and electricity production.

The driving distance for Volvo vehicles has been set to 200,000 km, which is also the functional unit in this study.

The fuel and energy related GHG emissions associated with the actual driving of the vehicle are divided into two categories:

- **Well-to-tank (WTT)** –Includes the environmental impact caused during production and distribution of the fuel or electricity to the fuel tank or traction battery in the vehicle. The fuel used in the ICE vehicle is assumed to be petrol blended with 5 per cent ethanol, and the production related emissions from both fuels are included. Electricity production is modelled according to global or EU-28 grid mix or as specific energy source (wind). The calculations for achieving the global electricity mix dataset are described in chapter 3.1.5.
- **Tank-to-wheel (TTW)** – Includes the tailpipe emissions during use. This is zero for C40 Recharge and XC40 Recharge and calculated to be 173g CO_2/km for the XC40 ICE (based on an average of produced XC40 ICE petrol cars).

The TTW emission data for the XC40 ICE is based on the WLTP driving cycle (Worldwide Harmonised Light Vehicles Test Procedure, used for certification of vehicles in EU). WLTP data are also used for obtaining energy consumption figures for C40 Recharge and XC40 Recharge. Losses during charging in the electricity use of the BEVs are included. The electricity use for C40 Recharge in this study is 211 Wh/km which is based on estimated average certified energy consumption of future produced C40 Recharge cars. The electricity use for XC40 Recharge is slightly higher, 241 Wh/km, which is based on an average of the XC40 Recharge vehicles produced. The weight of the vehicles is similar, but C40 Recharge uses less energy for driving mainly because of better aerodynamic properties of the car body.

3.5 End-of-life of the vehicle

3.5.1 Process description

At their end-of-life, it is assumed that all vehicles are collected and sent for end-of-life treatment.

The same methodology as described in chapter 2.4.4 – Allocations, is applied. Focusing on the point of lowest market value, according to the polluter pays principle, implies inclusion of steps such as dismantling and pre-treatment (shredding and specific component pre-treatment), while excluding material separation, refining or any credit for reuse in another product system.

End-of-life was modelled to represent global average situations as far as possible. Handling consists of a disassembly step to remove hazardous components and components that are candidates for specific recycling efforts. The disassembled parts are treated and the remaining vehicle is shredded. Depending on material type the resulting fractions go either to material recycling, incineration, or landfill. ***Figure 4*** gives an overview of the entire phase.

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

- Batteries
- Fuel
- Wheels, tyres
- Liquids:
  - – coolants
  - – antifreeze
  - – brake fluid
  - – air-conditioning gas
  - – shock absorber fluid
  - – windscreen wash
- Oils:
  - – engine
  - – gearbox
  - – transmission
  - – hydraulic oils
- Oil filters
- Catalytic converter
- Airbags and seat belt pretensioners

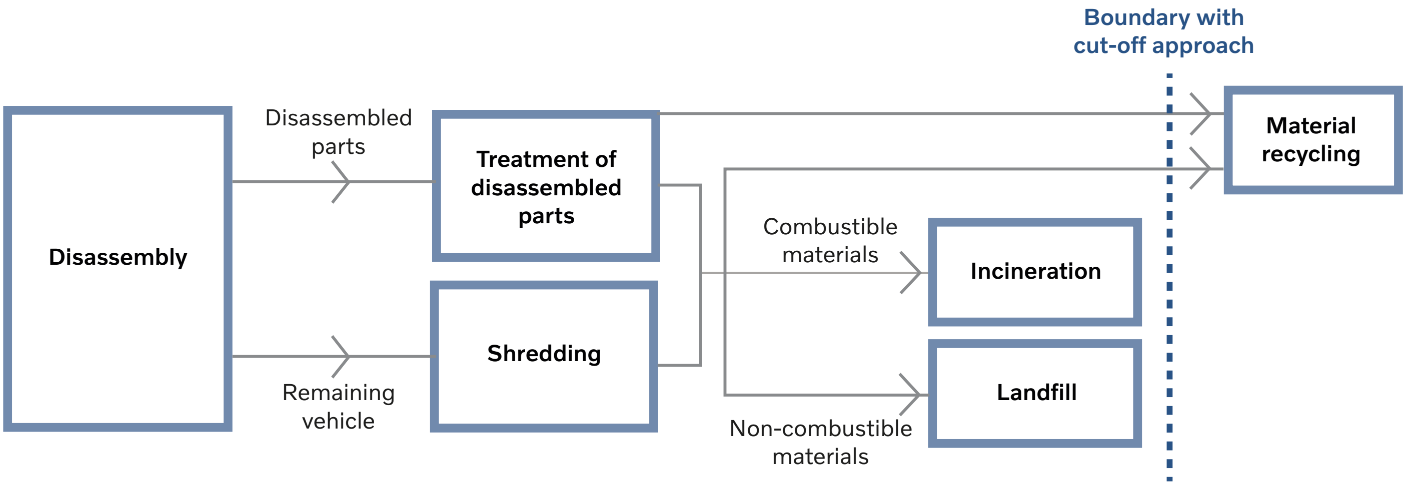


Figure 4. *End-of-life system boundaries.*

From a global perspective the treatment of fuels, oils and coolants generally implies incineration. The tyres are assumed to be salvaged for rubber recovery, and the lead batteries for lead recovery. The catalytic converter contains valuable metals and is disassembled for further recycling efforts. Oil filters are assumed to be incinerated, as are airbags and seat belt pretensioners, which are disassembled for safety reasons rather than the potential recycling value.

The Li-ion battery is assumed to be taken out of the vehicle and sent to recycling. 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 landfill. For the purpose 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, no energy recovery is included for the incineration steps, even though in some Volvo Cars 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 taking place, 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 3 – End-of-life assumptions and method*.

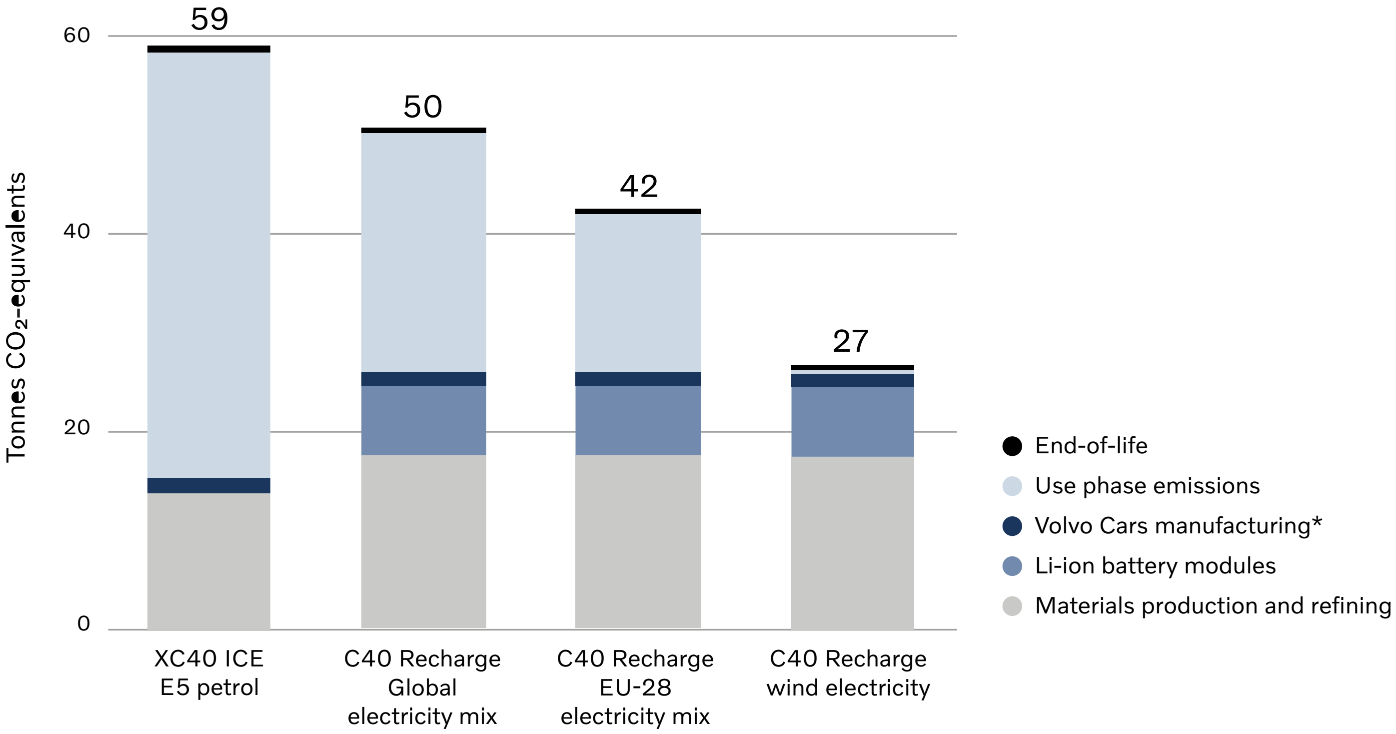
4. Results

4.1 C40 Recharge compared with XC40 ICE (E5 petrol)

The comparison of carbon footprint between C40 Recharge and XC40 ICE (E5 petrol) shows that the C40 Recharge has a 15 per cent lower carbon footprint than the XC40 ICE, calculated with a global electricity mix for driving (***figure 5*** and ***table 4***). Charging the C40 Recharge with an EU-28 electricity mix, the footprint is nearly 30 per cent lower compared to XC40 ICE and charging with wind power gives a reduction of more than 50 per cent.

> If the Li-ion battery is included in the Materials production and refining category, the increase in carbon footprint **is nearly 70 per cent.**

The “Materials production and refining” phase (excluding Li-ion battery modules production) causes almost 30 per cent more GHG emissions for the C40 Recharge compared with the XC40 ICE, mainly due to the increased materials of the C40 Recharge and the increased share of aluminium. When also including the Li-ion battery modules and Volvo Cars manufacturing, the GHG emissions are nearly 70 per cent higher for the C40 Recharge compared with XC40 ICE. However, when including the emissions from the use phase, the total carbon footprint is still lower for the C40 Recharge compared to the XC40 ICE for all three electricity mixes analysed. Manufacturing at Volvo Cars and the end-of-life treatment only give a small contribution to the total carbon footprint.



**Volvo Cars manufacturing includes both factories as well as inbound and outbound logistics.*

Figure 5. Carbon footprint for C40 Recharge and XC40 ICE with different electricity mixes used for the C40 Recharge.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

Vehicle type	Materials production and refining	Li-ion battery modules	Volvo Cars manufacturing	Use phase emissions	End-of-life	Total
XC40 ICE (E5 petrol)	14	-	1.7	43	0.6	**59**
C40 Recharge (global electricity mix)	18	7	1.4	24	0.5	**50**
C40 Recharge (EU-28 electricity mix)	18	7	1.4	16	0.5	**42**
C40 Recharge (wind electricity)	18	7	1.4	0.4	0.5	**27**

Table 4. Carbon footprint for XC40 ICE and C40 Recharge, with different electricity mixes used for the C40 Recharge.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values) and per phase in the life cycle.

Although total emissions from all phases except the use phase of the C40 Recharge are higher than for the XC40 ICE, the C40 Recharge will over the span of its lifetime cause less emissions thanks to lower emissions in the use phase. Where this break-even occurs depends on the difference in GHG emissions from the production of the car, and how carbon intense the electricity mix is in the use phase.

For all three electricity mixes in the LCA, the break-even occurs at 49,000, 77,000 and 110,000km respectively, all within the assumed life cycle of the vehicle (200,000km).

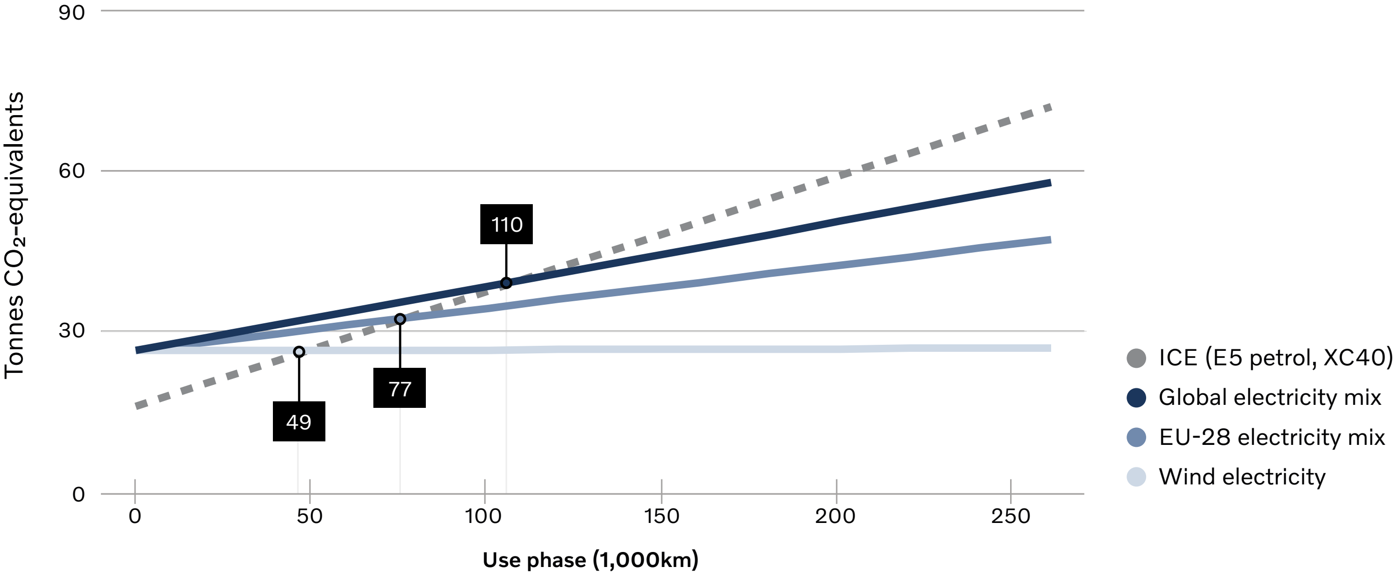


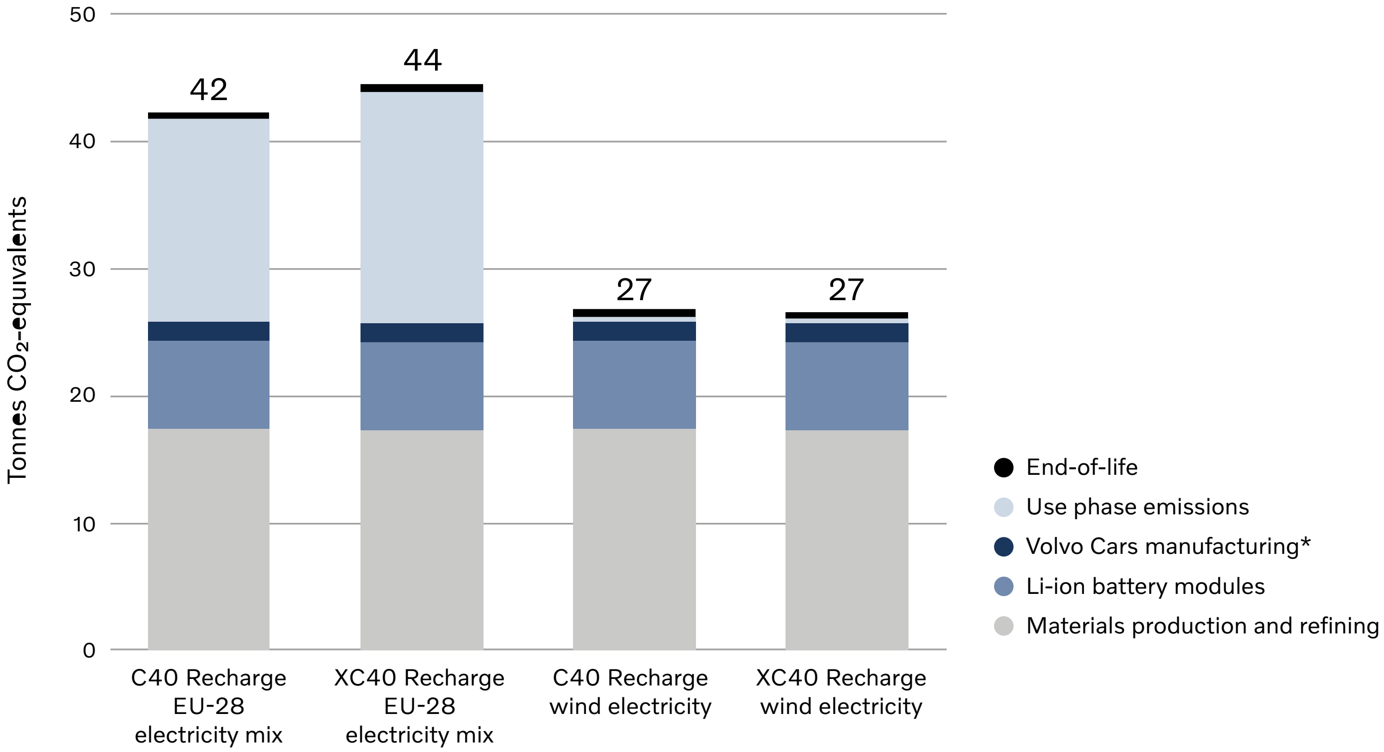
Figure 6. Break-even diagram*: Total amount of GHG emissions, depending on total kilometres driven, from XC40 ICE (dashed line) and C40 Recharge (with different electricity mixes in the use phase). Where the lines cross, break-even between the two vehicles occurs. All life cycle phases except use phase are summarised and set as the starting point for each line at zero distance.*

Vehicle type	Break-even (km)
C40 Recharge, Global electricity mix/XC40 ICE	110,000
C40 Recharge, EU-28 electricity mix/XC40 ICE	77,000
C40 Recharge, wind electricity mix/XC40 ICE	49,000

Table 5. *Number of kilometres driven at break-even between C40 Recharge and XC40 ICE (E5 petrol) with different electricity mixes.*

4.2 C40 Recharge compared with XC40 Recharge

C40 Recharge has a slightly lower carbon footprint compared with XC40 Recharge when EU-28 electricity mix is used for charging the car. This is mainly because of better aerodynamics. See comparison in ***figure 7*** and ***table 6*** below.



** Volvo Cars manufacturing includes both factories as well as inbound and outbound logistics.*

Figure 7. Carbon footprint for C40 Recharge and XC40 Recharge, with different electricity mixes.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

Vehicle type (electricity mix in the use phase)	Materials production and refining	Li-ion battery modules	Volvo Cars manufacturing	Use phase emissions	End-of-life	Total
C40 Recharge (global)	18	7	1.4	24	0.5	**50**
C40 Recharge (EU-28)	18	7	1.4	16	0.5	**42**
C40 Recharge Recharge (wind)	18	7	1.4	0.4	0.5	**27**
XC40 Recharge (global)	17	7	1.5	28	0.5	**54**
XC40 Recharge (EU-28)	17	7	1.5	18	0.5	**44**
XC40 Recharge (wind)	17	7	1.5	0.4	0.5	**27**

Table 6. Carbon footprint for C40 Recharge and XC40 Recharge with different electricity mixes for charging the car.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

GHG emissions in the “Materials and refining” phase for C40 Recharge is approximately 1 per cent higher compared to XC40 Recharge. This is mainly due to more aluminium in the car compared with XC40 Recharge and some more “undefined” materials. This is more than compensated when e.g., EU-28 or global electricity mix is used for driving the car. However, using wind power, the total carbon footprint becomes roughly the same, 27 tonnes CO_2-equivalents, because of the low carbon footprint of the use phase. The level of GHG emissions in the use phase with EU-28 electricity mix is nearly 13 per cent lower for the C40 Recharge, and the corresponding level in life cycle carbon footprint is roughly 5 per cent lower.

4.3 Production of materials and components

This chapter gives an insight into how different material types and components contribute to the GHG emissions in the materials production and refining phase including Li-ion battery modules production. See ***figures 8–10*** for the relative contributions to the GHG emissions for the different material types. ***Figure 8*** shows C40 Recharge, ***figure 9*** XC40 Recharge and ***figure 10*** XC40 ICE (E5 petrol).

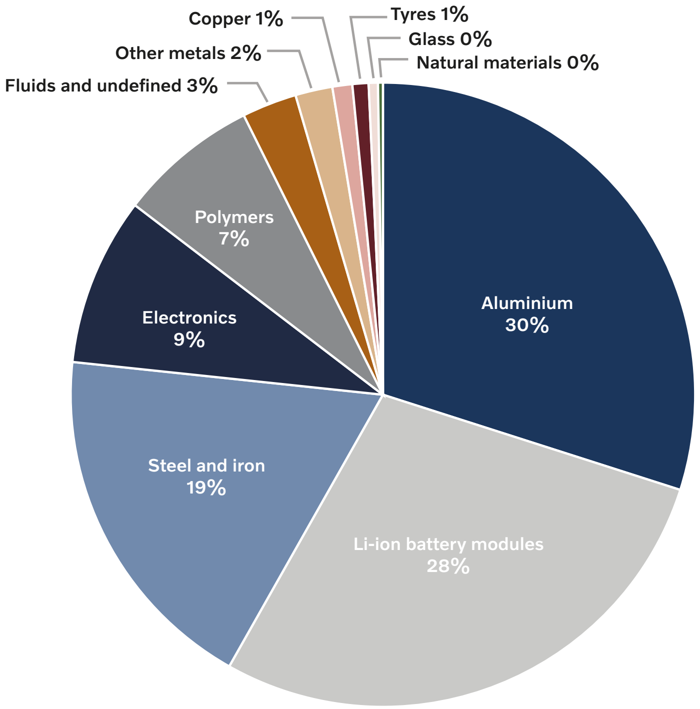


Figure 8. C40 Recharge.
Contribution to GHG emissions from production of different material types and Li-ion battery modules in the “Materials production and refining” phase.

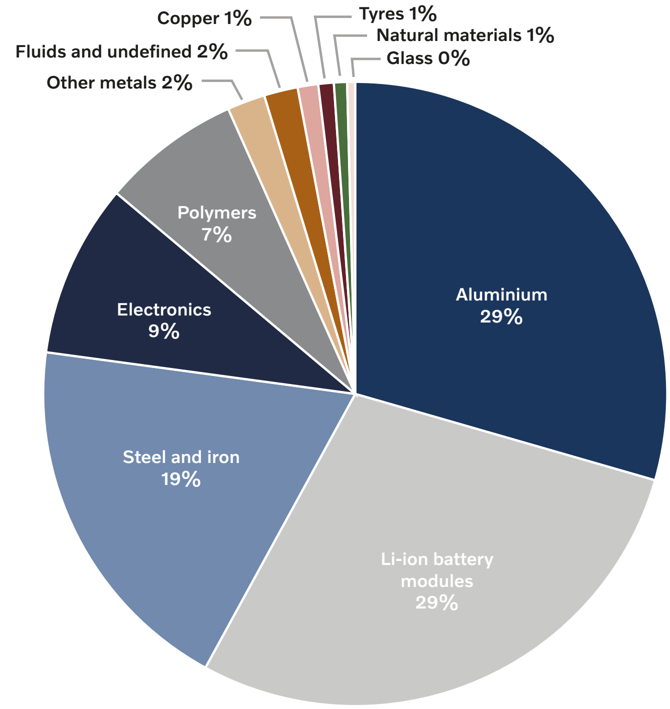


Figure 9. XC40 Recharge.
Contribution to GHG emissions from production of different material types and Li-ion battery modules in the "Materials production and refining" phase.

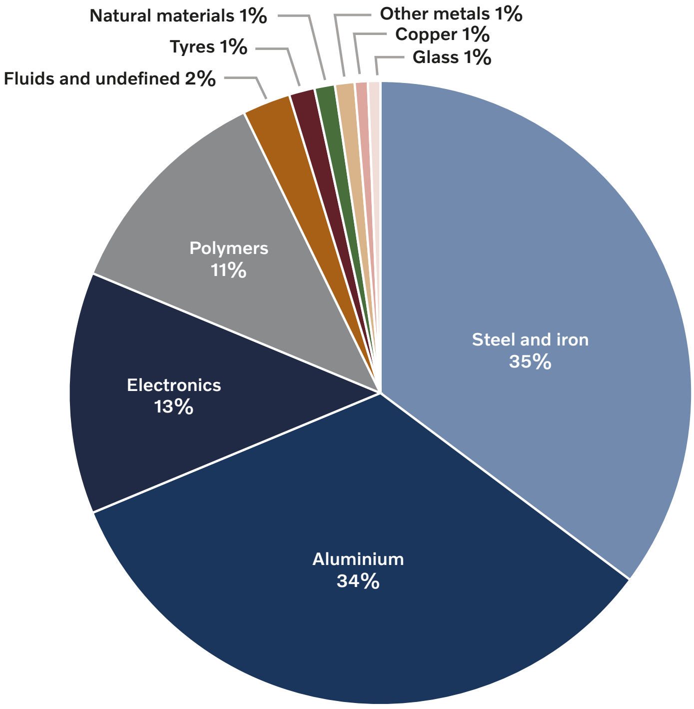


Figure 10. XC40 ICE.
Contribution to GHG emissions from production of different material types and Li-ion battery modules in the "Materials production and refining" phase.

For C40 Recharge, the GHG emissions from aluminium and Li-ion battery pack production make up the biggest share, 30 per cent and 28 per cent respectively while steel, iron and polymer materials contribute 19 per cent, 9 per cent and 7 per cent respectively. The emissions from the production of materials and components for XC40 are similar.

For XC40 ICE however, the main contributions to GHG emissions come from steel and iron (35 per cent) and aluminium (34 per cent).

More of how the carbon footprint can be reduced and what actions Volvo Cars has taken, can be found in chapter *5.2, sensitivity analysis* and chapter *6, discussion*.

5. Sensitivity analysis

Since most data in this study are conservative, it is interesting to investigate the effect of more probable data on the carbon footprint results. One example is the highly probable scenario that the carbon intensity of the electricity mix in Europe will be reduced during the assumed lifetime of the BEVs. Another example that is tested is the effect of using European material production data instead of the global one. This is especially relevant given that the first C40 Recharge will be produced in Europe with many regionally sourced parts and materials.

5.1 Explore future electricity grid mix for EU-28 for use phase

During the lifetime of the C40 Recharge, the European electricity mix will probably increase its share of renewable energy sources. However, a conservative approach for the electricity mix is chosen in the study, by using the current European (EU-28) electricity mix for the whole lifetime of the car. Therefore, a test on how a more realistic trend of the increased renewable share in the electricity mix affects the total carbon footprint was performed. See ***figure 11*** for the aggregated GHG emissions during the use phase of the C40 Recharge.

The different EU-28 scenarios are from IEA[21] and modelled in GaBi.

Stated policies scenario reflects the impact of existing policy frameworks and today's announced policy intentions and *sustainable development scenario* maps out a way to meet sustainable energy goals, fully aligned with the Paris Agreement by holding the rise in global temperatures to "well below 2C degrees".

The figure shows how the increased use of renewable energy sources in the scenarios for the European electricity mix affects the GHG emissions in a positive way, but also that new policies are needed to meet the climate goals set in the Paris agreement. The most efficient way to reduce GHG emissions are however clearly to change to electricity with much lower carbon intensity, such as wind with an emission factor of only approximately 3 per cent of the emission factor for the current EU-28 mix (according to the GaBi database).

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[21] World Energy Outlook 2017 – Analysis – IEA

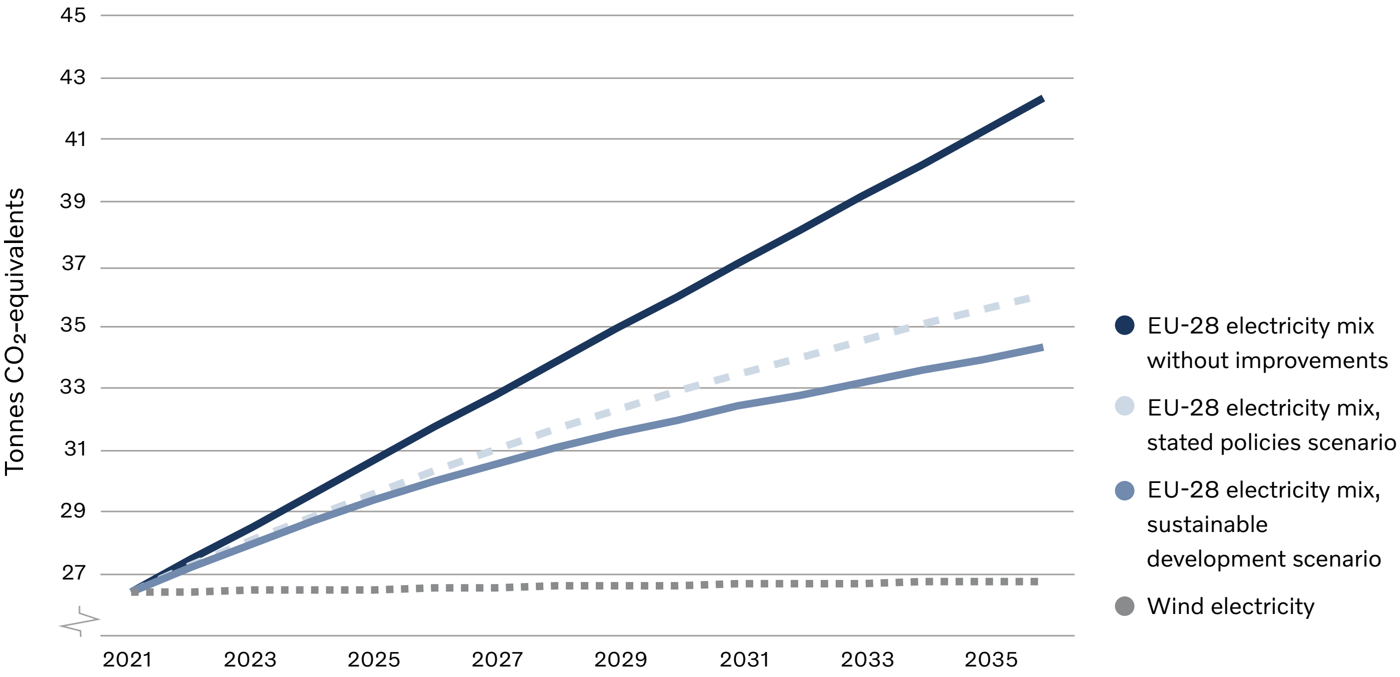


Figure 11. The total GHG emissions for the estimated lifetime of C40 Recharge.
All life cycle phases except use phase are summarised and set as the starting point for each line at year 2021.

5.2 Explore regionalised datasets for material production (EU compared to global)

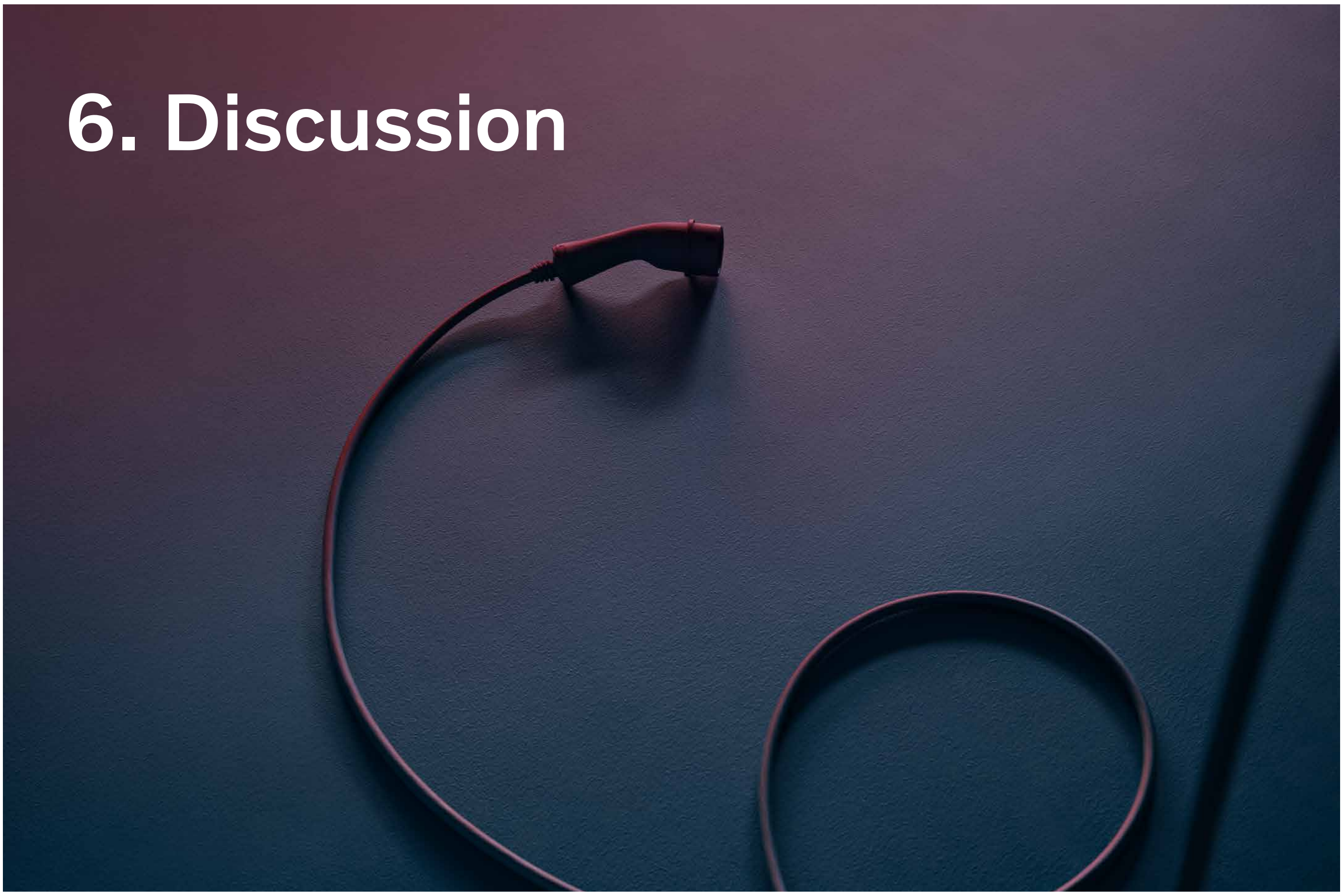
In this sensitivity analysis, it is assumed that some materials for the C40 Recharge are produced in Europe instead of globally sourced as in the base case. In fact, this car will be manufactured in Ghent in Belgium to start with, and materials will be partly regionally sourced. The main data for materials production that were changed to European average instead of global average are aluminium, steel, iron, polymers and tyres. Electronics and Li-ion battery modules data were not changed. The emission factors of European data compared to global data are lower for these chosen datasets; roughly 50 per cent for aluminium, 10 per cent for steel and iron, 10 per cent for polymers and 5 per cent for tyres. This calculation gives an approximate reduction of 17 per cent for the GHG emissions in the “Materials production and refining” phase and “Li-ion battery modules”.

This result clearly demonstrates that sourcing from suppliers that have products and materials with a lower carbon footprint today has a great potential to reduce the overall carbon footprint of the vehicle. This potential will likely increase, as other companies are likely to decarbonise their value chains as well. It also shows that the geographical scope of the study has a significant effect on the overall results, why an LCA could show an overly conservative or an overly optimistic result compared to the real-world situation.

The results also indicate that the reduction potential differs a lot for different materials. The carbon footprint of the production of primary aluminium is heavily dependent on the electricity mix used and thus the generic data varies quite a lot between regions.

Whereas the regional differences of producing steel are significantly less than for aluminium, the carbon footprint reduction will require both a technology change and a decarbonisation of the global energy system. This is further elaborated in the discussion chapter.

6. Discussion



This carbon footprint study of C40 Recharge, XC40 Recharge and XC40 ICE provides insight into both the relative contribution to the carbon footprint from different life cycle phases (see ***figures 5*** and ***7***) as well as the underlying causes for the emissions. In turn, these insights can be used to guide efforts into understanding and reducing the emissions. The comparisons show the differences and similarities between the BEV and the ICE vehicle technology, and the potential benefits of electrification.

6.1 The importance of electricity mix choice for charging the car

Testing of alternative electricity mixes for the C40 Recharge in the use phase shows that the choice of electricity source when charging the car is a crucial factor in determining the total life cycle carbon footprint. A C40 Recharge that runs on wind power has only half the carbon footprint of an XC40 ICE for the function of 200,000km total driving distance.

Scenarios for the European market indicate that the carbon intensity of electricity production may further decrease there. This would mean that there will likely be a continuous reduction of the BEVs carbon footprints even if no active choice of using renewable energy in the use phase is made, although an active choice for renewable electricity gives a much larger positive difference for the climate.

6.2 Shift of focus

When considering a global average electricity mix, the life cycle impact is split roughly 50/50 between the materials production and refining phases and the use phase (***figure 5***). In contrast, choosing wind based electricity for car charging reduces the life cycle carbon footprint significantly compared to driving with EU-28 or global electricity mix, and consequently the "Materials production and refining" phase dominates. This will shift the focus to the "Materials production and refining" phase and further emphasise the importance of efforts to reduce the GHG emissions in this phase. Volvo Cars is working towards reducing the GHG emissions from the "Materials production and refining" phase by 25 per cent per average vehicle from 2018 to 2025, which is an ambitious start towards achieving climate neutrality by 2040.

> The strategy of Volvo Cars working towards reducing the carbon footprint from the materials production and refining phase by 25 per cent per average vehicle from 2018 to 2025, which is an ambitious start towards achieving climate neutrality by 2040.

6.3 Energy sources for materials production and refining

The choice of energy source in the "Materials production and refining phase" also has an impact on the total carbon footprint, e.g., some metal production processes like the smelting process of primary aluminium production and the electrical furnace for steel production from recycled steel are very electricity intensive. However, changing electricity source has not yet been tested in the calculations since many of the background datasets are aggregated and therefore not possible to change. An indication of the possible effect of electricity choice was however given in the sensitivity analysis where regional average data for materials production was tested instead of global including these metals.

6.4 Technical development of materials production and refining

Reducing the impact of materials requires more efficient production, increased use of recycled content and more renewable energy in production. Therefore, Volvo Cars is currently exploring the use of fossil free steel in our products, having very low GHG emissions, as well as increasing the share of recycled content.

The GHG emissions from production of polymers for different plastics are currently also significant. These emissions can be reduced by increasing the use of recycled plastics and bioplastics which in turn also would reduce the emissions of fossil GHGs when incinerated after use. Volvo Cars aims to use at least 25 per cent recycled or bio-based plastics by year 2025 in their products[22].

6.5 Battery development

BEV driveline technology is still young compared to the ICE driveline implying a relatively higher potential for improvements. Recent studies have shown a general decrease in carbon footprint of battery production over recent years, and it is likely that it will continue decreasing.

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[22] Volvo sets goal of 25 percent recycled plastics in cars from 2025 | Reuters

6.6 The effects of the methodological choices

The choice of allocation method gives the result that all GHG emissions from scrap generation are allocated to the vehicles. This in turn results in a relatively high carbon footprint of the vehicles produced by Volvo Cars compared to some other studies where production of material ending up as scrap in the manufacturing is excluded[23]. Furthermore, the metal production datasets that have been used are average data, and further investigation is needed to assess to what extent this data differs from the supply network of Volvo Cars. The sensitivity analysis shows, that if data for some of the material production, especially aluminium, is European instead of global, a significant reduction of carbon footprint is achieved – an indication of how important sourcing of materials with low carbon footprint is.

Important to remember is that this study is conservative. Therefore, all aluminium is set to be primary, thus produced from bauxite ore, although it is highly probably that a large part of the cast aluminium production is based on recycled metal[24]. Primary aluminium production is much more energy-intensive to produce than recycled[25], so the real GHG emissions from aluminium production are probably lower.

6.7 Need for more transparency and traceability

Transparency and traceability of the value chains need to be improved and this is especially a challenge for complex products such as vehicles, electronics and Li-ion batteries.

For example, data for production of electronics have a large uncertainty due to their production complexity with many different, raw materials and suppliers. Specific LCI data for electronic parts are lacking and this problem is paid attention to by e.g., the Argonne National Laboratory[26].

The proposed new Li-ion battery regulation sets a requirement for battery “passports” which will push for tracing the supply chain. Also, more specific LCI data from the actual production sites, thus moving from industry average data, is also pushed for. Acknowledging the extreme complexity to harmonise methods and data, these improvements are a must for securing more precise carbon footprint reporting in the future, which in turn is needed to build trust for societies’ struggle to fight global warming. Several actions in this direction are ongoing with digitalisation as an enabler, e.g., by the European Commission and their so called “Green Deal[27]”.

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[23] E.g., GREET calculation model, https://greet.es.anl.gov/

[24] Material Economics, 2020. Preserving value in EU industrial materials – A value perspective on the use of steel, plastics and aluminium. https://materialeconomics.com/latest-updates/preserving-value-in-eu-industrial-materials

[25] https://www.iea.org/reports/aluminium

[26] Dai, Q., Kelly, J.C., Gaines, L. &Wang, M., 2019. Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications. Batteries 2019, 5 (48) Batteries | Free Full-Text | Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications (mdpi.com)

[27] A European Green Deal | European Commission (europa.eu)

7. Conclusions

The C40 Recharge has approximately 5 per cent lower total carbon footprint than XC40 Recharge when charged with EU-28 electricity mix. It has also a lower total carbon footprint than the XC40 ICE (E5 petrol) for all the analysed sources of electricity for the use phase.

The carbon footprints of a C40 Recharge, XC40 Recharge, both charged with EU-28 electricity mix, and XC40 ICE fuelled with E5 petrol are 42, 44 and 59 tonnes CO_2-equivalents respectively for a total driving distance of 200,000km. The reason for the lower carbon footprint of the Recharge models compared with XC40 ICE is due to lower emissions of greenhouse gases in the use phase. C40 Recharge has a 5 per cent lower carbon footprint than XC40 for the same driving distance and for charging with EU-28 electricity, 42 tons compared with 44 tons. For the lower carbon footprint of C40 Recharge compared with XC40 Recharge, this is due to the better aerodynamic properties of the car body. Comparing different electricity mixes, the carbon footprint for C40 Recharge when charging with global electricity mix, EU-28 electricity mix and wind power are 50, 42 and 27 tonnes CO_2-equivalents respectively.

The carbon footprint of C40 Recharge and BEVs in general could soon be even lower thanks to potential improvements in, e.g. battery technology, global energy systems and lower carbon footprints for materials and parts production in general.

The break-even analysis in the study investigates at what driving distance the carbon footprints of the C40 Recharge become less than the XC40 ICE (E5 petrol) based on alternative electricity mix. It shows that all break-even points for the tested electricity mixes occur within the used total driving distance of 200,000km. After the break-even point the carbon footprint of the C40 Recharge improves linearly compared with the XC40 ICE. The longer the lifetime, the better the relative carbon footprint of the C40 Recharge. It should be noted that a BEV sold on a market with carbon intensive electricity production indeed can be charged with electricity from renewable energy, which would decrease the carbon footprint substantially.

Furthermore, the results assumed a constant carbon intensity within the alternate electricity mix throughout the vehicle lifetime as shown likely to overestimate the total carbon footprint at least in Europe, as shown in the sensitivity analysis for the EU-28 electricity mix.

Appendix 1 – Complete list of Volvo Cars material library material categories

Material name	Material group
ABS (filled)	Polymers
ABS (unfilled)	Polymers
AdBlue	Fluids
Aluminium (matcat)	Aluminium
Anode*	
Aramid	Polymers
ASA (filled)	Polymers
ASA (unfilled)	Polymers
Brake fluid	Fluids
Cast iron (matcat)	Steel and iron
Catalytic coating	Glass
Cathode*	
Copper	Copper
Copper alloys	Copper
Cotton	Natural materials
Damper	Polymers
Diesel	Fluids
E/P (filled)	Polymers
E/P (unfilled)	Polymers
Elastomer	Polymers
Electronics	Electronics
EPDM	Polymers
EVAC (filled)	Polymers
EVAC (unfilled)	Polymers
Ferrite magnet	Other metals
Float glass	Glass
Friction	Natural materials
GF-fibre	Glass
Glycol	Fluids
Lead, battery	Other metals
Leather	Natural materials

Material name	Material group
Lubricants (matcat)	Fluids
Magnesium	Other metals
NdFeB	Other metals
NR	Polymers
PA (filled)	Polymers
PA (unfilled)	Polymers
PBT (filled)	Polymers
PBT (unfilled)	Polymers
PC (filled)	Polymers
PC (unfilled)	Polymers
PC+ABS (filled)	Polymers
PC+ABS (unfilled)	Polymers
PE (filled)	Polymers
PE (unfilled)	Polymers
PET (filled)	Polymers
PET (unfilled)	Polymers
Petrol	Fluids
PMMA (filled)	Polymers
PMMA (unfilled)	Polymers
Polyester	Polymers
Polyurethane (matcat)	Polymers
POM (filled)	Polymers
POM (unfilled)	Polymers
PP (filled)	Polymers
PP (unfilled)	Polymers
PVB (filled)	Polymers
PVB (unfilled)	Polymers
PVC (filled)	Polymers
PVC (unfilled)	Polymers
R-1234yf	Fluids
R-134a	Fluids

Material name	Material group
SBR	Polymers
Separator, Li battery*	
Silicone rubber	Polymers
Steel, sintered	Steel and iron
Steel, stainless, austenitic	Steel and iron
Steel, stainless, ferritic	Steel and iron
Steel, unalloyed	Steel and iron
Sulphuric acid	Fluids
Thermoplastic elastomers (matcat)	Polymers
Thermoplastics (matcat)	Polymers
Tyre	Polymers
Undefined	Fluids
Washer fluid	Fluids
Wood (paper, cellulose ...)	Natural materials
Zinc	Other metals

** Not used in any carbon footprint reporting presented in this report, since the Li-ion battery modules are modelled separately.*

Appendix 2 – Summary of data
Choices and assumptions for component manufacturing

Material	Assumption on component manufacturing	Comment	Material utilisation change to degree 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 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	
Cast aluminium	Die-casting process		95%
Wrought aluminium	Rolling + Aluminium sheet deep drawing	Assumed to represent different types of wrought processes	63%
Steel (in parts, processed at suppliers)	Steel sheet deep drawing	Sheet is assumed in line with the conservative approach	63%
Steel (stamped in a Volvo factory)	Steel scrap generated at Volvo Cars factories	The steel scrap generated at stamping in the Volvo factories, that is the steel in workstream “vehicle structures”	Confidential
Stainless steel	Steel sheet deep drawing	Sheet is assumed in line with 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%

Appendix 3 – End-of-life assumptions and method

A3.1 Transport

Transportation of materials sent to material recycling is included and it is assumed the material is transported 1,500km by truck.

A3.2 Disassembly

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

A3.3 Pre-treatment

Pre-treatment was included for the following disassembled components:

- Lead acid battery
- Catalytic converter (only ICE vehicles)
- Tyres
- Li-ion batteries (only from electric vehicles)

For the lead acid batteries, catalytic converter and tyres, ecoinvent datasets are used for the pre-treatment stage in this study.

The Li-ion battery is assumed to be transported 1,500km by truck to the recycling facility.

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

A3.4 Shredding

In the shredding process the vehicles are milled to smaller fractions. This process uses electricity. In order to estimate the amount of energy needed, the energy consumption per kg in the dataset "treatment of used glider," passenger car, shredding from ecoinvent 3.7.1 is used. The electricity used for this process is modelled as global average electricity grid mix as described in 3.1.6. Emissions of metals to water and air are omitted based on the scope focusing 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 to occur at the same site as dismantling.

A3.5 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 the material recycling, as mentioned above.

A3.6 Final disposal – incineration and landfill

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

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

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

Transportation of materials which are separated in the shredding processes and which are assumed to be recycled is estimated to 1,500km by truck.

A3.7 Data collection

This section provides an overview of the data collection activities relating to each life cycle stage. For a full list of datasets, see *Appendix 4 – Chosen datasets*.

According to the cut-off methodology, the processes presented in ***Table 7*** are included in the data collection effort.

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

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

Table 7. *Processes included in the data collection effort for end-of-life.*

Appendix 4 – Chosen datasets

The latest ecoinvent database is 3.7.1 which is used in this study.
All other sources are from GaBi professional and extension databases.

Material	Location	Name	Type	Source	Date used
ABS					
ABS (filled)					
ABS (filled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
ABS (filled)	RER	acrylonitrile-butadiene-styrene copolymer production	agg	ecoinvent 3.7.1	01-03-2021
ABS (unfilled)					
ABS (unfilled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
ABS (unfilled)	RER	acrylonitrile-butadiene-styrene copolymer production	agg	ecoinvent 3.7.1	01-03-2021
AdBlue					
AdBlue	EU-28	Urea (46% N)	agg	Fertilizers Europe	20-04-2020
AdBlue	EU-28	Tap water from surface water	agg	ts	20-04-2020
Aluminium					
Aluminium	GLO	Aluminium ingot mix IAI 2015	agg	IAI/Sphera	01-02-2021
Aluminium	EU-28+EFTA	Primary aluminium ingot consumption mix (2015)	agg	European Aluminium	01-02-2021
Aramid					
Aramid	DE	Aramide fiber (para aramid)	agg	ts	28-12-2020
ASA (filled)					
ASA (filled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
ASA (filled)	RER	acrylonitrile-butadiene-styrene copolymer production	agg	ecoinvent 3.7.1	01-03-2021
ASA (unfilled)					
ASA (unfilled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
ASA (unfilled)	RER	acrylonitrile-butadiene-styrene copolymer production	agg	ecoinvent 3.7.1	01-03-2021
Brake fluid					

Material	Location	Name	Type	Source	Date used
Brake fluid	GLO	market for diethylene glycol	agg	ecoinvent 3.7.1	01-03-2021
Cast iron					
Cast iron	DE	Cast iron part (automotive) – open energy inputs	p-agg	Sphera	01-02-2021
Catalytic coating					
Catalytic coating	ZA	market for platinum group metal concentrate	agg	ecoinvent 3.7.1	01-03-2021
Copper					
Copper	EU-28	Copper Wire Mix (Europe 2015)	agg	DKI/ECI	01-02-2021
Copper alloys					
Copper alloys	GLO	Copper mix (99,999% from electrolysis)	agg	Sphera	01-02-2021
Copper alloys	GLO	market for zinc	agg	ecoinvent 3.7.1	01-03-2021
Copper alloys	GLO	Tin	agg	Sphera	01-02-2021
Cotton					
Cotton	GLO	market for textile, woven cotton	agg	ecoinvent 3.7.1	01-03-2021
Damper					
Damper	RER	Polymethylmethacrylate sheet (PMMA)	agg	PlasticsEurope	01-02-2021
Diesel					
Diesel	EU-28	Diesel mix at filling station	agg	Sphera	01-02-2021
E/P (filled)					
E/P (filled)	RoW	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
E/P (filled)	RER	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
E/P (unfilled)					
E/P (unfilled)	RoW	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
E/P (unfilled)	RER	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
Elastomer					
Elastomer	RoW	market for calcium carbonate, precipitated	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	RER	market for calcium carbonate, precipitated	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	RoW	market for lime	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	RER	market for lime	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	GLO	market for carbon black	agg	ecoinvent 3.7.1	01-03-2021

Material	Location	Name	Type	Source	Date used
Elastomer	GLO	market for polyethylene terephthalate, granulate, amorphous	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	GLO	market for zinc oxide	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	RER	zinc oxide production	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	GLO	market for synthetic rubber	agg	ecoinvent 3.7.1	01-03-2021
Elastomer	RER	synthetic rubber production	agg	ecoinvent 3.7.1	01-03-2021
Electronics					
Electronics	GLO	market for printed wiring board, surface mounted, unspecified, Pb containing	agg	ecoinvent 3.7.1	01-03-2021
EPDM					
EPDM	DE	Ethylene Propylene Diene Elastomer (EPDM)	agg	Sphera	01-02-2021
EVAC (filled)					
EVAC (filled)	RoW	market for ethylene vinyl acetate copolymer	agg	ecoinvent 3.7.1	01-03-2021
EVAC (filled)	RER	market for ethylene vinyl acetate copolymer	agg	ecoinvent 3.7.1	01-03-2021
EVAC (unfilled)					
EVAC (unfilled)	RoW	market for ethylene vinyl acetate copolymer	agg	ecoinvent 3.7.1	01-03-2021
Ferrite magnet					
Ferrite magnet	GLO	market for ferrite	agg	ecoinvent 3.7.1	01-03-2021
Float glass					
Float glass	EU-28	Float flat glass	agg	Sphera	01-02-2021
Friction					
Friction	DE	Cast iron part (automotive) - open energy inputs	p-agg	Sphera	01-02-2021
Friction	GLO	market for zirconium oxide	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for graphite	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for barium sulfide	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for barite	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for aluminium hydroxide	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for magnesium oxide	agg	ecoinvent 3.7.1	01-03-2021
Friction	GLO	market for expanded vermiculite	agg	ecoinvent 3.7.1	01-03-2021
Friction	EU-28	Calcined petroleum coke	agg	Sphera	01-02-2021
GF-fibre					

Material	Location	Name	Type	Source	Date used
GF-fibre	GLO	market for glass fibre	agg	ecoinvent 3.7.1	01-03-2021
GF-fibre	RER	glass fibre production	agg	ecoinvent 3.7.1	01-03-2021
Glycol					
Glycol	EU-28	Ethylene glycol	agg	PlasticsEurope	01-02-2021
Lead, battery					
Lead, battery	DE	Lead (99,995%)	agg	Sphera	01-02-2021
Leather					
Leather	DE	Cattle hide, fresh, from slaughterhouse (economic allocation)	agg	Sphera	01-02-2021
Lubricants					
Lubricants	EU-28	Lubricants at refinery	agg	Sphera	01-02-2021
Magnesium, generic					
Magnesium, generic	CN	Magnesium	agg	Sphera	01-02-2021
NdFeB magnet					
NdFeB magnet	GLO	market for permanent magnet, electric passenger car motor	agg	ecoinvent 3.7.1	01-03-2021
NR					
NR	DE	Natural rubber (NR)	agg	Sphera	01-02-2021
PA (filled)					
PA (filled)	RoW	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
PA (filled)	RER	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
PA (unfilled)					
PA (unfilled)	RoW	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
PA (unfilled)	RER	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
PBT (filled)					
PBT (filled)	DE	Polybutylene Terephthalate Granulate (PBT) Mix	agg	Sphera	01-02-2021
PBT (unfilled)					
PBT (unfilled)	DE	Polybutylene Terephthalate Granulate (PBT) Mix	agg	Sphera	01-02-2021
PC (filled)					
PC (filled)	GLO	market for polycarbonate	agg	ecoinvent 3.7.1	01-03-2021
PC (unfilled)					
PC (unfilled)	GLO	market for polycarbonate	agg	ecoinvent 3.7.1	01-03-2021
PC+ABS (filled)					
PC+ABS (filled)	GLO	market for polycarbonate	agg	ecoinvent 3.7.1	01-03-2021

Material	Location	Name	Type	Source	Date used
PC+ABS (filled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
PC+ABS (unfilled)					
PC+ABS (unfilled)	GLO	market for polycarbonate	agg	ecoinvent 3.7.1	01-03-2021
PC+ABS (unfilled)	GLO	market for acrylonitrile-butadiene-styrene copolymer	agg	ecoinvent 3.7.1	01-03-2021
PE (filled)					
PE (filled)	RoW	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
PE (filled)	RER	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
PE (unfilled)					
PE (unfilled)	RoW	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
PE (unfilled)	RER	polyethylene production, low density, granulate	agg	ecoinvent 3.7.1	01-03-2021
PET (filled)					
PET (filled)	GLO	market for polyethylene terephthalate, granulate, amorphous	agg	ecoinvent 3.7.1	01-03-2021
PET (unfilled)					
PET (unfilled)	GLO	market for polyethylene terephthalate, granulate, amorphous	agg	ecoinvent 3.7.1	01-03-2021
Petrol					
Petrol	EU-28	Gasoline mix (regular) at refinery	agg	Sphera	01-02-2021
PMMA (filled)					
PMMA (filled)	RER	Polymethylmethacrylate sheet (PMMA)	agg	PlasticsEurope	01-02-2021
PMMA (unfilled)					
PMMA (unfilled)	RER	Polymethylmethacrylate sheet (PMMA)	agg	PlasticsEurope	01-02-2021
Polyester					
Polyester	GLO	market for fibre, polyester	agg	ecoinvent 3.7.1	01-03-2021
Polyurethane (matcat)					
Polyurethane (matcat)	RoW	market for polyurethane, rigid foam	agg	ecoinvent 3.7.1	01-03-2021
Polyurethane (matcat)	RER	market for polyurethane, rigid foam	agg	ecoinvent 3.7.1	01-03-2021
POM (filled)					
POM (filled)	EU-28	Polyoxymethylene (POM)	agg	PlasticsEurope	01-02-2021

Material	Location	Name	Type	Source	Date used
POM (unfilled)					
POM (unfilled)	EU-28	Polyoxymethylene (POM)	agg	PlasticsEurope	01-02-2021
PP (filled)					
PP (filled)	GLO	market for polypropylene, granulate	agg	ecoinvent 3.7.1	01-03-2021
PP (unfilled)					
PP (unfilled)	GLO	market for polypropylene, granulate	agg	ecoinvent 3.7.1	01-03-2021
PVB (filled)					
PVB (filled)	DE	Polyvinyl butyral granulate (PVB) by-product ethyl acetate	agg	Sphera	01-02-2021
PVB (unfilled)					
PVB (unfilled)	DE	Polyvinyl butyral granulate (PVB) by-product ethyl acetate	agg	Sphera	01-02-2021
PVC (filled)					
PVC (filled)	RoW	polyvinylchloride production, suspension polymerisation	agg	ecoinvent 3.7.1	01-03-2021
PVC (filled)	RER	polyvinylchloride production, suspension polymerisation	agg	ecoinvent 3.7.1	01-03-2021
PVC (unfilled)					
PVC (unfilled)	RoW	polyvinylchloride production, suspension polymerisation	agg	ecoinvent 3.7.1	01-03-2021
PVC (unfilled)	RER	polyvinylchloride production, suspension polymerisation	agg	ecoinvent 3.7.1	01-03-2021
R-1234yf					
R-1234yf	DE	R-1234yf production (estimation)	agg	ts	30-11-2020
R-134a					
R-134a	GLO	market for refrigerant R134a	agg	ecoinvent 3.7.1	01-03-2021
SBR					
SBR	DE	Styrene-butadiene rubber (S-SBR) mix	agg	Sphera	01-02-2021
Silicon rubber					
Silicon rubber	DE	Silicone rubber (RTV-2, condensation)	agg	Sphera	01-02-2021
Steel, sintered					
Steel, sintered	GLO	Steel hot dip galvanised	agg	worldsteel	01-02-2021
Steel, sintered	EU	Steel hot dip galvanised	agg	worldsteel	01-02-2021
Steel, stainless, austenitic					

Material	Location	Name	Type	Source	Date used
Steel, stainless, austenitic	EU-28	Stainless steel cold rolled coil (304)	p-agg	Eurofer	01-02-2021
Steel, stainless, ferritic					
Steel, stainless, ferritic	EU-28	Stainless steel cold rolled coil (430)	p-agg	Eurofer	01-02-2021
Steel, unalloyed					
Steel, unalloyed	GLO	Steel hot dip galvanised	agg	worldsteel	01-02-2021
Steel, unalloyed	EU	Steel hot dip galvanised	agg	worldsteel	01-02-2021
Sulphuric acid					
Sulphuric acid	EU-28	Sulphuric acid (96%)	agg	Sphera	01-02-2021
Thermoplastic elastomers (matcat)					
Thermoplastic elastomers (matcat)	DE	Polypropylene/Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix	agg	Sphera	01-02-2021
Thermoplastics (matcat)					
Thermoplastics (matcat)	RoW	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
Thermoplastics (matcat)	RER	market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
Tyre					
Tyre	DE	Styrene-butadiene rubber (S-SBR) mix	agg	Sphera	01-02-2021
Tyre	EU-28	Water (deionised)	agg	Sphera	01-02-2021
Undefined					
Undefined	RoW	Market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
Undefined	RER	Market for nylon 6	agg	ecoinvent 3.7.1	01-03-2021
Washer fluid					
Washer fluid	DE	Ethanol	agg	Sphera	01-02-2021
Wood					
Wood	EU-28	Laminated veneer lumber (EN15804 A1-A3)	agg	Sphera	01-02-2021
Zinc alloys					
Zinc alloys	GLO	Special high grade zinc	p-agg	IZA	01-02-2021

Manufacturing processes

Material	Location	Name	Type	Source	Date used
Aluminium, manufacturing (DE, EU-28)					
	DE	Aluminium die-cast part	u-so	ts	01-01-2020
	EU-28	Aluminium sheet – open input aluminium rolling ingot	p-agg	ts	20-04-2020
	DE	Aluminium sheet deep drawing	u-so	ts	01-01-2020
Manufacturing (general assumption)					
		Manufacturing (general assumption)	u-so		15-05-2020
Manufacturing, leather (general assumption)					
		Manufacturing, leather	u-so		01-06-2020
Polymers (all categories) manufacturing (GLO)					
	DE	Plastic injection moulding part (unspecific)	u-so	ts	01-02-2019
Stainless steel manufacturing (DE)					
	DE	Steel sheet deep drawing (multi-level)	u-so	ts	01-01-2020
Steel unalloyed, manufacturing (DE, VCC data)					
	DE	Steel sheet deep drawing (multi-level)	u-so	ts	01-01-2020
		Steel manufacturing (VCC data)	u-so		11-05-2020
	DE	Aluminium die-cast part	u-so	ts	01-01-2020
	EU-28	Aluminium sheet – open input aluminium rolling ingot	p-agg	ts	20-04-2020
	DE	Aluminium sheet deep drawing	u-so	ts	01-01-2020

Electricity grid mix

Material	Location	Name	Type	Source	Date used
EU-28 electricity grid mix					
EU-28 electricity grid mix	EU-28	Electricity grid mix 1kV-60kV	agg	Sphera	01-03-2021
Electricity from wind power					
Electricity from wind power	EU-28	Electricity from wind power	agg	Sphera	01-03-2021
GLO electricity grid mix					
GLO electricity grid mix	EU-28	Electricity from lignite	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from natural gas	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from hydro power	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from nuclear	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from wind power	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from heavy fuel oil (HFO)	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from photovoltaic	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from waste	agg	Sphera	01-03-2021
GLO electricity grid mix	EU-28	Electricity from geothermal	agg	Sphera	01-03-2021
EU-28 electricity grid mix – stated policies 2025					
EU-28 electricity grid mix – stated policies 2025	EU-28	Electricity grid mix (2025) (little improvements in sustainability policy)	agg	Sphera	01-06-2021
EU-28 electricity grid mix – stated policies 2030					
EU-28 electricity grid mix – stated policies 2030	EU-28	Electricity grid mix (2030) (little improvements in sustainability policy)	agg	Sphera	01-06-2021
EU-28 electricity grid mix – stated policies 2040					
EU-28 electricity grid mix – stated policies 2040	EU-28	Electricity grid mix (2040) (little improvements in sustainability policy)	agg	Sphera	01-06-2021

Material	Location	Name	Type	Source	Date used
EU-28 electricity grid mix – sustainable development 2025					
EU-28 electricity grid mix – sustainable development 2025	EU-28	Electricity grid mix (2025) (significant improvements in sustainability policy)	agg	Sphera	01-06-2021
EU-28 electricity grid mix – sustainable development 2030					
EU-28 electricity grid mix – sustainable development 2030	EU-28	Electricity grid mix (2030) (significant improvements in sustainability policy)	agg	Sphera	01-06-2021
EU-28 electricity grid mix – sustainable development 2040					
EU-28 electricity grid mix – sustainable development 2040	EU-28	Electricity grid mix (2040) (significant improvements in sustainability policy)	agg	Sphera	01-06-2021

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