Life Cycle Analysis of Passenger Cars With Electric Drive (BEV)

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The life cycle analysis examines whether alternative drive technologies, such as electromobility, are actually more climate-friendly than vehicles with combustion engines. For a detailed assessment and thus a holistic presentation of the life cycle assessment, the entire life cycle of the vehicles must be mapped, starting with the extraction of raw materials and the manufacturing process of a vehicle. Frequently, there are divergent statements about the sustainability of alternative drive systems. This is often due to the fact that topics such as production or the disposal/recycling of the vehicles and, above all, the central component of the battery are often ignored. The question arises as to how and whether the current state of research provides sufficient information about these phases and their ecological assessment. The aim of the work is to present the life cycle of an electric vehicle based on the current state of research. To this end, 15 relevant studies/publications were selected for analysis and comparison. The assumptions made in the publications lead to some significantly divergent results. The energy-intensive manufacturing process for battery cells is largely responsible for the resulting emissions. Due to different assumptions, the CO_2 emissions for the battery are characterized by a wide variance.

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1 Introduction

The increasing use of alternative drive systems for vehicles offers the potential to improve the environmental impact of transportation. Life cycle analysis, also known as life cycle assessment, is used to investigate whether alternative drive technologies, e.g. electromobility, are actually more climate-friendly than vehicles with combustion engines. To this end, the environmental impact, e.g. greenhouse gas (GHG) emissions, is mapped over the entire life cycle of the vehicles, which includes the phases of manufacturing, use and disposal or recycling. A striking feature of the discussion about the "environmental friendliness" of vehicles is the discrepancy between the various assessments. Study results in which BEVs perform excellently contrast with results in which the gap in the CO_2 balance is very small or (depending on the parameters selected) the combustion engine performs even better (Buchal, 2019). The aim of the thesis is to define criteria for the assessment of the life cycle of electric vehicles based on the current state of research and to analyze the reasons for the different assessments of environmental friendliness. To this end, the question of the extent to which the current state of research provides any information at all about a comprehensive ecological assessment of electric vehicles will be investigated. This word focuses on individual transportation with electric vehicles.

2 Theoretical Background / Literature review

When comparing alternative drive systems, the focus is often on the vehicle use phase, the so-called tank-to-wheel (TtW) consideration. As electric vehicles do not emit any CO_2 while driving, the use phase has a clear advantage in the life cycle assessment. Vehicle manufacturers take advantage of this fact and have advertised some of their products as "zero-emission vehicles". However, this does not take into account the provision of energy, including the extraction of raw materials and fuel production, which is expressed in the so-called well-to-tank (WtT) approach. However, the life cycle assessment of an electric vehicle is influenced not only by the use phase but also by the emissions and energy consumption generated during the vehicle manufacturing and the disposal/recycling phase. The availability of data and emission values for the individual life cycle phases determine the possibilities for correctly evaluating the vehicle life cycle assessment. The partial consideration of individual phases, such as the use phase, is one of the main reasons for divergent statements on the sustainability of alternative drive systems. Topics such as the manufacturing (including the extraction of raw materials) or disposal/recycling of vehicles are often ignored.

In principle, the product life cycle of vehicles can be divided into three main processes: the manufacturing phase including the extraction of raw materials, the use phase and finally the disposal phase including the recycling process (Broch, 2017). For a holistic view and the possibility of a comprehensive ecological assessment of vehicles, it is important that all phases of the vehicle's life are considered (Bothe & Steinfort, 2020). The consideration of a product over its entire life cycle is also referred to as cradle-to-grave (Herrmann, 2010). The manufacturing phase from the extraction of raw materials to the production of preliminary products and the completion of the end product is described as cradle-to-gate. A sub-process of the manufacturing phase, specifically the production of the end product in the manufacturing plant with the exception of raw material extraction, is described as gate-to-gate (Broch, 2017). In the use phase, a distinction is made between the provision of energy (well-to-tank, WtT) and the actual use of the vehicle (tank-to-wheel, TtW) (Bothe & Steinfort, 2020). Together, both emission values are referred to as well-to-wheel (WtW). The life cycle of a vehicle ends with its disposal after use (Volkswagen AG, 2019). With measures to recycle the vehicle, raw materials can be recovered and fed back into the production cycle (Bothe & Steinfort, 2020). The following figure (cf. figure 1) shows a simplified representation of an electric vehicle life cycle:

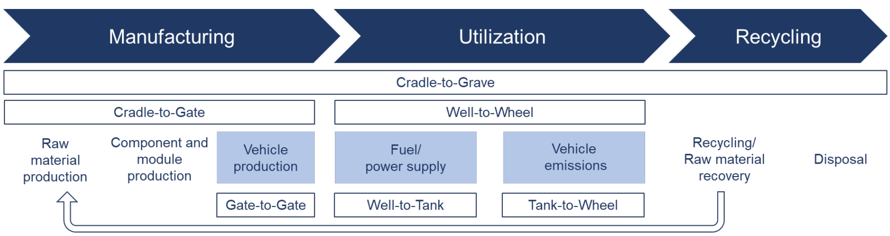

Figure 1: Simplified representation of the life cycle of an electric car
Source: author's compilation (Volkswagen AG, 2019; Broch, 2017)

For this work, 15 relevant studies and publications were selected. The title, abstract and structure were used to check whether the publication was suitable for the purposes of this work. Due to the constant technological progress in the automotive industry, topicality, i.e. the year of publication and the data collection period of the studies, plays an important role. The period of the studies analyzed here is limited to the years from 2018 to the end of 2022. The selected studies were conducted by national and international research institutes or institutions. In some cases, car manufacturers themselves also publish carbon footprints for their electric vehicles. In References, the studies used are identified by an additional indication after the year of publication, e.g. Bieker, G. (2021) (study 09).

3 Methodology

The studies were analyzed with regard to the criteria relevant to this paper and the results were summarized in a structured manner. All data and research results from the selected sources were analyzed in accordance with the defined criteria. A distinction is made between main criteria and respective sub-criteria.

The first main criterion (A) is the various basic assumptions of the studies. Sub-criteria are, for example, the scope of the study and vehicle parameters. The other main criteria are based on the life cycle of an electric vehicle with the manufacturing (B), utilization (C) and disposal/recycling phase (D). Criterion B is further subdivided into B1 for the basic vehicle and B2 for the battery. Important sub-criteria include battery size, country of production, electricity mix, driving cycle and consideration of battery recycling.

4 Results

In order not to go beyond the scope of this paper, the following is limited to a selection of important criteria and also a selection of a few studies. Despite these limitations, it will become clear why the studies show such different results.

An initial indication of the different results can be seen in the number of vehicles considered (cf. table 1).

In the case of emissions for the manufacturing phase, there are either conversion factors or flat-rate values are assumed (cf. table 2).

Table 1: Ad A - Basic assumptions

sub criterion	study 01	study 02	study 07	study 08	study 11
Number of vehicles	790 vehicles; all vehicle classes; simple vehicle equipment	2 vehicles; the electric vehicle as a sports car with high engine power	30,000 different vehicles available on the European market	39 different vehicles and technology combinations	n.a.

Source: author's compilation

Table 2: Ad B1 - Manufacturing phase basic vehicle

sub criterion	study 01	study 02	study 07 (Kroher)	study 10	study 14
Calculation emissions for BEV	4.5 kg CO_2e * empty weight of vehicle in kg	8,000 kg	39.1 g/km	n.a.	7,270 kg

Source: author's compilation

There are very large deviations in the emission coefficients for the vehicle battery. The decisive factor here is the assumptions about the electricity mix in the country where the battery is manufactured (cf. table 3).

Table 3: Ad B2 - Manufacturing phase battery

sub criterion	study 01	study 05	study 09 (EU)	study 13 (China)	study 13 (EU)
kg CO_2 equivalent per kWh battery capacity	83.5	75	54	185	124

Source: author's compilation

The following figure (cf. figure 2) shows the bandwidths and calculation coefficients used for selected studies.

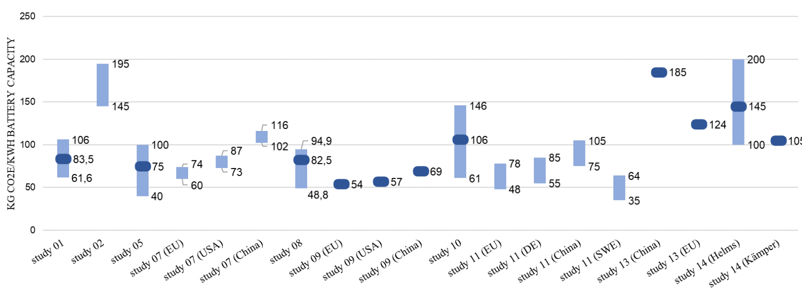

Figure 2: GHG emissions of battery production per study
Source: author's compilation

When operating a BEV, both the electricity mix of the country in question and the type of electricity used, i.e. conventional electricity vs. green electricity from renewable power generation by wind or solar plants, must be taken into account (cf. table 4).

Table 4: Ad C - Utilization phase

sub criterion	study 01	study 02	study 09	study 10	study 13
Power mix	– Conventional electricity: 0.401 kg CO_2-eq/kWh – Renewable electricity: 0.036 kg CO_2-eq/kWh	0.55 CO_2 emissions kg/kWh	– China: 509-622 g CO2-eq/kWh – Europe: 164-199 g CO2-eq/kWh – India: 561-746 g CO2-eq/kWh – USA: 239-357 g CO_2-eq/kWh	– Conventional electricity 2018: 530 g/kWh 2030: 347 g/kWh – Renewable electricity: 25 g/kWh	n.a.

Source: author's compilation

No uniform line can be seen in the consideration of CO_2 credits from battery recycling (cf. table 5).

Table 5: Ad D - Disposal/recycling phase

sub criterion	study 01	study 02	study 03	study 05	study 11
Credit through recycling/ second life strategy	Yes,credit through recycling	No	n.a.	No	CO_2- footprint reduction potential: 19% in 2020 and 22% in 2030

Source: author's compilation

5 Discussion

Numerous studies deal with the comprehensive ecological assessment of electric vehicles. In general, it can be stated that the assumption of different input parameters is the main reason for the divergence of results in the environmental assessment. The results of the studies must always be interpreted in relation to the input parameters used in the study. A comparison of the studies is made more difficult due to the different assumptions and focuses of the authors.

Other aspects can also be included in the discussion. These include, for example, the approach or structure of the work, which on the one hand adheres to standards such as ISO standard 14040 (cf. study 13) or follows its own structure (cf. study 02). Furthermore, the selection and number of vehicle types considered plays a major role. The data basis used should also be mentioned, e.g. with regard to energy consumption in battery production. In a study by Wietschel from 2019 (cf. study 10), a CO_2-coefficient in the range of 150-200 kg CO_2/kWh is given, while the update from 2020 uses values in the range of 61-106 kg CO_2/kWh. Another important aspect is the consideration of the production location of the battery. The production of this vehicle component in a country with a poor electricity mix, such as China or India, significantly worsens the CO_2 balance.

In addition to the energy supply, the cell chemistry is also relevant for the environmental balance of an electric vehicle. There is an emerging trend towards a reduced cobalt content, which significantly improves the CO_2-balance. The measurement method for electricity consumption during the use phase plays another important role. Here, the outdated NEFZ method (cf. study 02) should be replaced by the extended measurement method, the WLTP cycle (cf. study 06). There is no uniform picture regarding credits for the reduction of emissions through battery recycling. Only in more recent publications (cf. study 1 or 11) this aspect is addressed under the keyword “second life". This refers to the continued use of batteries, which generally still have 70% to 80% of their original capacity, as stationary electricity storage units. A number of projects are already testing how "second use" can be deployed to store electricity from renewable energies and compensate fluctuations in the grid (Fuchs & Siegel, 2023). Finally, it should be noted that the focus of the studies examined is on GHG emissions. Other environmental impacts such as water pollution and scarcity, land consumption, noise pollution and particulate matter are largely excluded from the considerations.

6 Conclusions

In order to take account of the different results, it makes sense to make the results of this analysis available in a tool. The appropriate parameters can then be selected for specific vehicles in order to achieve the most correct results possible. However, this requires the availability of the necessary information, e.g. the country of manufacture of the battery. Work is already underway to integrate this tool into the DIPO tool, which can be used to determine the economic efficiency and sustainability of vehicles with alternative drive systems (Bongard et al., 2022; Bongard & Main, 2023).

For further research, it should be noted that technological progress is developing rapidly, especially in battery production and recycling. These developments make a significant contribution to improving the carbon footprint of vehicles. The availability and analysis of current data therefore play an important role in research work. A carbon footprint must always be considered in its entirety and depends strongly on the assumptions and data basis made in each case. A precise analysis of the data basis and the assumptions made is therefore essential.

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