LIFE CYCLE ASSESSMENT OF LONG HAULAGE TRUCKS

BATTERY ELECTRIC VS INTERNAL COMBUSTION ENGINE

CONTENTS

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EXECUTIVE SUMMARY

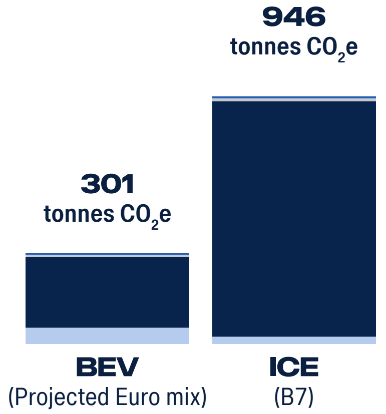
Scania's purpose is to drive the shift towards a sustainable transport system. A holistic view is key to supporting our customers' business and addressing environmental impacts. To track current status and sustainability progress, Scania uses scientific, fact-based methods. One such method used is Life Cycle Assessment (LCA), which enables a detailed analysis of the environmental impacts throughout the life cycle for the product under study. The report at hand summarises the work process and key findings from an LCA study completed in the fall of 2024. The study, conducted in line with DIN EN ISO 14040/44[1], is a comparative life cycle assessment of a battery electric truck and a conventional diesel-driven truck in the long haulage segment. It covers the entire vehicle lifecycle from cradle to grave, including all processes directly related to the product's life cycle, such as raw material extraction, manufacturing, use, maintenance and disposal. The study evaluates several impact categories, but focuses on climate change impact, often referred to as carbon footprint, which currently receives the highest attention both internally and in society in general.

Scope of the study

The study is based on two representative 4x2 long haulage tractors, both characterised by specifications typical for vehicles in the European long-haulage segment. The vehicle specifications are as similar as possible, considering the different drivetrains. As a baseline, the electricity consumed by the battery electric vehicle (BEV) during its use phase is modelled with a projected evolution of the European grid mix, based on the World Energy Outlook 2023 report[2] from the International Energy Agency (IEA). It gives an indication of the performance of the BEV from an European average grid mix perspective. The internal combustion engine (ICE) vehicle use phase is modelled with European diesel B7. As a sensitivity analysis, wind electricity and waste based HVO are investigated to explore the full CO_2e reduction potential of both vehicles. The total driven distance is set to 1 300 000 kilometres, with fuel and energy consumption values derived from VECTO simulations.

Carbon footprint reduction potential

The production of the BEV results in a higher environmental burden compared with the ICE vehicle. A carbon footprint of 24 tonnes for the ICE vehicle is increased to 55 tonnes for the BEV. This is largely driven by battery cell manufacturing. Heavy-duty vehicles (HDVs) are typically characterised by a high utilisation rate, making the use phase the most influencing life cycle phase in terms of climate change impact. In this phase, significant reductions can be achieved with the transition to fully electric vehicles. Despite a more than doubled carbon footprint from production, the full life cycle footprint is reduced by 68% when comparing the BEV with the ICE vehicle (see figure i).



	BEV (Projected Euro mix)	ICE (B7)
End-of-life	2,81	3,15
Maintenance	9,71	10,45
Use WtW	233,10	908,66
Cradle-to-gate	54,96	24,15
Sum (tonnes CO_2e)	**300,58**	**946,41**

Figure i. Full life cycle climate change impact in tonnes of CO_2e.

[1] ISO 14044:2006 "Environmental management — Life cycle assessment — Requirements and guidelines" and ISO 14040:2006 "Environmental management – Life cycle assessment – Principless and framework"

[2] IEA (2023), World Energy Outlook 2023, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2023, Licence: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

The CO_2e break-even, defined as the point where the additional production burden of the BEV is offset due to lower accumulated use phase emissions, will typically occur within less than a year in operation when comparing the BEV with the ICE vehicle (see figure ii).

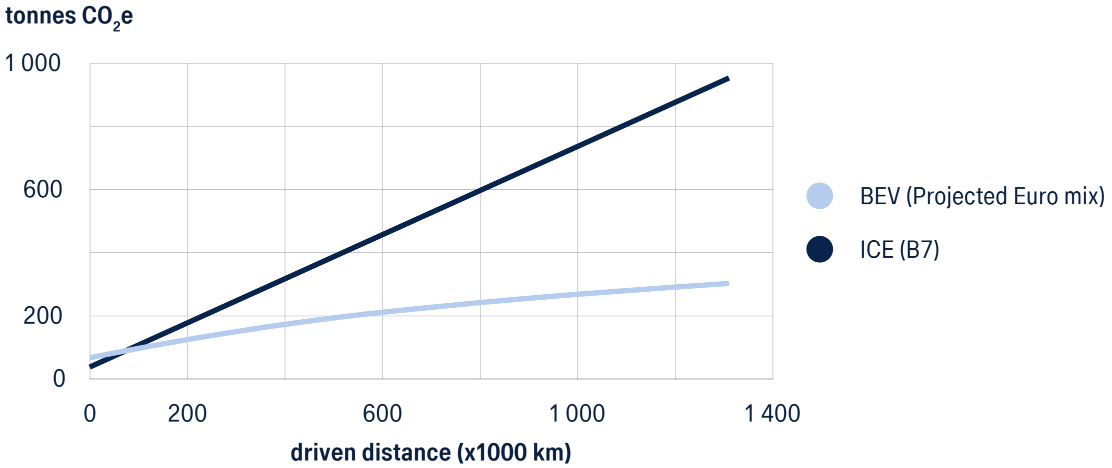


Figure ii. Climate change impact as a function of driven kilometres. Aggregated impacts from production, maintenance and end-of-life is set as the starting point for the curves.

The reduction in climate change impact that can be seen when comparing the BEV with the ICE vehicle is directly dependent on the carbon intensity in the use phase electricity. Using wind electricity will increase the lifetime reduction to 90%. While the lowest possible climate change impact is enabled by the BEV, there is also a clear potential to lower the impacts from the ICE vehicle by using waste based HVO. A lifetime reduction of 81% is achieved by switching from diesel B7 to waste based HVO. However, one aspect of waste-based HVO is the limited potential for large-scale production. Waste-based feedstocks are a limited resource[3], while renewable electricity does not have this limitation in the long term. Nevertheless, waste-based HVO is still a good alternative for decarbonisation in HDV use cases where a BEV is not yet an option.

The great performance showed by the BEV in the climate change impact category comes with other environmental trade-offs. Six other impact categories are investigated, and the BEV shows worse performance in four of them. The increased aluminum and copper content accounts for part of this, but it is primarily the production of battery cells that drives these impacts. This highlights the importance of monitoring other environmental impacts beyond climate change. However, to evaluate one impact category against another requires normalisation and weighting of the results. Currently, there is no established and mature method for doing this. ISO 14040/44 emphasise that these steps should not be used for external communication as they can introduce subjectivity into the results. Therefore, no assumptions or statements are made regarding the importance of one impact category over another.

The results from the LCA are not intended to be compared to other studies or to other manufacturer LCAs. The choice of functional unit, methodology, scope and access to primary data have a great influence on the final result. Scania welcomes the long-term development of harmonised LCA guidelines and is committed to contributing to this development.

Key findings

- The production of the BEV results in a carbon footprint of 55 tonnes CO_2e, compared to a footprint of 24 tonnes for the ICE vehicle.
- Based on the European grid mix and its projected development, the BEV's total life cycle carbon footprint is 68% lower than that of the ICE vehicle running on diesel B7.
- Based on the use of wind electricity, the BEV's total life cycle carbon footprint is 90% lower than that of the ICE vehicle running on diesel B7.
- Low well-to-wheel emissions during operation mean that CO_2e break-even (where the increased production footprint of the BEV is offset) is typically reached within one year of operation.

[3] European Commission: Directorate-General for Research and Innovation, Georgiadou, M., Goumas, T. and Chiaramonti, D., Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels – Final report, Georgiadou, M.(editor), Goumas, T.(editor) and Chiaramonti, D.(editor), Publications Office of the European Union, 2024, https://data.europa.eu/-doi/10.2777/679307

INTRODUCTION

Sustainability plays a crucial role in Scania's strategy and business model. To track current status and sustainability progress, Scania uses scientific fact-based methods. One such method used is Life Cycle Assessment (LCA), which enables a detailed analysis of the environmental impacts throughout the life cycle for the products under study. Current legislation focuses on tailpipe emissions, while LCA provides a holistic view of a vehicle's total environmental footprint. This methodology can identify hidden environmental costs and benefits that tailpipe emissions regulations might overlook. Although LCA is not a legal requirement, its adoption could drive innovation and lead to more environmentally friendly transport solutions. LCA complements existing legislation by providing a broader perspective on environmental impact, encouraging a shift towards truly sustainable practices in the heavy-duty vehicle industry

The report at hand summarises key findings from an LCA study completed in the fall of 2024. The LCA analyses two vehicles in the long haulage segment, one fully electric and its counterpart with a conventional drivetrain. The study was performed as a comparative study, which enables displaying the environmental impacts of the BEV in relation to the corresponding impacts of the conventional vehicle. Its purpose is to enhance Scania's internal knowledge and enable fact-based communication to customers and other stakeholders outside Scania.

The LCA was critically reviewed by independent third party IVL Svenska Miljöinstitutet in November/December 2024, following the ISO 14040/44 standards.

The results from the LCA are not intended to be compared to other studies or to other manufacturer LCAs. The choice of functional unit, methodology, scope and access to primary data have a great influence on the final result. Scania welcomes the long-term development of harmonised LCA guidelines and is committed to contributing to this development.

TERMS AND DEFINITIONS

Life Cycle Assessment (LCA)

A life cycle assessment is a systematic method for assessing the environmental impacts of a product or service throughout its entire life cycle. This includes phases such as raw material extraction, production, use and disposal. By analysing and quantifying energy consumption, resource use and emissions at each life cycle phase, the LCA gives a holistic approach to the environmental impacts. It is widely used in various industries, including automotive, to assess and improve the environmental performance of products and processes. The four phases of the LCA (see Figure 1), as described by ISO 14040 are goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation. Results are analysed for each impact category, and differences between products and life cycle phases are discussed.

Life Cycle Inventory (LCI)

The life cycle inventory is a part of the LCA that involves collecting and modelling all necessary data related to a product's life cycle. This process quantifies raw material use, energy requirements and emissions, creating a comprehensive inventory of elementary flows to and from the ecosphere. This inventory serves as the foundation for assessing the environmental impacts associated with the product.

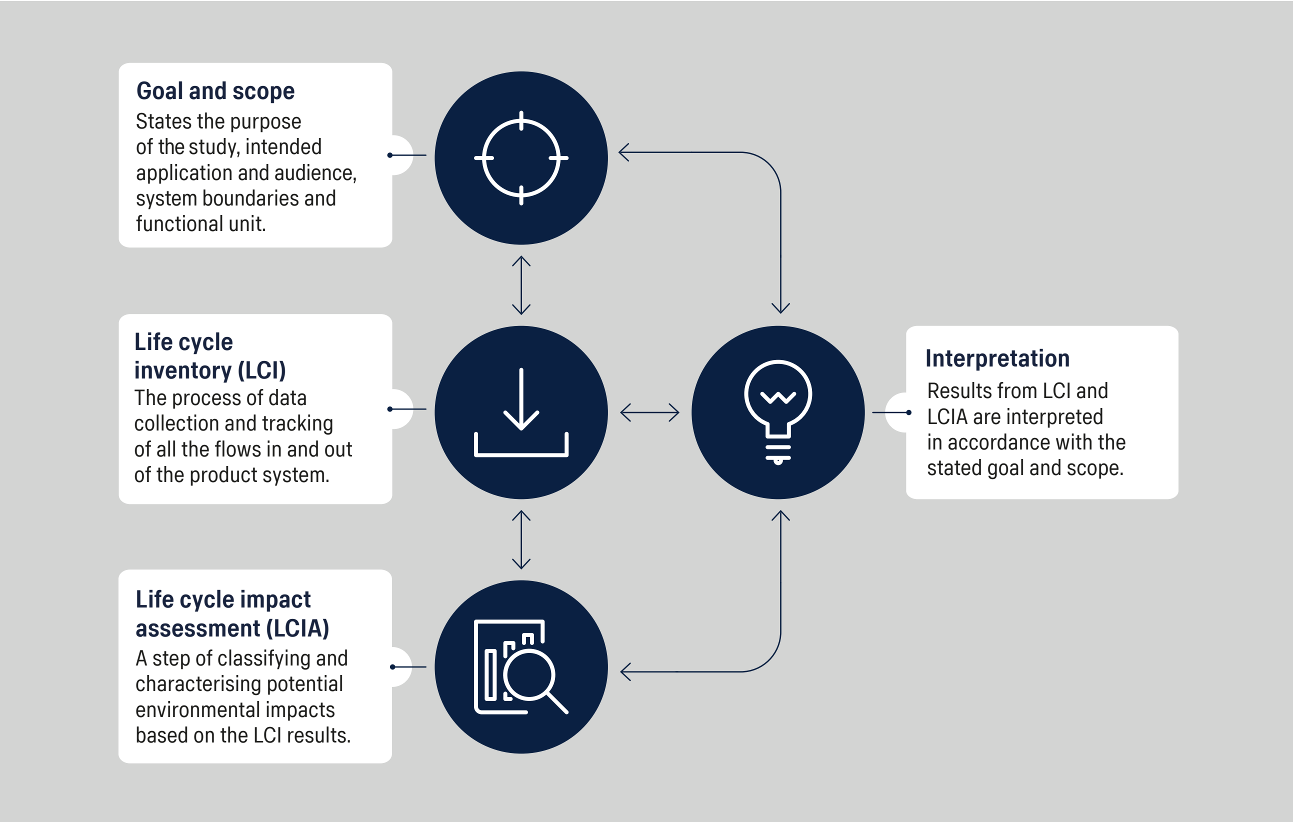


Figure 1. The four phases of LCA.

Life Cycle Impact Assessment (LCIA)

The life cycle impact assessment is a part of the LCA that involves converting the elementary flows identified in the LCI into potential environmental impacts. This is typically divided into four steps: classification, characterisation, normalisation and weighting. The analysis at hand includes classification and characterisation as the mandatory LCIA steps, while normalisation and weighting are excluded, as they are not recommended for external communication by ISO 14040/44. The classification step assigns LCI results to specific environmental impact categories (e.g., CO_2 and CH_4 are categorised under Climate change). The characterisation step then uses characterisation factors to convert the LCI results for each impact category into impact category indicators (e.g., CH_4 is expressed as CO_2 equivalents (CO_2e)).

LCIA methodology

The LCIA methodology encompasses a comprehensive set of methods used to calculate various impacts, also known as impact categories. An impact refers to the consequences of emissions identified in the life cycle inventory on the environment, human health, and resource availability. Different methodologies can be employed to assess the same impact category. It's crucial to choose a recognized and robust methodology, as this ensures the assessment is credible and applicable. Different methodologies may yield varying results, so selecting one that aligns with the study's goals is essential.

Functional unit

The functional unit in an LCA is the specific unit for which results are reported. It defines and quantifies the primary function of the product being analysed, serves as a reference point for relating inputs and outputs, and forms the foundation for comparison and analysis.

Impact category

An impact category groups various emissions that contribute to a similar environmental effect. Emissions causing the same type of impact are aggregated into a single unit, which represents that specific impact category (examples of impact categories: Climate change, Eutrophication, Acidification).

BOM

The bill of materials (BOM) is a comprehensive list of all materials used in the vehicle, along with the quantity of each material.

Cradle-to-grave

A cradle-to-grave assessment evaluates the environmental impacts at every phase of a product's life cycle. From extraction of natural resources (the "cradle"), followed by manufacturing, transportation, product use and ultimately disposal (the "grave"). In essence, it encompasses the entire life cycle of a product.

Dataset

A dataset in LCA refers to a document or file containing life cycle information for a specified product or process (e.g., a material or a process). It includes descriptive metadata as well as quantitative data related to the life cycle inventory and/or life cycle impact assessment.

Cut-off

Cut-off rules allow LCA practitioners to conduct assessments without modeling the entire product system. These rules enable the omission of non-relevant activities, processes, products or elementary flows from the system model, streamlining the analysis while still ensuring meaningful results.

TOOLS AND DATABASE

LCA for experts

LCA software with LCI databases from Sphera Solutions GmbH[4].

LEAD database

LEAD database is the Volkswagen Group internal LCA database including Sphera specific and VW Group developed datasets. Content version 2023.2 was used in this study. Datasets from the LEAD database are referred to as LEAD datasets.

Scania Mapping List

Scania mapping list is an XML file connecting each material in a model with the adequate LEAD dataset. It enables automated model generation in SlimLCI+.

Slim LCI+

The SlimLCI+ tool matches LEAD datasets with the BOM, based on Scania Mapping List.

IMDS

The International Material Data System (IMDS)[5] is a standardised automotive material data system that enables suppliers to report the material composition of parts. The system helps manufacturers ensure compliance with environmental regulations and promotes transparency in material sourcing.

SMART

Scania tool (by iPoint-systems GmbH) for managing Material Data Sheets (MDS) from IMDS.

Translation Tool

The Translation Tool is a MATLAB based tool developed by the LCA team at Scania. The main functionality of the tool is to translate and condense the extensive amount of materials reported in IMDS into a manageable number of materials to be modelled.

VECTO

The Vehicle Energy Consumption calculation Tool (VECTO)[6] is developed by the European Commission as the official simulation tool for calculating fuel and energy consumption in heavy-duty vehicles (HDVs), specifically for the declaration of CO_2e emissions.

4 https://sphera.com/solutions/product-stewardhip/life-cyle-assessment-software-and-data/lca-for-experts/
5 https://www.mdsystem.com/imdsnt/startpage/index.jsp
6 https://web.jrc.ec.europa.eu/policy-model-inventory/explormodels/model-vecto/

GOAL AND SCOPE

The goal of the LCA is to assess the environmental impacts of a battery electric long haulage truck and a conventional, diesel driven counterpart. The results can each be used independently, but the study enables a comparison between the two. The results are made public with the intention to increase knowledge and transparency of the life cycle environmental impacts of Scania vehicles and the comparison between a BEV and an ICE vehicle in specific. The intended audience is customers, decision makers, researchers and the public. The LCA follows an attributional approach, which quantifies the environmental impacts associated with the life cycle of the vehicles based on measured, historical data. It effectively captures the total emissions directly linked to the vehicles. Methodology EN15804+A2 is used to quantify full life cycle environmental impacts of the vehicles at midpoint level. Several impact categories are investigated, but in this report, most emphasis is laid on the impact category Climate change. The decision of inclusion or exclusion of a particular impact category in a communication is mainly determined by its relevance and the method maturity level.

System boundary

The study encompasses the complete life cycle of the vehicles, often referred to as ‘cradle-to-grave’. This includes every phase in the vehicle life, starting from the extraction of raw materials, moving through the production and operational phase of the vehicle, and concluding with its end-of-life disposal. A schematic description of the system boundary can be seen in Figure 2.

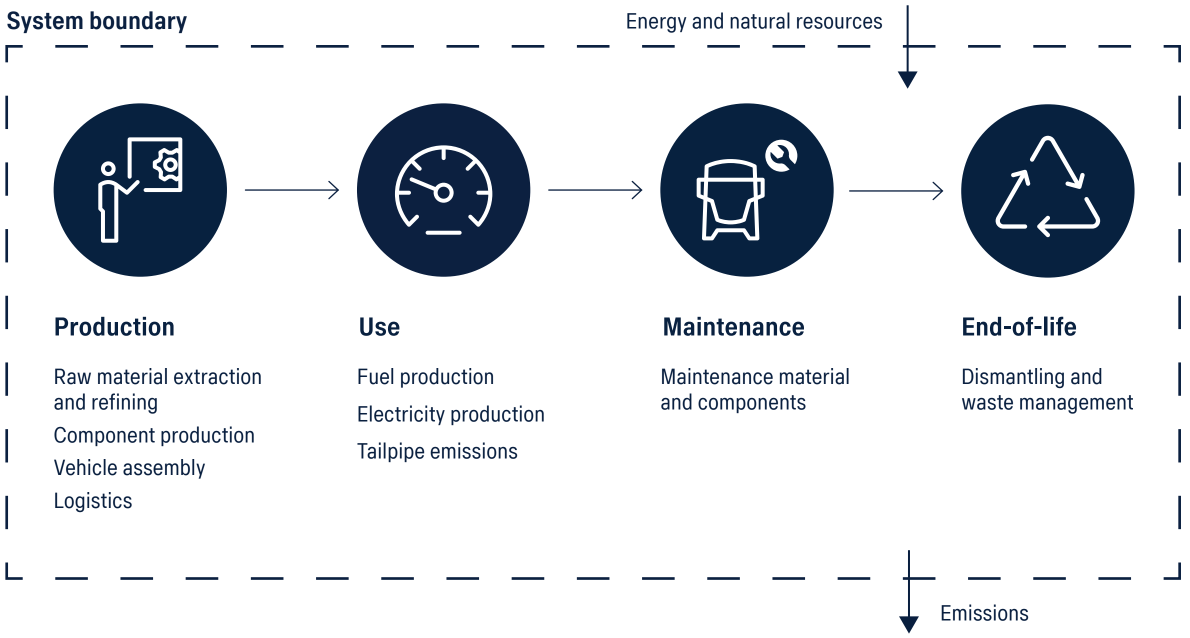


Figure 2. Schematic description of the system boundary.

Data source and quality

Foreground data in the form of vehicle part lists originates from the Scania PDM system (Product Data Management system). IMDS is the information source for the material composition for parts and components. The data is Scania and vehicle specific, hence providing highest possible representativeness, accuracy and consistency. Data related to Scania in-house component and vehicle production and logistic operations originates from Scania's environmental reporting system. Background datasets (from the LEAD database) are selected in the most appropriate manner, taking into account technological relevance and geographical scope. The selected datasets primarily rely on European references. In cases where European average data is unavailable, datasets from relevant European countries are utilised. If no suitable country-specific dataset exists, a global average dataset is used. Additionally, a country-specific dataset may be prioritised over a broader European dataset to enhance granularity and representativeness. For rare earth metals, datasets from China are used, reflecting the global supply chain dynamics. The VW group LEAD database is used for background datasets for modelling production, use, maintenance and end-of-life phases. Database version 2023.2, based on Sphera database version CUP 2023.2 with reference year 2019 or newer is used. For Scania internal data, reference year 2023 is used. For the specific components tyres and propulsion battery cells, primary data in form of 3rd party verified LCIA results from supplier are used.

Allocations

An allocation method is necessary when the environmental impacts of a process must be distributed among multiple products or services. The allocation can be based on various criteria, such as mass, energy content, or economic value. The allocations utilised in the background datasets are detailed in the Sphera software documentation[7]. In the inventory of in-house production and logistic flows, total annual figures are evenly distributed across the number of vehicles produced, representing a straightforward approach. Beyond this, no additional allocations have been required.

Cut-off rules

No intentional cut-off is applied in the inventory phase concerning the vehicle parts lists, BOMs or other inventory data. Cut-off criteria in background datasets are described in Sphera software documentation. In the end-of-life phase, the simple cut-off approach is used and no credits for energy recovered or secondary materials derived are taken into account.

[7] https://lcadatabase.sphera.com/

Electricity modelling

The electricity modelling follows a consistent location-based approach throughout all life cycle phases. Scania already secures fossil-free electricity for its entire in-house electricity consumption through contractual agreements and is in the process of requiring the same from key suppliers as part of its sustainability efforts. Including these measures in an LCA necessitates a market-based approach. However, several challenges are recognised that need to be addressed before fully incorporating a market-based approach is possible.

Functional unit

The functional unit is: a truck operating for 1 300 000 km under representative driving cycles and payload conditions (further elaborated on page 14).

The vehicles

The choice of vehicles is of high importance for the relevance of the study. Scania's modular system enables uniquely adapted vehicles for every sort of customer operation. The analysis is based on two vehicles, one BEV and one ICE vehicle, characterised by specifications typical for operating in the long haulage segment. To ensure a fair and relevant comparison, the vehicle specifications are as similar as possible, considering the different drive lines. The trucks are two-axled articulated vehicles with an overview specification shown in Table 1 below.

Table 1. Overview specifications of the vehicles.

Specifications	BEV	ICE
Chassis adaptation	Articulated (tractor)	Articulated (tractor)
Wheel configuration	4x2	4x2
Chassis height	Normal	Normal
Axle distance (mm)	4 150	3 750
Suspension system, front / rear	Leaf / Air (type B)	Leaf / Air (type B)
Axle, front / rear	AM640S / AD400SA	AM420S / AD410SA
GVW technical (tonnes)	20,5	19
Propulsion	Electric motor EM C1-4, 400kW (520 hp)	Diesel engine DC13 175, 460 hp
Battery capacity	624 kWh installed capacity	
Gearbox		G25CM1 with retarder
Cab type	CR high	CR high
Cab length	20	20
Curb weight (tonnes)	10,2	8,0

Propulsion battery life length is a subject with high relevance due to batteries being a significant contributor to emissions and impacts from the vehicle production phase. Since BEVs are relatively recent products on the market, experience and statistics from vehicle operations are limited. With a battery setup like the one on the BEV under study and under long haulage operating conditions, a lifespan of at least 1 300 000 km can be expected. Based on this, no battery change is assumed in the study. The electrical range and charging strategies will have an effect on how the BEV is operated. The study does not explore how usage patterns may differ between the BEV and the ICE vehicle, and since the functional unit is not influenced by charging pattern or range, the LCA results are not affected either.

LIFE CYCLE INVENTORY

In the life cycle inventory phase of the LCA, data is collected and models are built up for production, use, maintenance and end-of-life phases. The processes of data collection and modelling differ across the life cycle phases and are presented on an overview level in the following chapter.

Production phase (cradle-to-gate)

The production phase includes raw material extraction, material processing, product manufacturing, and logistics. The basis for the cradle-to-gate assessment is the creation of a Bill of Materials (BOM). The BOM is a comprehensive list of all materials used in the production of the vehicle. A unique parts list for the vehicle is derived from Scania's product data management system. Material information for each part, as reported by the part suppliers, is extracted from the International Material Data System (IMDS) using the SMART tool and forms the BOM. The BOM generated for each truck is an extensive file and can consist of more than 10 000 different material designations. To facilitate the modeling of the material data, the materials are sorted and grouped into about 700 different defined materials in an automated process using Scanias Translation Tool. Based on the Scania mapping list, the best suited dataset from the LEAD database is mapped to each of the materials. This step is performed in the SlimLCI+ tool and results in a vehicle model that is analysed in the LCA for experts software (GaBi) from Sphera.

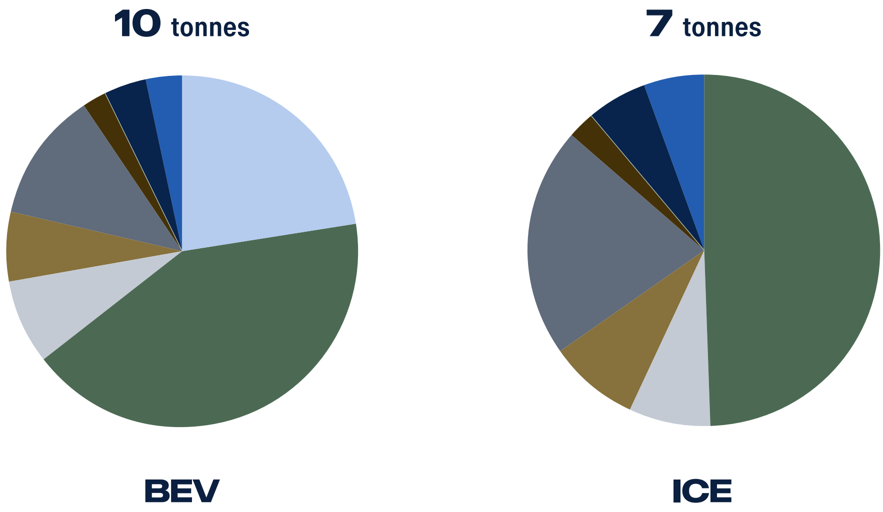
The LEAD datasets encompass all process steps from raw material extraction to a semifinished product. In the vehicle model, this is complemented by adding part manufacturing process steps, such as hot roll forming for steel and injection moulding for plastics, using a material category based approach.

The manufacturing process steps also account for scrap being generated during part manufacturing, i.e., material waste that is not being used in the final part. A material category based approach is applied and all environmental burdens from the production of the scrap material is fully allocated to the vehicle.

Furthermore, to make the cradle-to-gate assessment complete, in-house activities related to the production of components and vehicles are modelled. This encompasses the inventory of material, energy and emission flows from all Scania production facilities. Logistic operations such as transport of parts and components from direct suppliers as well as the transport of the produced vehicles to the dealership are also accounted for.

Tyres and propulsion battery cells are treated separately from the rest of the vehicle BOM in terms of how they are modelled. The environmental impacts (LCIA results) from production of these components have been made available to Scania in cooperation with the suppliers Michelin (tyres) and Northvolt (battery cells). Using supplier-specific primary information for these components ensures a high level of model completeness and accuracy.

Figure 3 describes the material composition of the two vehicles grouped into broader material categories. The rest category contains everything that is not covered by the other categories, such as for example glass and textiles.



	BEV		ICE	
Battery cells	2,31	23%		
Steel	4,30	42%	3,56	50%
Aluminium	0,80	8%	0,53	7%
Plastics & Rubber	0,64	6%	0,59	8%
Cast iron	1,23	12%	1,53	21%
Other metals	0,24	2%	0,17	2%
Electronics	0,01	0,1%	0,01	0,1%
Tyres	0,39	4%	0,39	5%
Rest	0,33	3%	0,39	5%
Sum (tonnes)	**10,24**		**7,17**	

Figure 3. Material composition of the two vehicles.

Use phase

The environmental impacts from the use phase constitute a substantial portion of the overall life cycle impacts of the vehicles. The calculation of energy and fuel consumption for the vehicles, as well as modeling the well-to-wheel (WtW) impacts from electricity generation and fuel production, forms the basis for the assessment. Vehicle maintenance is considered part of the use phase and is modelled and reported separately for transparency reasons.

Energy and fuel consumption

An essential part of assessing the impacts from the use phase is to get representative energy and fuel consumption values for the vehicles. A simulation-based approach using the VECTO tool is employed. The choice of VECTO as the simulation tool ensures transparency and that both vehicles are given similar and fair conditions.

Using VECTO according to standard procedures involves applying a combination of drive cycles, payloads, and weighting factors specific to the vehicle class being simulated. The vehicles in the study are both classified as class 5LH. This means that the simulation includes both long haulage and regional delivery cycles. The applied payload varies between 2,6 to 19,3 tons. The resulting energy consumption for the BEV and the fuel consumption for the ICE vehicle are presented in Table 2.

Table 2. Energy and fuel consumptions for the vehicles

	VECTO consumption result
BEV	1,14 kWh/km
ICE	23,56 l/100km

During BEV charging, losses occur both in the charging equipment and in the vehicle. These losses vary due to factors such as battery temperature, charging speed, and battery charging state. A charging loss factor of 10% is applied when calculating the total energy consumption for the BEV. This loss factor covers losses in both the charging equipment and the vehicle.

Well-to-tank

The well-to-tank (WtT) model takes into account the emissions from activities involved in the generation of electricity and the production of fuel used by the vehicles (from the well to the tank). The production of AdBlue is also included.

Electricity generation technology can vary greatly between countries and regions. It is important to be aware that the WtT impacts from electricity can differ significantly depending on the geographical location where the BEV is operated. In this study, the geographical scope is Europe; therefore, the European grid mix is the foundation for the use phase electricity modelling. The European grid mix includes electricity from various sources such as coal, natural gas, nuclear, and renewable energy. The relative shares are subject to change over time. Therefore, to provide an estimate of the real-world environmental impacts over the full life cycle, Scania has adopted a method that accounts for the evolution of the grid mix composition, in contrast to using a static electricity mix approach. The method is based on two inputs.

1. The prognosed European grid mix composition, taken from IEA World Energy Outlook 2023 report, Electricity production Stated policies scenario (STEPS).
2. Scania internal statistics on yearly driven distance distribution for its vehicles.

Forecasted annual European grid mixes are calculated by interpolating between the projected years in the WEO 2023 report. Scania's internal statistics on driven distance distribution over the vehicle lifespan are used to distribute the total driven kilometers (1 300 000) over the modeled years. The result is an electricity mix that reflects both the European grid evolution over time and the anticipated distribution of the total driven kilometers for the vehicle. The mix will hereafter be referred to as the Projected Euro mix.

For the ICE vehicle, European diesel B7 is assumed to be the fuel. It is assumed that the WtT impacts from the European diesel mix and AdBlue will remain stable throughout the lifespan of the vehicles in this study.

Tank-to-wheel

The tank-to-wheel (TtW) model assesses the use of the fuel within the vehicle, covering the combustion process and the tailpipe emissions during vehicle operation. Modeling of TtW is only relevant for the ICE vehicle since the BEV do not have any tailpipe emissions. The model considers emissions of CO_2, CO, NMHC, NO_x, PM, NH_3 and N_2O.

Well-to-wheel

Well-to-wheel (WtW) is the combination of WtT and TtW, providing a comprehensive view of the total environmental impact of the fuel/energy from its extraction to its use in the vehicle. WtW values for the impact category climate change are presented in Table 3.

Table 3. Well-to-wheel values for the impact category climate change for the fuel/electricity.

Fuel / electricity	Well-to-wheel value
B7 (including AdBlue)	3,55 kg CO_2e/kg
Projected Euro mix	141 g CO_2e/kWh

Non-exhaust emissions

Non-exhaust emissions refer to emissions that are not produced by the combustion of fuel in the engine. These emissions include particles and pollutants released from brake wear, tyre wear and road surface wear. Non-exhaust emissions contribute to the overall environmental impact of the vehicle, including air pollution and potential health risks. These emissions are hard to quantify, and currently, no specific Scania figures are available. To ensure these emissions are not overlooked, values representative of heavy-duty vehicles are taken from the EMEP/EEA air pollutant emission inventory guidebook 2023[8].

Maintenance

Maintenance is periodically performed on the trucks, as well as the exchange of wear parts. The extent of the maintenance and wear depends on the use of the vehicle. For the purpose of this study, representative maintenance and wear part consumption for the vehicles have been used. The maintenance includes the replacement of filters (air, fuel, oil, exhaust), and the change of transmission oil, engine oil, and cooling liquids. The wear parts considered are brake pads, starter batteries, and tyres. The current knowledge and statistical basis on tyre wear of an electric truck compared with a conventional one is limited. The difference in curb weight between the vehicles leads to a higher average gross train weight (GTW) for the BEV. Based on the principle that tyre wear is proportional to the load on the tyre, the number of tyres exchanged during the lifetime is assumed to be 15% higher for the BEV. The modelling of the maintenance basically follows the principles of the production modelling (vehicle modelling). A comprehensive list of maintenance/wear parts and fluids for the complete vehicle lifetime is put together, and material information from IMDS is collected. The resulting maintenance BOM is modelled with the best-suited datasets from the LEAD database. Following the same approach as in the production phase, the environmental impacts from tyre production are based on primary supplier-specific data (LCIA results). The maintenance and exchange of wear parts also generate waste, and the environmental impacts caused by the end-of-life of maintenance and wear parts are included in the model.

End-of-life

The end-of-life model assumes that the vehicles are treated at a dismantling center. The vehicles are dismantled and parts and components separated into different fractions based on their material composition. The model is based on the simple cut-off approach. This means that the environmental burdens associated with the vehicle end-of-life process are accounted for until the respective material fraction has reached its end of waste state, i.e., the material is in a form that can be easily handled by recycling or recovery value chains. No system expansion is applied i.e., no credits are taken for secondary materials emerging from recycling processes or energy recovered in waste incineration plants. In Figure 4, a schematic overview of the process model is shown.

[8] https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023

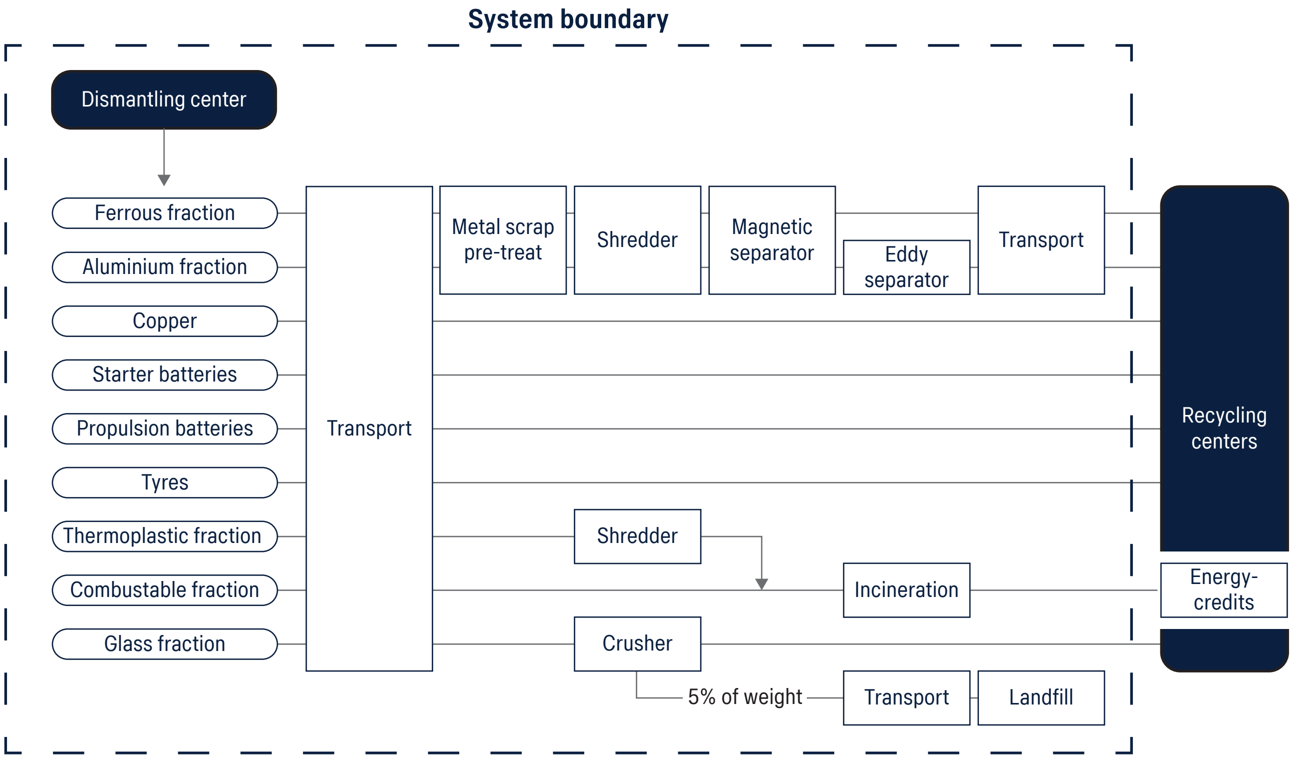


Figure 4. End-of-life schematic overview.

The separated materials are transported to designated material processing centers (e.g. metal pretreatment facilities or waste incineration plants) where they enter their recycling and recovery value chains. In the end-of-life model, the entire combustible fraction (including thermoplastics) is assumed to go to incineration. This is a deliberately conservative approach due to the lack of reliable data on recycling.

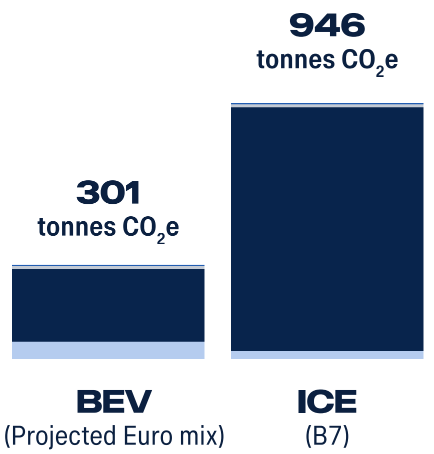
End-of-life for the BEV does not necessarily mean end-of-life for the propulsion batteries. Scania is continuously exploring the possibilities for second-life applications for propulsion batteries. However, there is currently significant uncertainty regarding the end-of-life flow for propulsion batteries, especially concerning the proportion of batteries repurposed for second-life versus those directed towards recycling. Overall, the end-of-life management of battery packs is associated with numerous uncertainties. Due to the lack of robust assumptions, no second-life is assumed in the study. The chosen approach is to allocate the entire burden of battery manufacturing to the vehicle's lifecycle and to include the transport of battery packs to recycling facilities within the end-of-life model.

RESULTS

The climate change impact is an environmental impact category of high interest and relevance when comparing BEVs with ICE vehicles. Therefore, most emphasis is placed on this impact category. The climate change impact category describes the emission of greenhouse gases, which lead to an increase in the absorption of solar radiation within the atmosphere, thereby contributing to a rise in global average temperatures. Different greenhouse gases have varying impacts on global warming. For example, methane (CH_4) and nitrous oxide (N_2O) are much more potent than carbon dioxide (CO_2) in terms of their global warming potential (GWP). By converting all greenhouse gases into the reference unit of CO_2 equivalents (CO_2e), the aggregated impact on climate change can be presented.

Climate change impact - full life cycle

In Figure 5, the full life cycle climate change impact of the vehicles is presented. Due to the high utilisation rate typically associated with HDVs, the use phase is the most influential life cycle phase in terms of climate change impact. When comparing the total values for the BEV with the ICE vehicle, a reduction of 68% can be observed.

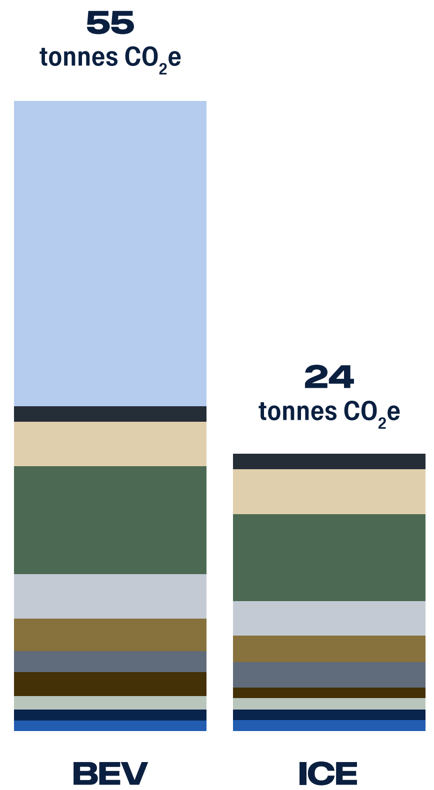


	BEV (Projected Euro mix)		ICE (B7)	
End-of-life	2,81	1%	3,15	0,3%
Maintenance	9,71	3%	10,45	1%
Use WtW	233,10	78%	908,66	96%
Cradle-to-gate	54,96	18%	24,15	3%
Sum (tonnes CO_2e)	**300,58**		**946,41**	

Figure 5. Full life cycle climate change impact in tonnes of CO_2e.

Climate change impact - vehicle production

Climate change impact from the production phase (cradle-to-gate) is presented in Figure 6. The figure gives an overview on the contributors to the climate change impact from the production phase. The greater part of the impact comes from the process of raw material extracting and refining. The impact from the production phase is 128% higher for the BEV with 55 tonnes CO_2e compared with 24 tonnes CO_2e for the ICE vehicle.

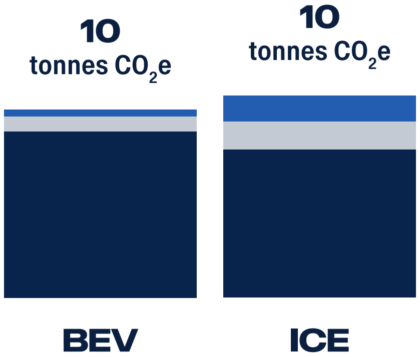


	BEV		ICE	
Battery cells	26,64	49%		
Logistics	1,33	2%	1,33	5%
In-house	3,92	7%	3,92	16%
Steel	9,40	17%	7,58	31%
Aluminium	3,90	7%	3,02	13%
Plastics & Rubber	2,83	5%	2,31	10%
Cast iron	1,83	3%	2,25	9%
Other metals	2,07	4%	0,88	4%
Electronics	1,22	2%	0,97	4%
Tyres	0,95	2%	0,95	4%
Rest	0,87	2%	0,93	4%
Sum (tonnes CO_2e)	**54,96**		**24,15**	

Figure 6. Climate change impact from production in tonnes of CO_2e.

Climate change impact - vehicle maintenance

The climate change impact from maintenance only differs moderately between the BEV and the ICE vehicle. This is primarily due to tyre consumption being the major contributing factor, and this does not deviate significantly between the vehicles. Tyres have been separated from other maintenance and wear parts and are reported separately in Figure 7 below to highlight their importance. The somewhat higher tyre impact for the BEV is due to the assumption of 15% higher tyre wear. The impact from waste handling and maintenance parts being higher for the ICE vehicle is mainly due to the amount of engine and transmission oil used during the vehicle's lifetime.



	BEV		ICE	
Waste handling	0,37	4%	1,35	13%
Maintenance + Wear	0,76	8%	1,47	14%
Tyres	8,59	88%	7,63	73%
Sum (tonnes CO_2e)	**9,71**		**10,45**	

Figure 7. Climate change impact from maintenance in tonnes of CO_2e.

Climate change break-even

The production of the BEV results in a higher climate change impact compared to the ICE vehicle, primarily due to the production of propulsion batteries. Throughout the remainder of the operational life, greenhouse gas emissions continue from the use of the vehicles until they reach their end-of-life. At some point, the additional burden from BEV production will be offset, as the emissions from the use phase are less for the BEV compared to the ICE vehicle. Figure 8 illustrates the total, accumulated climate change impact as a function of driven kilometres. The impacts from production, maintenance, and end-of-life are aggregated and set as the starting point for the curves. The lines intersect at 73 400 km and this is the so-called breakeven point, where the additional production burden for the BEV is offset. This distance is typically reached within less than a year in operation.

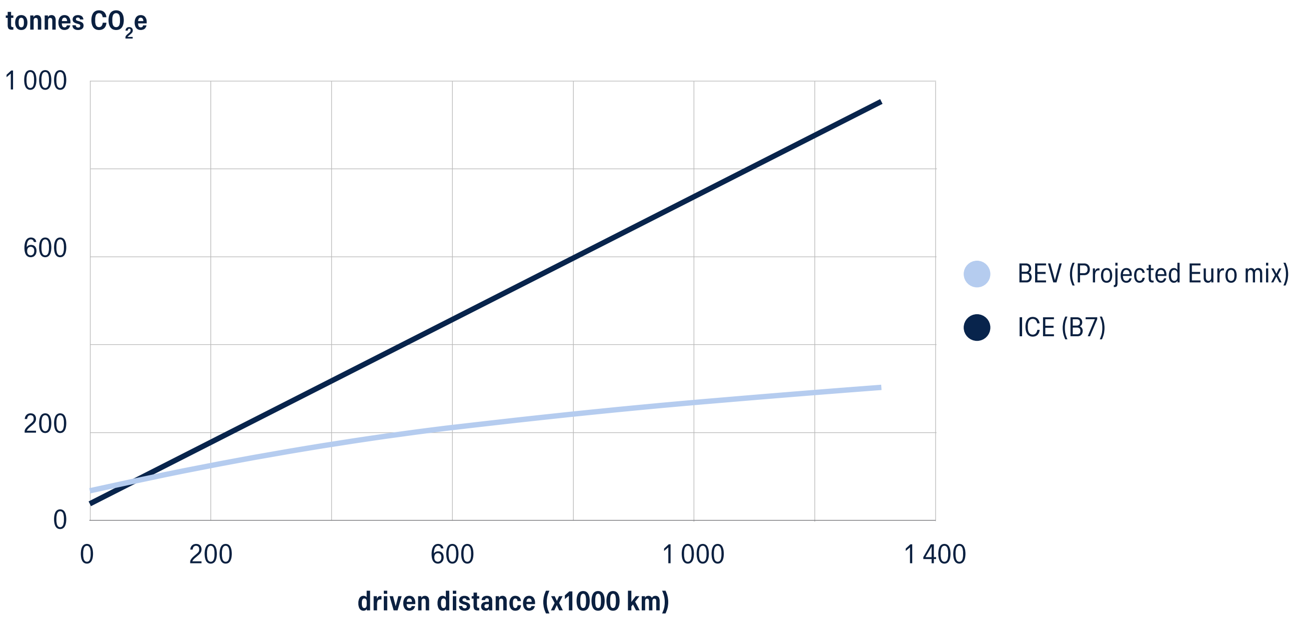


Figure 8. Climate change impact as a function of driven kilometres. Aggregated impacts from production, maintenance and end-of-life is set as the starting point for the curves.

Other environmental impacts

While climate change impact is an environmental impact category of particular interest and importance, it is crucial to recognise and monitor other environmental impacts as well. Figure 9 shows the impacts in six other impact categories investigated in the LCA. The selection of impact categories has partly changed compared with earlier communicated LCA reports from Scania. The current selection is primarily based on relevance, method maturity and harmonisation within TRATON group. It can be expected that this selection may evolve in the future as methods and standards advance.

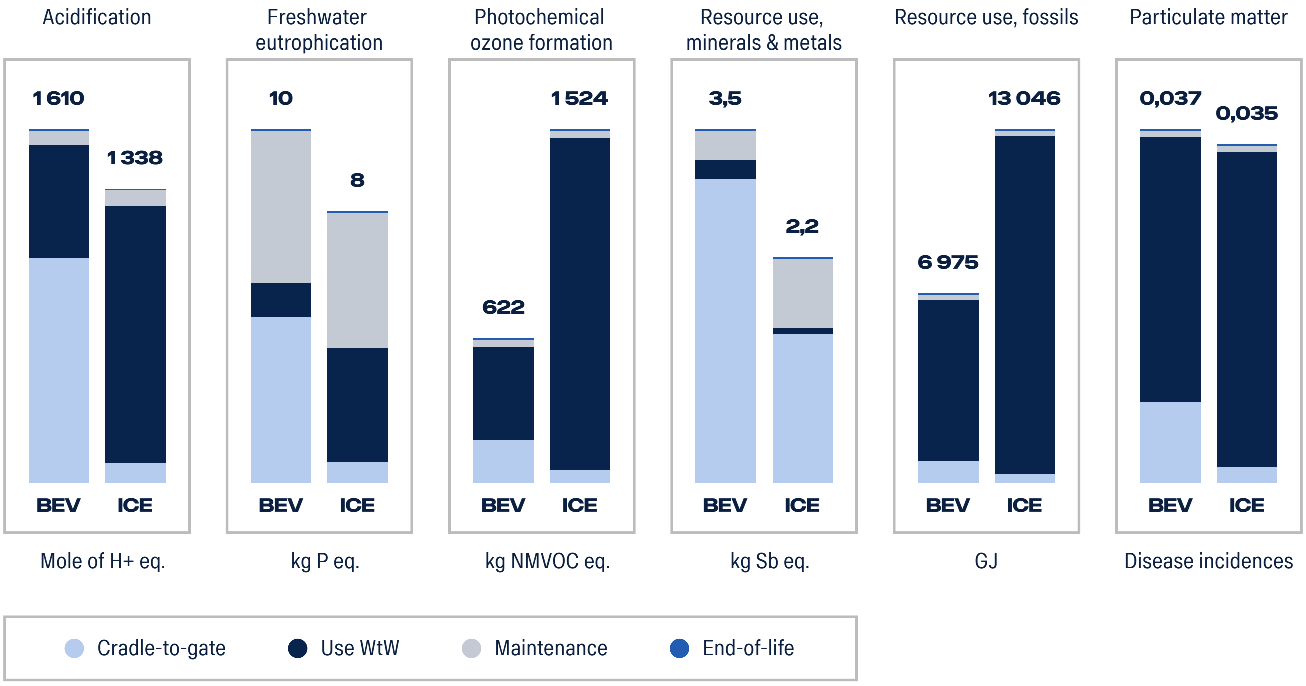


Figure 9. Impacts for BEV and ICE vehicle in 6 impact categories.

In general, for the categories where the BEV has a greater total impact, this is primarily due to vehicle production, particularly the battery cells. The contribution from the production phase of the BEV is higher in all impact categories. Conversely, for the categories where the ICE vehicle has a greater total impact, this is mainly due to emissions during the use phase. ICE vehicle tailpipe emissions are a dominant contributor in the use phase for the impact categories of Acidification, Photochemical ozone formation and Fossil resource use. Since the BEV does not emit any tailpipe emissions, its contribution in the use phase comes from electricity generation, except in the impact category of Particulate matter, where tyre and brake wear play a dominant role. In the category of Freshwater eutrophication, the relative importance of maintenance is greater than in other categories. This is primarily driven by emissions from tyre production.

SENSITIVITY ANALYSIS

The electricity assumptions in the use phase significantly impact the overall results for the BEV. The Projected Euro mix, which reflects the evolution of the European grid mix, provides a reference for the performance of the BEV. However, depending on where the vehicle is operated, the carbon intensity of the electricity mix will vary, and so will the full lifetime results. The carbon intensity range in the electricity mixes within Europe is broad.

An analysis was conducted to determine which carbon intensity in the electricity that would result in a total lifetime impact equivalent to using diesel B7 in the ICE vehicle. The result shows that if the electricity has a static carbon intensity below 530 gCO_2e/kWh the total lifetime climate change impact for the BEV will be lower than that of the ICE vehicle running on diesel B7. This indicates that the BEV is clearly the better choice from a climate perspective for the vast majority of countries in Europe today. To explore this a bit further and to give an indication, an analysis was done where several country grid mixes were applied (source: Our World in Data, Carbon intensity of electricity generation 2023)[9].

It should be noted that these calculations assume a static carbon intensity over the full vehicle lifespan. In reality, the majority of country grid mixes will be decarbonised to varying degrees over this period. A large share of the vehicles are also operating across country boarders and will charge from different grid mixes. Therefore, the values in Figure 10 shall only be considered as indicative.

[9] https://ourworldindata.org/grapher/carbon-intensity-electricity?region=Europe

An analysis of using electricity from wind power (14 gCO_2e/kWh) was also conducted to indicate the potential of the BEV when green electricity is used. The full lifetime climate change impact is 90 tonnes CO_2e, which represents a 90% reduction compared to the ICE vehicle running on diesel B7.

In the case of the ICE vehicle, differences in use phase climate change impacts can also be expected with different blend-in rates of biodiesel in the fuel. Biodiesel blend-in rates vary across countries due to national initiatives in addition to regulations, but B7 (7% blend-in rate) is representative for the total European situation. It is possible to run the ICE vehicle on 100% biodiesel, and therefore an analysis was conducted where waste based HVO was used to indicate the potential of using diesel from renewable sources in the ICE vehicle. The full lifetime climate change impact is 183 tonnes CO_2e, which is a reduction of 81% compared with diesel B7.

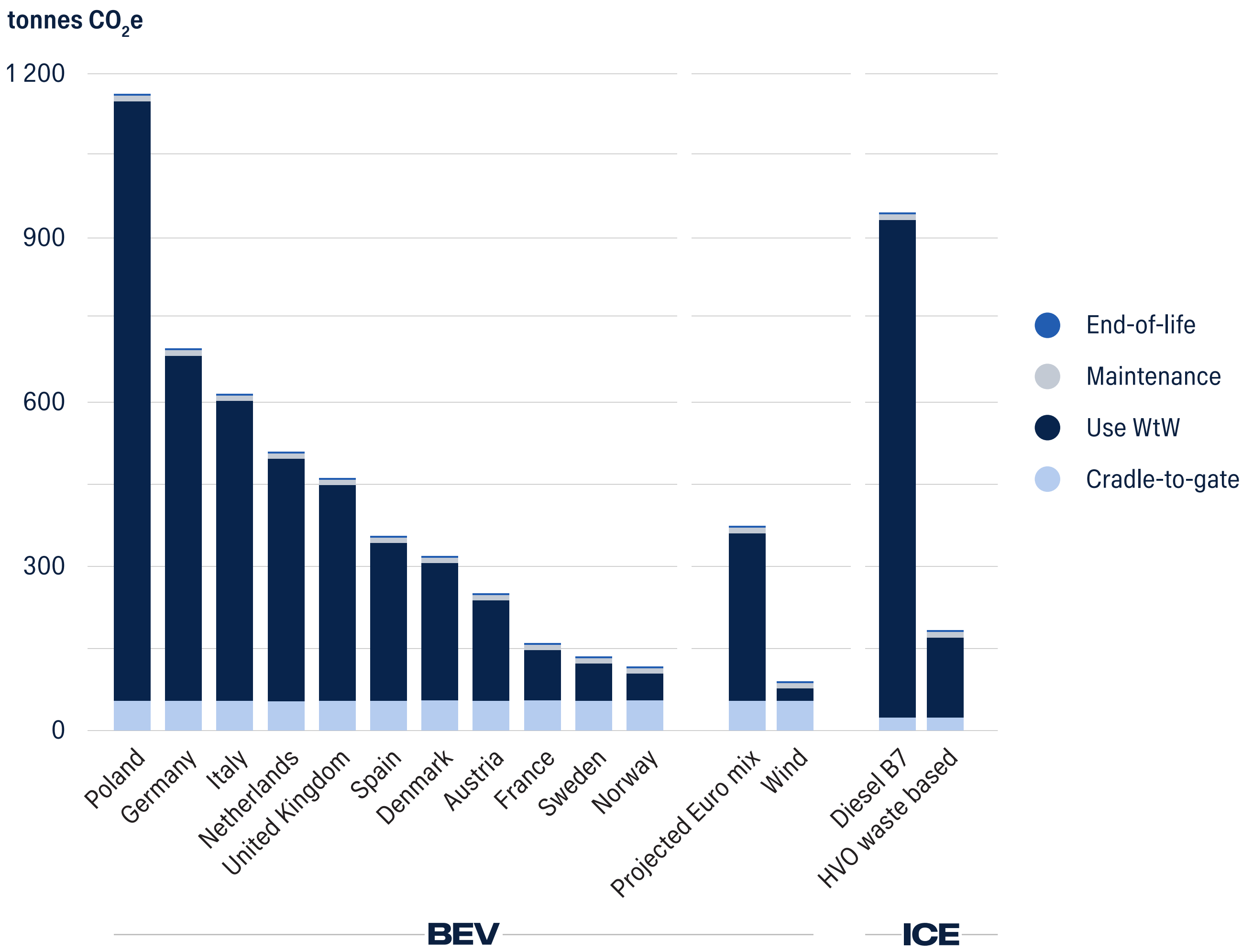
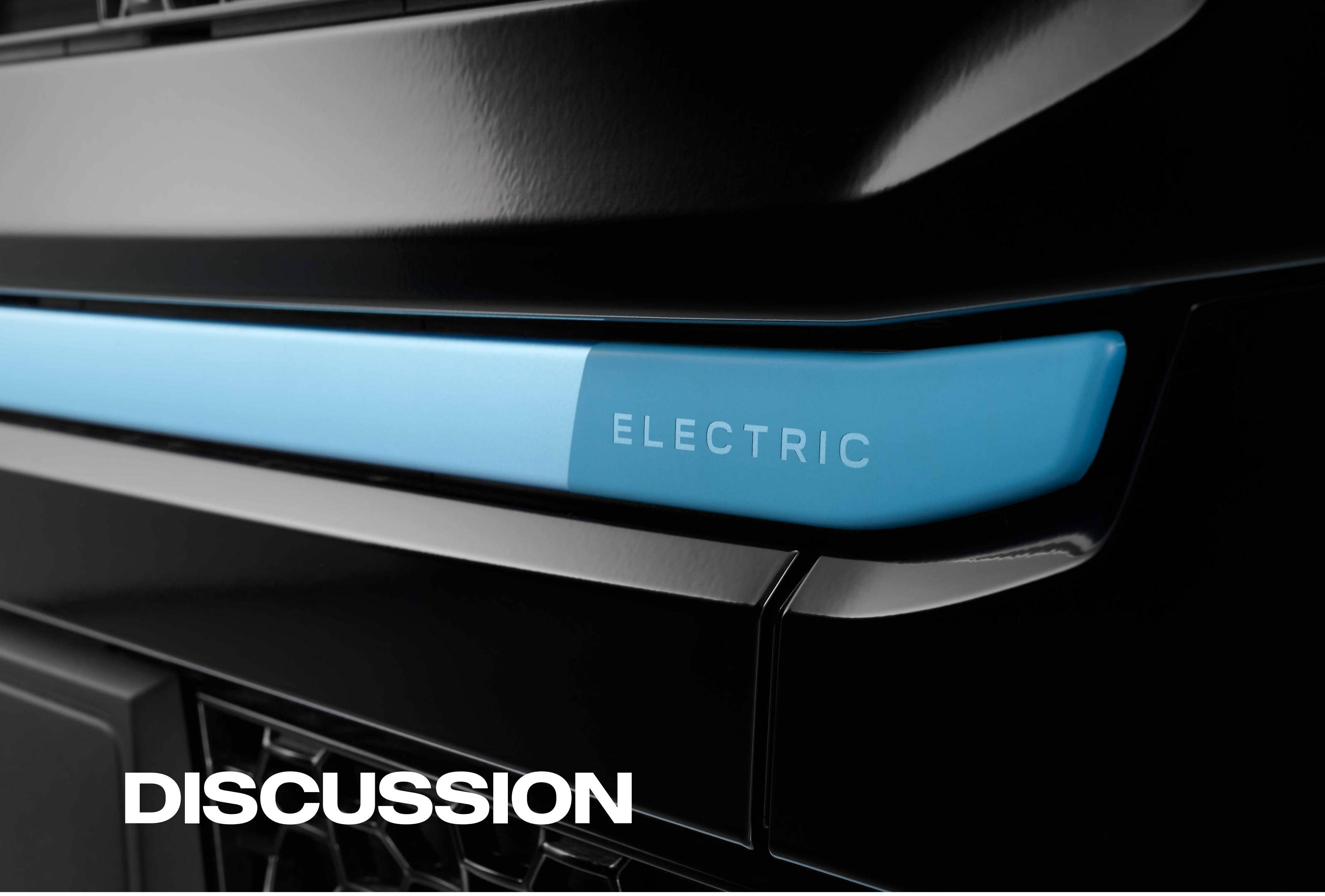


Figure 10. Full life cycle climate change impacts in tonnes of CO_2e. 11 selected European country mixes (2023), Dynamic Euro mix and wind electricity applied in BEV use phase. Diesel B7 and waste based HVO applied in ICE vehicle use phase.



DISCUSSION

Impacts beyond climate change

The great performance of the BEV in terms of CO_2e reduction comes with other environmental trade-offs. When comparing the vehicles, the impacts of the BEV are higher in 4 out of the 6 other investigated impact categories. The emission burden from production is undeniably higher for battery electric vehicles and this is what primarily causes the total impacts being higher for the BEV in some categories. The increased aluminium and copper content accounts for part of this, but it is primarily the production of battery cells that drives the worse performance of the BEV. This underscores that battery cells are a critical focus area for BEVs and that monitoring other environmental impacts beyond climate change is important. This is particularly relevant due to the risk of the burden shifting that may occur with the transition from conventional to electric vehicles.

To evaluate one impact category against another requires normalisation and weighting. The normalisation step in LCA is a method to interpret and contextualise the environmental impacts by comparing them to a reference system. The weighting step assigns importance to each impact category to prioritise the impacts. Currently, there is no established and mature method for normalisation and weighting of impact categories. Therefore, no assumptions or statements are made regarding the importance of one impact category over another. Scania is monitoring the progress in this area and sees a need for a robust and recognised methodology.

Decarbonisation actions in the supply chain

As the use phase impacts decrease with the transition from conventional to electric drivetrains, attention shifts toward the production phase, as a significant amount of the environmental impacts will be associated with vehicle manufacturing. For a BEV powered by low-fossil-content electricity in the use phase, the production can already today be a dominant contributor to the total lifetime carbon footprint. This motivates intensified efforts on production related sustainability initiatives, such as decarbonising of supply chain and developing batteries with a lower carbon footprint. The findings in the study confirm previous results from Scania LCAs and underline the importance of Scania's efforts to reduce carbon emissions from material hotspots: steel, cast iron, aluminium, and battery cells.

Use phase electricity and fuel

In comparison with an ICE vehicle, it is challenging to find a relevant use phase scenario for a BEV because the environmental impact of electricity production varies significantly between geographical areas and with different technologies. In contrast, the environmental impact from the production of conventional fuel is generally more stable. It is also evident that emissions from electricity production change over time to a greater extent than those from conventional fuel production. The ambition with the Projected Euro mix is to reflect the changes in the grid mix that can be expected during the vehicle’s lifespan as realistically as possible with available data and knowledge. It also takes into account that the share of total driven kilometres is higher at the beginning of the vehicle's lifespan than at the end. One can argue that the European grid mix is not practically relevant for any single vehicle in operation, but by creating the Projected Euro mix, based on the forecasted evolution of the European grid mix, the results represent the average performance of a BEV operated in Europe. Scania believes that this approach provides a more relevant representation of the use phase emissions than assuming a static European grid mix applied over the entire service life.

The use of waste-based HVO instead of diesel B7 results in a significant reduction of Well-to-Wheel emissions during the use phase for a conventional truck. However, there are a couple of aspects to consider in this context. One aspect of waste-based HVO is the limited potential for large-scale production. Waste-based feedstocks are a limited resource, while renewable electricity does not have this limitation in the long term. Another aspect is whether the fuel can be more beneficial in sectors where electrification is more challenging, e.g., maritime and aviation. Nevertheless, waste-based HVO is still a good alternative for decarbonisation in HDV use cases where BEV is not yet an option.

CONCLUSIONS

The production of an electric truck comes with a significantly higher carbon footprint. For the specific vehicles compared in this study, the BEV has a carbon footprint from production of 55 tons CO_2e compared to 24 tons for the ICE vehicle, which is an increase of 128%. The battery cells are the single largest contributor to this increase, accounting for 49% of the BEV production carbon footprint. It is expected that this difference will decrease over time with the efforts in supply chain decarbonisation and advancements in battery cell manufacturing. From a complete life cycle perspective however, there is a clear potential to drastically reduce the carbon footprint by transitioning to electric vehicles, as the use phase is typically associated with much higher CO_2e emissions than vehicle production. The use phase impact for the BEV is directly linked to the carbon intensity of the electricity used during operation. With the Projected Euro mix, the reduction is 68% and when investigating the option with green electricity (in this case represented by wind electricity with 14 gCO_2e/kWh) the lifetime CO_2e emissions can be reduced with 90% compared with a conventional vehicle on diesel B7.

The study also shows that when using biodiesel in form of waste based HVO in the conventional vehicle, the total lifetime CO_2e emissions are reduced with 81%. Waste based HVO, however comes with some concerns and is not a solution for big scale decarbonisation of the transport sector.

The transition to electrified vehicles comes with a risk of burden shifting. The production of battery cells drives the impact also in other impact categories beyond climate change. Monitoring other environmental impacts and addressing the emissions that drive these impact categories is important.