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Subject review
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Greenhouse Gas Emissions of Electric Cars - A Comprehensive Evaluation

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Abstract: As an important trend in the automotive industry, electrification of propulsion systems has potential to significantly reduce greenhouse gas emissions of the transportation sector. Whereas electric vehicles do not produce exhaust emissions during driving, the impact of electricity provision for charging the batteries as well as the impact of vehicle production play an essential role in a holistic consideration of the carbon footprint. The paper introduces a comprehensive evaluation of greenhouse gas emission-related factors of battery-electric cars, considering the entire product life cycle. This comprises vehicle production, including battery system, electric powertrain and other relevant components, the car's use phase under consideration of different electricity mixes, user patterns and the end-of-life phase. The results of the study can serve as a basis for comparison with the characteristics of cars driven by conventional propulsion systems and allow a detailed discussion of the different technologies, especially under consideration of future development trends.

Keywords: electric cars; greenhouse gas emissions; life cycle assessment; production technologies; technology evaluation

1 INTRODUCTION

The electrification of powertrain systems seems to be an effective method to reduce greenhouse gas emissions of the transportation sector. In this way, governments in worldwide markets introduce legislative boundary conditions to push forward a transition towards electric vehicles. Exemplarily, the European Commission released vehicle fleet-related restrictions of CO_2 exhaust emissions for new personal cars that targets to a considerable reduction of fuel consumption of cars driven by combustion engines. The mid-term fleet targets of CO_2 emission, e.g. for 2030, are on such low level, which cannot be reached by fleets consisting of cars driven by combustion engines only. In this way, manufacturers are forced to bring a certain share of electric cars into the market within a short time frame.

Electric cars to not produce tailpipe exhaust emissions, as they are limited by the above-mentioned legislations. In this way, they are very advantageous not only under environmental aspects but also from the viewpoint of car manufacturers to reach the fleet emission targets. On the other hand, the efforts for production of electric cars, especially of their battery systems, are very high. In this context, electric cars are under critics and there is an ongoing discussion about the actual total greenhouse gas impact of this technology, considering the entire life cycle.

The present work contributes to this discussion by delivering a holistic reflexion of the different influencing factors on the total carbon footprint of electric cars. The results deliver objective data to support an independent evaluation of the technologies as well as discussions and decision-making processes in governmental- and academic institutions, car manufacturer enterprises and the supplier industry. In this context, the methodology of life cycle assessment has been applied to enable a holistic and objective evaluation of the entire life cycle of electric cars, including materials provision, production, use phase and end-of-life treatment.

2 LIFE CYCLE ASSESSMENT IN THE AUTOMOTIVE INDUSTRY

Life cycle assessment (LCA) is a standardized procedure that is increasingly applied to evaluate and compare different products and their technologies, required resources and related processes of materials- and energy supply, manufacturing, logistics, the product's usage as well as the end-of-life treatment including recycling and waste management. In the automotive industry, standardized LCA is typically conducted according to the ISO 14040 and the ISO 14044 [1, 2]. In this way, the procedure of an LCA is classified into the following four main steps: *Definition of goal and scope*, *Inventory analysis*, *Impact assessment* and the *Interpretation of results* (Fig. 1).

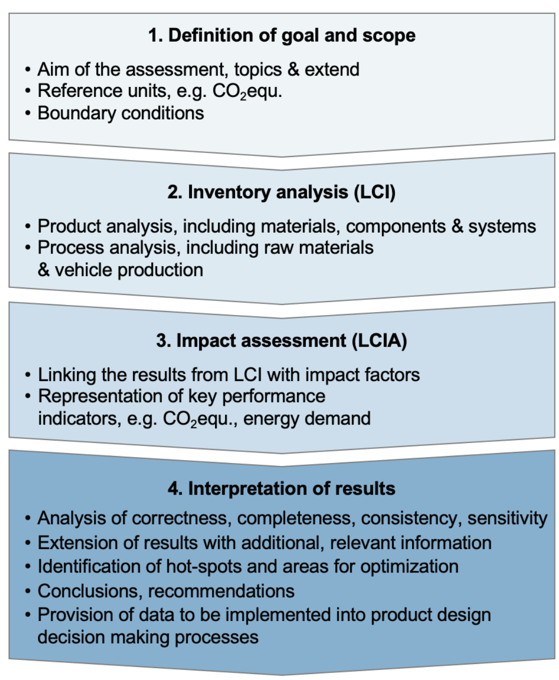

Figure 1 Phases of life cycle assessment (LCA)

2.1 Definition of Goal and Scope

The first phase, *Definition of goal and scope,* targets to a clear determination of system limits, boundary conditions, considered factors and potential limitations of the study. As an important factor, the resulting parameters have to be defined, e.g., energy demand, global warming potential, resource depletion, toxication potential, energy consumption. In the present investigation, the global warming potential is considered in form of carbon dioxide equivalent emissions (CO_2equ.). This means that all influencing factors on global warming are converted into one representative parameter. This approach became very popular in the last years because it delivers one key performance indicator that can be used for evaluation and discussion of different technologies. As one weakness of this method it has to be considered that a reduction of data to one representative key parameter does not allow reflection of all the different factors that might have impact on a holistic LCA, e.g., land use, resources demand, environmental pollution, energy storage and system efficiency, but it enables a simplified representation, comparison of technologies and discussion of affecting parameters.

2.2 Inventory Analysis

As an important section of LCA, the *Inventory analysis* focuses on a product analysis of systems, modules and components of a car and the corresponding materials. In addition, the production processes are considered, beginning from raw materials extraction and production, the creation of components and systems as well as manufacturing and assembling processes. The inventory analysis is conducted top-town and targets to a definition of main modules, sub-modules and components. As a relevant factor in the automotive industry, supply chain as well as transportation and logistics have to be considered, too. Fig. 2 shows an exemplary top-level structure of an electric car, including the main modules. Depending on car type and size, implemented technologies, powertrain system and equipment, each module influences the results of an LCA in different ways.

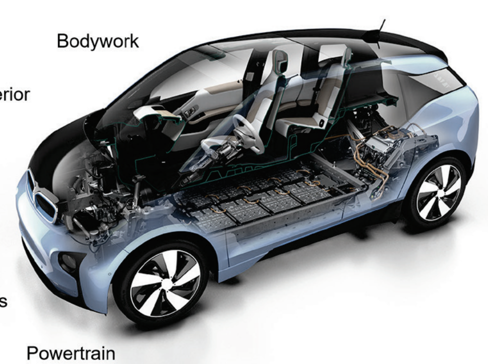

Figure 2 Main modules of an electric car, modified from [3]

In case of battery-electric vehicles (BEV), the main modules might differ significantly from those of conventional cars driven by combustion engines. The *Bodywork*, which includes vehicle body as well as doors and closures, is usually made of material combinations, whereas steel sheets and / or aluminium components represent the central structure of mass production cars. In addition, synthetic materials can be used as covers and protection elements. Carbon fibre reinforced plastics (CFRP) is not widely used in mass production, but in some specific applications, e.g., sports cars of different manufacturers and one electric compact car today [4].

Exterior components include plastic parts for bumper, styling and outer components, but also supplementary elements that complement the vehicle body. The exterior module typically has a low carbon footprint in relation to the bodywork.

Interior includes seats, inner panels, dashboard, air condition system and a number of comfort-related equipment. Besides the seats, the comfort equipment has a considerable impact on both, greenhouse gas emission impact and vehicle weight.

The *Electrics* module includes electric standard components, wiring, sensors, actuators and controllers as well as the supply of electric and electronics systems on different voltage levels. In case of battery-electric vehicles, this module represents the low-voltage system, which is connected to the high-voltage system of the powertrain including lithium-ion battery, inverter and electric motor.

The *Chassis* contains the lower vehicle structure, suspension, brakes and wheels. Electric cars often have a different vehicle architecture in comparison to conventionally powered cars, which comprises a large, flat battery below the passenger cabin.

One main component of the *Powertrain* module of battery-electric cars represents the high-voltage battery system for energy storage including a high-voltage charging system. The electric energy storage capability of the battery significantly influences the driving range. In this way, large battery systems are implemented, which has a big influence on the vehicle architecture and the other main modules. In addition, lithium-ion batteries are sensitive against various types of external influences, e.g., temperature, vibration, mechanical deformation, which requires extensive protection measures. In this way, the high-voltage battery system has the largest impact on CO_2 equivalent emissions considering materials provision and vehicle manufacturing. For today's BEV models, the battery system typically contributes with about 30 % to 50 % of the total production-related carbon footprint, whereas the actual share is influenced by the battery size, vehicle class, and the production technologies applied [5]. The batteries provide an energy storage capacity ranging from about 10 kWh in small cars up to more than 100 kWh in large luxury cars. Typical voltage levels are 400 V and 800 V, which requires extensive effort for protection [6].

In an inventory analysis of the battery system, the different materials used and the various manufacturing processes have to be investigated and analysed [7]. In general, automotive battery manufacturing can be separated into the production of cells and the production of the battery unit, including assembling of cells to modules, adding conductors, sensors and controllers, as well as integration of the entire battery with thermal system, battery management and housing. In most cases, the cells are produced at cell supplier factories in China, South Korea or Japan and shipped to the battery system manufacturing plants located near the car manufacturer's vehicle assembly lines today. Some car manufacturers integrate the entire battery manufacturing chain in large, so-called giga-factories, e.g., [8].

Besides the battery, the electric powertrain structure consists of one or several inverter(s) that control the corresponding electric motor(s). Inverters are high performance power electronics components and electric motors are typically designed as synchronous or asynchronous motors, consisting of rotor, stator and housing [9]. Synchronous motors can be designed as permanent magnets- or externally excited synchronous machines. In case of permanent magnets, the production-related impact is considerably higher because of the extensive impact of raw materials provision [10]. The torque provided by the electric motors is transferred via a mechanical gear box - in most cases a simple, non-shiftable transmission - to the differential gear and the drive axles.

2.3 Impact Assessment

The *Impact assessment* represents the third phase of an LCA. It targets to a linkage of data and the representation of characteristic parameters, for example the resources- and energy demand and environmental pollution factors. In the present work, the carbon footprint in form of CO_2 equivalent emissions is calculated, because this parameter is increasingly used across different industries. Fig. 3 shows an overview of the main phases and influencing factors that have been considered in the study.

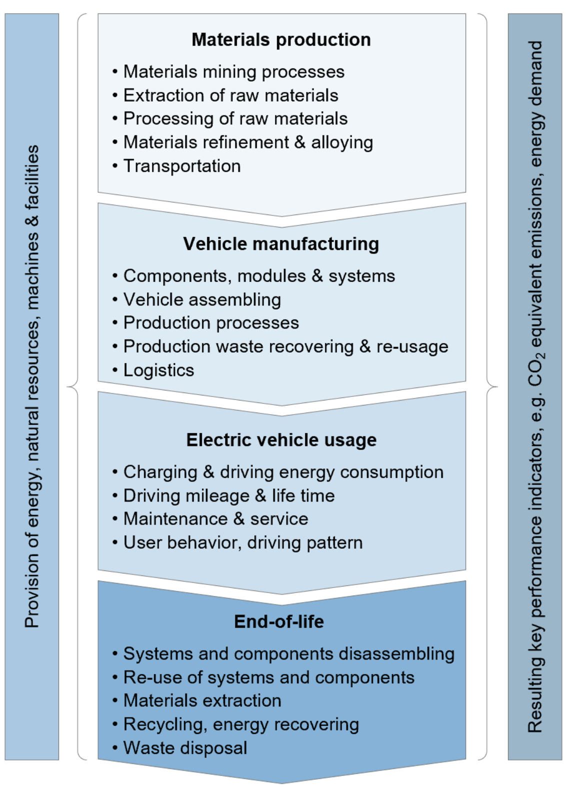

Figure 3 Main phases and influencing parameters of an automotive LCA

A holistic application of LCA represents a complex task that requires high effort and detailed investigations of the different sections in a life cycle. This includes raw materials extraction, manufacturing and assembling processes as sequences of production, aspects of the product's usage and service efforts as well as dismantling, recycling and disposal in the final life cycle phase.

The provision of energy and natural resources has an important impact on the life cycle behaviour. This includes electrical and chemical energy that is required in all sections of the life cycle, as well as air, water and of course resources for materials production and vehicle manufacturing. In this way, impacts of raw materials sourcing and processing are explicitly investigated and material-related aspects are also considered in the sections of vehicle manufacturing, car usage and end-of-life. In case of recycling, a certain share of materials can be extracted and returned to the previous sections of the vehicle life cycle to reduce the total carbon equivalent impact.

As electric energy plays a major role throughout all sections of the life cycle of electric cars, the carbon footprint of electricity provision is of high interest. This is related to the use phase of the car, where the battery is charged from the electricity grid, but also to the entire chain of manufacturing-related processes, starting with the provision of raw-materials and including the production of components, modules and systems, as well as logistics and vehicle assembling. In this context it has to be considered that delivery of materials and supplied components might be provided from various countries or regions with different carbon footprints of electric power generation.

Table 1 LCA-based CO_2 equivalent emissions of selected technologies of electric power generation [11, 12, 13, 14]

Technology of electric power generation	LCA grams CO_2 equivalents per kWh electric energy
Brown coal:	1100 g/kWh
Hard coal:	950 g/kWh
Oil:	700 g/kWh
Natural gas:	450 g/kWh
Solar cells:	50 g/kWh
Wood chips:	40 g/kWh
Bio gas:	25 g/kWh
Wind power:	25 g/kWh
Nuclear power:	25 g/kWh
Hydro power:	20 g/kWh

Tab. 1 shows the CO_2 equivalent emissions of selected technologies of electric power generation in an LCA-consideration. This includes the contributions to the total carbon footprints of building the power plants, as well as service efforts and the required resources for electricity generation. Fossil-based technologies convert chemically stored energy, e.g., in form of coal, oil or natural gas, and consequently have a high carbon footprint. So-called renewable technologies convert bio-mass, sun radiation, wind- or hydro energy to electric energy and have a significantly lower total greenhouse gas emission impact factor. Nuclear energy is not considered as renewable, but the

CO_2 footprint of electricity is very low. It has to be stated, that in the present LCA-oriented investigation, efforts for construction, service and maintenance are considered, but not those of nuclear waste deposition and risks of potential nuclear accidents.

Table 2 CO_2 equivalent emission intensity of electric power generation in selected countries [11, 12, 13, 14, 15, 16, 17]

Country	LCA grams CO_2 equivalents per kWh electric energy
Poland:	682 g/kWh
China:	600 g/kWh
Japan:	450 g/kWh
USA:	430 g/kWh
Germany:	382 g/kWh
EU 28:	296 g/kWh
United Kingdom:	278 g/kWh
France:	59 g/kWh
Sweden:	52 g/kWh
Norway:	35 g/kWh

In the present study, the carbon footprint of electric power generation in the related countries and regions is considered for the corresponding life cycle process sequence. In view of vehicle manufacturing, this includes materials provision, manufacturing of supplied components and systems, as well as vehicle assembly. In addition, recycling processes are also considered at the corresponding geographical locations, e.g., in case of battery cell recycling. In the concerned regions, different technologies of electric power generation are applied, which results in so-called electricity mixes. Based on the electricity mix, the average CO_2 equivalent emissions of electric power generation can be calculated for the regions and countries. In this context, Table 2 lists the CO_2 equivalent emission intensity of electricity production in selected countries.

2.4 Interpretation of Results

In the fourth section of LCA, the results are interpreted and put into context of the investigated product application, see Fig. 1. Considering battery-electric cars, this is applied onto two main phases, vehicle production and use phase of the cars. The effects of the end-of-life phase are considered in the vehicle production phase, as potential recycling of materials and energy recovery can be fed back to the production processes. Due to the focus on carbon footprint in the present work, other environmental impacts are not investigated in further detail here, but of course represent relevant factors, e.g., depletion of resources, air pollution and waste management.

Vehicle production includes the sections of material preparation, vehicle manufacturing and potential recovery of materials and energy the end-of-life phase. The carbon footprint of BEV production is significantly influenced by vehicle type and size, battery technology and capacity, powertrain technology as well as the vehicle's configuration and equipment. In addition, technologies of material sourcing, vehicle manufacturing and the behind lying processes of energy provision are to be considered. In this way, results published by car manufacturers, suppliers and scientific institutions, may show certain dissimilarities, e.g., [18-22]. Due to the high carbon footprint of battery system production, the total CO_2 equivalent emissions of BEV production are about 50 % to 100 % higher than those of the production of comparable cars driven by combustion engines [5].

With the target to display and discuss the manufacturing-related greenhouse gas emission characteristics of an actual case study, Figure 4 indicates a breakdown of the contributions to CO_2 equivalent emissions of an exemplary battery-electric vehicle production. The shown breakdown is calculated for a synthetic compact electric car, which represents averaged characteristics as a result of a conducted analysis in the European market. Tab. 3 gives an overview of the main technical parameters of the considered vehicle.

Table 3 Main characteristics of the investigated electric compact car

Car type:	Compact car (C-class)
Vehicle mass:	1800 kg
Propulsion:	Permanent magnets synchr. motor
Max. power:	110 kW
Battery capacity:	60 kWh
Country of battery cell production:	China
Country of vehicle manufacturing:	Germany
Car body main material:	Steel
Vehicle comfort equipment level:	Standard
Total carbon footprint of production:	14.0 tonnes CO_2 equivalents

Considering the main modules, it is visible that battery system production has the largest carbon footprint. It is influenced by the battery size, active materials of anode and especially cathode, the applied production technologies and the electricity mix that is provided in the geographical location of cell production. For the investigated car, the battery system is responsible for 50 % (7 tonnes) of the total production-related carbon footprint. *Car bodywork*, *Electric powertrain* and *Interior* come next, but at a significantly lower level with each 10 % to 14 % (1.4 t to 2.0 t).

The main module *Electrics & electronics* includes electrics low-voltage systems of the car and has a carbon impact of 8 %, respectively 1.1 tonnes. *Exterior* and *Chassis* modules play an inferior role with just 3 % and 5 % of the production-related CO_2 equivalent emissions.

Putting a focus on the influences of different applied materials it becomes visible, that the material provision for the production of *Battery cells* (here considered as one representative parameter for cell production) plays an important role, but the percentage of CO_2 equivalent emissions impact is clearly lower than those of the *Battery system* main module. Reason for this is the high relevance of electricity in battery cell production, which has a share of nearly 50 % of cell's carbon footprint. In this way, the applied electric power generation technology significantly influences the total carbon footprint of battery cell manufacturing. With 23 % and 15 % share of the total production-related carbon footprint, the "traditional" materials *Steel* and *Aluminium* have a considerable impact on the carbon footprint. The materials-related CO_2 equivalent emission impact shown in Fig. 4 considers the *Electrics & electronics* components in a simplified representation in one block that amounts to 20 %, respectively 2.8 tonnes. This comprises all electrics and electronics components of the high-voltage system (including the battery, but excluding the cells), and of the low-voltage system, e.g., cables and wires, sensors, microcontrollers. Relatively low carbon footprint of production show *Polymers* (7 %), *other Metals* (4 %) and *other Materials* (3 %).

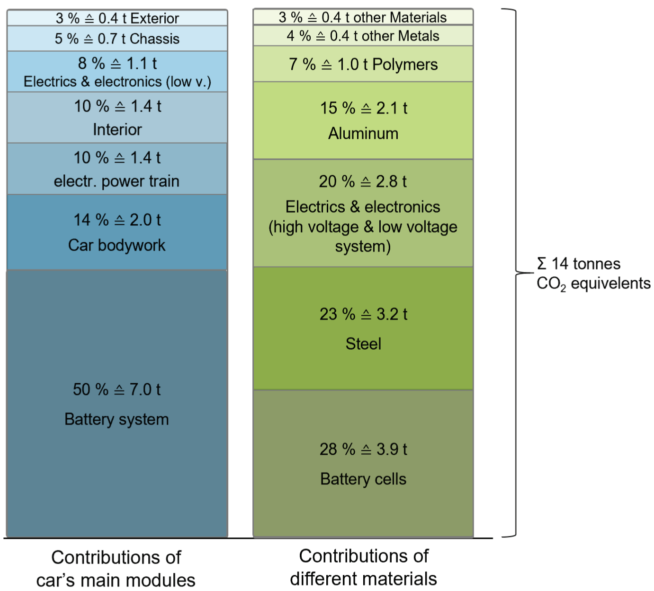

Figure 4 Contributions of main modules and different materials to CO_2 equivalent emissions of an exemplary electric vehicle production

Not explicitly shown in the diagram, but of high relevance is the electric energy consumption and the underlying carbon footprint of electric power generation of the different processes. In the present research, various CO_2 equivalent emission factors are taken under consideration according to the geographical electricity mix, respectively the specific technology of power generation (Table 1 and Table 2). For the exemplary compact car under consideration, the *Battery system* production has a high CO_2 equivalent emission level, because the cells are delivered from China with a relatively high carbon footprint of electric power generation.

A reduction of the carbon footprint is topic of extensive ongoing improvements of BEV manufacturing. In this context, an optimization of battery production plays an essential role, which includes scaling effects by increasing production volume, improvement of cell production processes, a higher integration of battery systems, recycling as well as the usage of low-carbon electricity. It is expected that design improvements and process-related optimizations have the potential to reduce the manufacturing-related carbon footprint of automotive battery systems about 50 % [23]. In addition, the application of electric energy from renewable, respectively low-carbon sources has further potential. By effective implementation of improvements, it can be estimated that the total carbon footprint of electric car production can be lowered about 30 % within the next 10 years, decreasing the production-related greenhouse gas emissions of BEV closer to a level of cars driven by combustion engines.

To reach this target, recycling plays an essential role. Considering the segmentation of main modules as introduced above, the battery system is of high importance. The other modules are also relevant of course, but have a lower share of carbon footprint and their recycling processes are well established in the industry today. This is different with the automotive battery systems. In theory, recycling and recovering of sensitive materials can be conducted, but due to complexity of batteries dismantling, safety-critical behaviour of high-voltage systems and complex processes for material extraction, automotive battery recycling is not applied on a large scale today. Research in this field covers a standardization of battery systems in combination with improved dismantling capabilities and the development of effective recycling procedures for large volumes. Due to the high importance of battery recycling in the future, legislative boundary conditions are set (e.g., in China [24]) or in preparation (e.g., in the EU [25]) to provide a fundament for the effective re-use of relevant materials on a large scale, considering the fast growth of electric car fleets.

The **car's use phase** is characterized by vehicle application-related aspects in the hand of private customers and in case of commercial use. Relevant factors for the calculation of the LCA-based carbon footprint of this phase include driving energy demand and energy consumption of auxiliaries, energy losses during charging, and also the impacts of service, maintenance, spare- and wear parts. It has to be stated, that in modern electric cars, the battery system is designed for life-time durability. Typically, car manufacturers provide warranty in the range of about 150000 to 200000 km, or 8 to 10 years, by ensuring minimum 70 % to 80 % of remaining battery capacity. In this way, a replacement of the battery system is not considered in the present investigation. In relation to the greenhouse gas emission impact of vehicle manufacturing and propulsion, the effects of service, maintenance and spare parts are relatively low.

The energy consumption of the propulsion system is influenced by vehicle driving resistances, efficiency of the powertrain and the actual operator-related driving style, respectively driving pattern. The charging losses are defined by technical characteristics of charging system and battery, but also by the user behaviour, respectively the actually applied charging power. Low power charging takes longer time, but enables high efficiency of the charging process of up to 95 %. High power charging, so-called super charging, is able to reduce the charging time considerably, but can lead to electrical losses of more than 30 %, which requires specific cooling of charging system and battery.

User behaviour-related factors are very complex to consider and topic of different investigations, e.g., [26]. In the present work, the standardized driving cycle WLTC (world harmonized light vehicles test cycle, [27]) and averaged user patterns are taken under consideration. This includes consideration of charging losses for an assumed charging behavior of 75 % slow charging (maximum 11 kW) and 25 % high-power charging (up to 100 kW). Based on conducted measurement series, the energy consumption of the considered electric compact car (C-segment) in the standardized driving cycle has been defined with 16 kWh per 100 km and the energy demand of auxiliary systems, e.g., climate condition of the passenger cabin, lights, electronics, are taken into account with plus 10 %. Summing up charging- and driving energy as well as energy consumption of other electrical systems in the car results in total with 20 kWh per 100 km (Fig. 5).

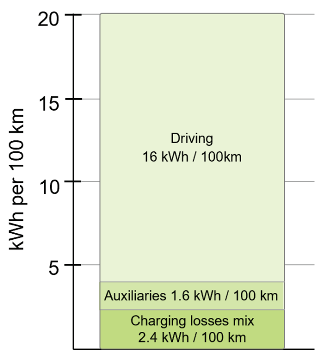

Figure 5 Energy demand distribution of an exemplary electric compact car

In a similar way as it is for the vehicle production phase, the technology of electric power generation has a large impact on the CO_2 equivalent emissions of the use phase, because it defines the carbon impact of the energy required for vehicle propulsion. In a typical consideration, the carbon footprint of propulsion is calculated as a function of the driving distance, e.g., in grams CO_2 equivalents per driven kilometre. In case of cars driven by combustion engines, this impact is composed of the so-called well-to-tank emissions, which consider the production and provision of fuel, and the so-called tank-to-wheel emissions, which consider the conversion of fuel in the engine to drive the car - thus the fuel consumption. Battery-electric cars do not produce CO_2 emissions during driving (they have no exhaust emissions). In this way, their carbon footprint of driving is exclusively defined by the electric energy demand of the car and the CO_2 equivalent emissions of the applied electric power generation technology mix.

Fig. 6 shows the total CO_2 equivalent emissions of the investigated electric compact car that is operated in selected countries with different carbon footprint of electric power generation. In countries with high share of fossil-based electricity production technologies, e.g., Poland and China, the carbon footprint when operating electric cars is very high - it is even in the range of the total carbon footprint of cars driven by modern combustion engines. In countries with low-carbon power generation, the greenhouse gas emission impact of electric car's operation is very low, nearly zero, e.g., in France, Sweden and Norway. In this way, Figure 6 points to the high relevance of the transition of the energy sector towards low-emission power generation technologies.

It has to be stated that this work focusses on the carbon footprint of the different technologies and does not consider other, potentially relevant influencing factors and risks, e.g., land use, water supply, environmental impacts, as well as nuclear waste management and nuclear risks. Independent from the automotive industry, but related to that, it is important to consider these factors in a comprehensive discussion of future energy systems.

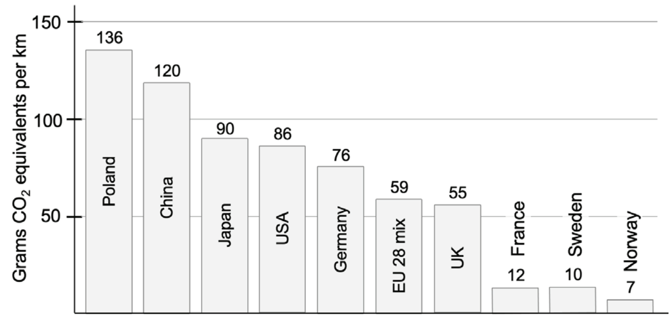

Figure 6 CO_2 equivalent emissions of an exemplary electric compact car operated in selected countries with different carbon footprint of electric power

The **total life cycle** carbon footprint of an electric car is calculated by summation of the CO_2 equivalent emissions of vehicle production and those of the car's use phase. As stated above, the influences of the end-of-life phase including recycling and materials recovering is considered in the LCA section of production in this work. Combining the carbon footprints of production and use phase, Figure 7 illustrates the life cycle CO_2 equivalent emissions of the exemplary electric compact car operated in selected countries with different carbon footprints of electric power generation and an assumed life-time usage of 200000 km.

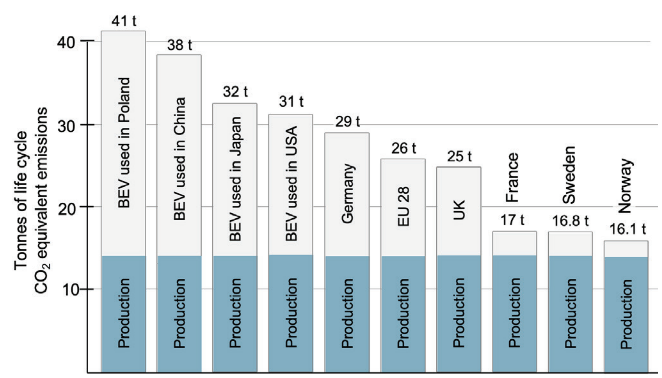

Figure 7 Life cycle CO_2 equivalent emissions of an exemplary electric compact car operated in selected countries with different carbon footprints of electric power generation and a life-time usage of 200000 km

In the present consideration, the vehicle production is defined to be in central Europe and the battery cell production in China. With 14 tonnes, the manufacturing-related CO_2 equivalent emissions represent an exemplary behaviour that might be different for other cars and in specific cases under dissimilar boundary conditions. In any case, the impact of electricity provision to the total carbon footprint is clearly visible. The high carbon footprint of BEV production is compensated relatively quickly in case that the cars are operated in countries with low-carbon electricity production. In countries or regions with high-carbon electricity mix, the use phase represents one major contributor to the life cycle greenhouse gas emission impact, whereas in countries with a lower carbon footprint of the average electricity mix, the section of vehicle production becomes more significant, e.g., in case of the median mix of the European Union (EU 28). In this context, Fig. 7 points to the importance of a reduction of the production-related carbon footprint, e.g., by moving manufacturing of battery cells from China to European countries with low-carbon electricity, and / or the use of solar, wind- and hydro energy in specific manufacturing plants. In addition, the supply of low-carbon electric power for the operation of BEV is essential to reach the ambitious goals of the "New European Green Deal", which targets to a CO_2 – neutral continent in 2050 [28].

Not shown here, but potentially of interest is the life-cycle greenhouse gas emission impact of electric cars in comparison with cars driven by combustion engines and hybrid cars. This topic was not content of the present work, but has been investigated by the authors in other publications, e.g., [5, 29]. The process of LCA and a comparison of different automotive energy storage and propulsion systems is relatively complex, because cars driven by combustion engines have varying architectures, modules and systems than electric cars. In any case, for the considered compact car segment and cars with comparable sizes and performances, the total life cycle CO_2 equivalent emissions, including vehicle production and a usage of 200000 km amount to about 40 t for a modern car driven by gasoline engine and about 33 t for a modern full-hybrid car with gasoline engine [5]. These numbers show, that in case of operation an electric car in countries with high electricity carbon footprint, the benefits are small - or nearly zero. In comparison with modern, efficient hybrid cars, the electric vehicle might have a higher greenhouse gas impact. On the other hand, when considering low-carbon electric power generation, the life cycle related greenhouse gas emission impact of electric cars is significantly lower than those of cars driven by combustion engines, even if their footprint of vehicle production might be higher than those of conventional cars.

3 CONCLUSION

A comprehensive evaluation of battery-electric cars with focus on their impact on greenhouse gas emissions requires the application of holistic life cycle assessment. This includes a detailed analysis of the vehicle’s structures, their main modules and the related manufacturing processes. In addition, the use phase of electric cars is investigated under consideration of the energy demand of operation as well as of service and maintenance-related efforts. Finally, the end-of-life phase provides a certain potential of materials recovery and energy conversion, but in case of automotive high-voltage battery systems the corresponding processes are not yet implemented on industrial scale.

The carbon footprint of electric cars production is significantly influenced by battery manufacturing, which involves both capacious demand on laborious materials and excessive consumption of electric energy. Today, main share of battery cells is produced by involvement of high-carbon electricity, consequently leading to an extensive greenhouse gas emission impact.

The results of the investigation point to the importance of electric power generation, which has a significant impact on all phases of electric cars life cycles. In this way, the carbon footprint of the provided electric energy influences vehicle production and - to an even higher extend - vehicle usage. In case of the application of low-carbon impact electricity, battery-electric cars have a high potential to significantly reduce the greenhouse gas emissions of the transportation sector. But in case of electricity supply from fossil sources, the benefits are very limited and may reach the levels of cars driven by combustion engines with conventional fuels.

Considering future trends of an increasing implementation of electric power generation with low CO_2 equivalent emissions and the introduction of optimized manufacturing technologies, battery-electric cars have a great potential to contribute to a reduction of greenhouse gas emissions towards the ambitious targets of carbon-neutral economies.

Notice

The paper will be presented at MOTSP 2022 – 13th International Conference Management of Technology – Step to Sustainable Production, which will take place in Primošten/Dalmatia (Croatia) on June 8–10, 2022. The paper will not be published anywhere else.

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