Life Cycle Assessment of Electric and Hybrid Electric Cars

Bachelorarbeit

zur Erlangung des akademischen Grades
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1. Introduction

When Berta Benz completed her first motorized journey with the Benz Patent Motorwagen in 1888, it was hardly possible to predict the influence that the automobile would one day have on humanity. Initially considered noisy and unnecessary, today a life without an automobile would be unthinkable for many. The new technology was made suitable for the masses with the introduction of assembly line production by Henry Ford in 1902. Distances could now be covered quickly and comfortably, goods could be transported even to the most remote places in the world, and the way to a motorized society was paved (Dietsche & Kuhlgatz, 2014). Almost 150 years later, more than 48 million motorized passenger vehicles roll across the roads of Germany alone (Kraftfahrt-Bundesamt, 2021). The concept of an internal combustion engine with pistons and some sort of fossil fuel has remained mostly the same over the entire period. Nikolaus August Otto had the idea as early as 1861, when he developed the combustion four-stroke engine. Also known as the Otto engine. At its core, we are still using a technology from the 18th century today (Dietsche & Kuhlgatz, 2014). There was a first wave of electrification in motor vehicles at the turn of the century in the late 1890s. But the advantages of the internal combustion engine with its virtually infinite range and inexpensive oil quickly pushed the battery-powered electric vehicle back into a marginal existence (Guarnieri, 2012). The fact that the burning of fossil fuels produces various pollutants, including the climate damaging CO_2, seemed to play a minor role for a long time. Only with the emergence of social environmental awareness and the realization of the dangers of climate change are manufacturers, politicians and consumers trying to establish alternative drive concepts for motor vehicles (Samaras & Meisterling, 2008). In this context, the battery electric vehicle (BEV) is experiencing a comeback. Thanks to modern lithium-ion batteries (LIB), electric energy can be stored faster and in larger quantities. But most importantly the cost of LIB has decreased significantly over the last century and is expected to decrease further (Bloomberg Finance L.P., 2020). Yet, the still relatively high price of an electric vehicle compared to a conventional one is a major argument for many private consumers in Germany to decide in favor of an internal combustion vehicle (Bobeth & Matthies, 2018). The Covid-19 pandemic that broke out worldwide in spring 2020 is providing an unexpected boost to the spread of electric cars. As part of the federal government's economic stimulus package (BAFA), newly registered electric and hybrid electric vehicles will be subsidized with up to 9000€ from June 2020 (Bundesamt für Wirtschaft und Ausfuhrkontrolle, 2020). As a consequence, the number of newly registered electric cars in Germany is growing rapidly (Fig. 1). It seems as if the mobility revolution in Germany has already been decided in favor of the battery-electric or hybrid-electric car. To the consumer, a BEV suggests an environmentally friendly method of motorized mobility. In advertising and also politically, this positive image is being conveyed (Bobeth & Matthies, 2018). The trend towards a growing share of BEV in German or even global road traffic is clearly predictable. Major car companies like Volvo, GM and Ford have already announced to stop the production of their internal combustion engine powered vehicles (ICV) in the near future (Köllner, 2021). The fact that even a battery electric vehicle is not automatically sustainable can be easily forgotten.

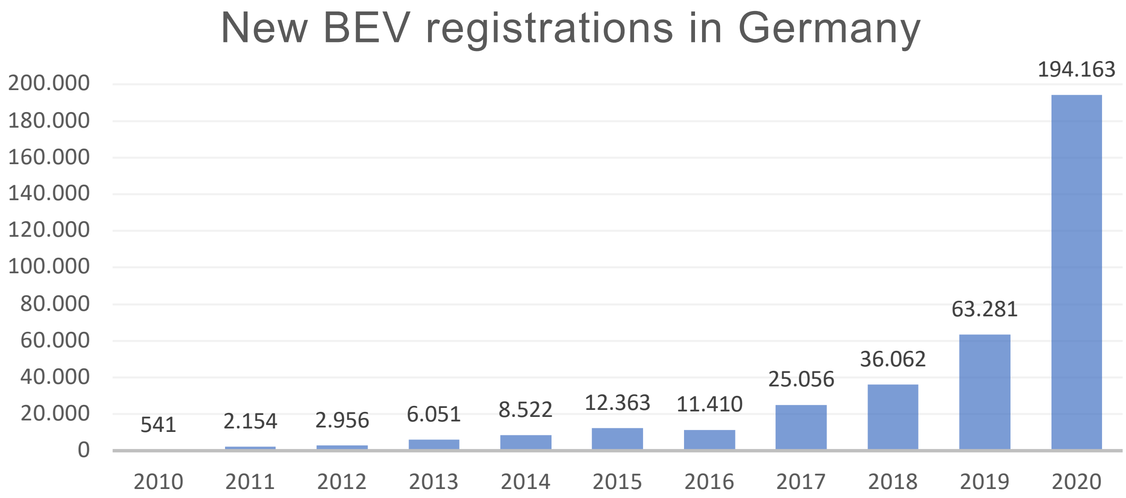

Figure 1 *Number of new BEV registrations in Germany by year. Own illustration. Data: (Kraftfahrtbundesamt, cited from Statista, 2021)*

In this context, the question of the life cycle assessment (LCA), which measurers emissions from production to use to recycling, is crucial for the sustainability of a product. The first research question is therefore:

RQ1: Do battery electric and hybrid-electric passenger vehicle offer a sustainable mobility concept for personal passenger transport in Germany?

While ICV burn fuel in their engine to convert it to kinetic energy, the electric power of a BEV or HEV has to be generated externally. The key to a "green" (sustainable) electric vehicle is therefore the given framework parameters. In particular, the way in which electricity is generated and the origin of the resources play a significant role in the LCA of BEVs and HEVs. The share of electricity from renewable sources in Germany in 2020 was 47%. The remaining electricity is still generated from fossil fuels and nuclear power (Statistisches Bundesamt (Destatis), 2021). Therefore, the second research question is:

RQ2: What must be done to improve the life cycle assessment of battery electric and hybrid electric passenger vehicles?

The motivation for this work was provided by an ongoing debate about the sustainability of automotive transportation. Especially in the social media comment sections of different political parties and news pages in Germany, users discuss the relevance of E-mobility. The CO_2 tax, which was introduced in 2021, increases the cost of fossil fuels and further intensifies the debate (Bundesministerium für Wirtschaft und Energie, 2020). I personally have made the experience that these discussions are most times more or less superficial. For the supporters, the electricity for BEV always seems to be "green", and the critics argue with a much higher demand for resources in the production process. However, profound arguments and concrete figures are rare. The aim of this thesis is therefore to critically examine the life cycle assessment of BEVs and HEVs and to provide empirical evidence. For this purpose, a qualitative research approach was chosen in addition to a literature review. The content of the paper is structured as followed: Chapter 2: Theoretical foundation follows the introduction. This chapter explains the most important terms concerning BEVs and HEVs. In addition, the research methodology used for this thesis is presented. Chapter 3 contains a case study with an approximate LCA for different representative consumer driving scenarios of BEVs and HEVs in comparison to conventional ICVs. To compare the findings of the LCA with current opinions, a qualitative study on the life cycle assessment of BEVs and HEVs was conducted. For this research, various experts in the field were interviewed. The interview results are then discussed in Chapter 4 and compared with the findings from the literature review. In addition, limitations are pointed out. A final conclusion and possible outlook can be found in the last chapter.

2. Theoretical foundation

Like all new technologies, E-mobility has to establish itself in the market. Reasons for consumers to decide against new technologies can be various. Unawareness, lack of understanding or fear are possible motives (Marangunić & Granić, 2015). The intention of the following chapter is to provide an overview of the theoretical framework of this thesis. On the one hand, the history and technical background of the different drive systems are highlighted. On the other hand, the most important terms for this work are defined and explained as well as a short overview of the European energy mix is given. For that a literature search was conducted in renowned scientific databases. Details on the methodology can be found under 2.1. In general, the comparison of sustainability is very complex, because many different factors have to be considered. Different models come to different results with similar data. An LCA is thereby always based on some kind of generic assumptions. Due to the partial lack of robust and recent data, some reference values have been chosen or have been estimated. There is also a focus on well-to-wheel analysis of fuels and electricity production, as this is particularly important for BEVs and HEVs.

2.1 Research methodology

The concept of a life cycle analysis is globally recognized and has already been carried out many times by automotive manufacturers, associations and research institutes. As a result, a large amount of primary and secondary literature already exists. In the context of this thesis, results and data from various sources were compiled to design an LCA for specific use cases of BEVs and HEVs (see 3.4). The following table (Tab.1) gives an overview of the keywords used and the corresponding hits in the scientific database search engine Google Scholar. The number of hits can be used as an indicator of the research effort to date in the individual areas. According to this, relatively little research has been done specifically in the area of LCAs for BEVs, since the technology is comparatively new and current research results are still unavailable. Therefore, particularly frequently cited or very recent articles were used as a basis for this work. Extending the literature review, experts in the field of mobility were asked detailed examination of the underlying parameters. There is also a lack of reliable forecasts for the future development of electromobility. It is therefore questionable whether other forms of propulsion, such as natural gas or LPG, will also play a role in the future, as these can also be produced sustainably in some cases. Gas-powered vehicles were not discussed further in this paper. In other studies, however, natural gas vehicles could beat BEVs and HEVs with the currently lowest life cycle emissions (Jungmeier et al., 2019). For the qualitative analysis, a larger group of participants would have been necessary for more validity. However, due to staff shortages during the Covid-19 crisis and upcoming federal election, only a hand full participants agreed to be interviewed.

6. Conclusion and outlook

This section summarizes the results of the LCA as well as the qualitative study and answers the research questions. The LCA showed that BEVs with the underlying EEM are only partially more sustainable than other drive concepts. There are several key factors that affect these findings: 1.) Electricity mix: In the LCA model, an electricity mix from 2010 was used. However, as shown in 2.5, the share of renewable energies in the EEM is growing significantly. For a better comparability, WtW Emsissions of the EEM 2021 and more modern ICVs would have to be used. But robust and comparable emissions data is rare and often not up to date. However, for large cities with smog pollution problems, shifting emissions alone can help improve urban air quality. 2.) Battery capacity: a lot of electricity is consumed in the production of the LIB. Emissions for this are heavily dependent on the underlying electricity mix. Currently, the capacity of LIBs for newly developed vehicles is still growing considerably. With each additional kilowatt-hour of LIB capacity, emissions during production increase by approximately 150 kg CO_2 equivalent. But as the efficiency of the electric motors increases, energy consumption during operation decreases. As a result, electric vehicles can achieve the same maximum ranges even with smaller LIBs. For example, a Hyundai Ioniq Electric Style consumes an average of 16.3 kWh/100 km, while a Mercedes EQC 400 AMG Line achieves 27.6 kWh/100 km (ADAC, 2021). The Hyundai would therefore have an approximately 70% longer range with the same battery size. 3.) Individual driving profiles: An LCA always provides only average values and is therefore never 100% representative for the consumer. His driving profile is crucial for the sustainability of the vehicle, so no general recommendation can be made. The subsidization of HEVs as company vehicles has shown that, if used incorrectly, a generally ecological vehicle concept does not make sense for certain types of costumers. 4.) Resources: For the production of LIBs, large amounts of raw materials are still used today. For the future, concepts for a better sustainability of the production and methods to measure social and ecological impacts of resource extraction would have to be developed. 5.) Durability: Since the production of LIBs emits a lot of emissions, the lifetime of the LIB is decisive for the overall emissions of BEVs. As the analysis of the Compact Vehicle has shown, the total CO_2 emissions of the BEV would be lower than those of a comparable ICV. However, since the LIB battery has to be replaced at 180,000 km, the high production emissions are again applied. For the battery lifetime, the values vary widely in different studies. Estimates go from 100.000

km to over 3000000 km total range. So far, there are not enough long-term studies to provide robust values for this variable. In addition, the service life of a vehicle for both ICVs and BEVs is highly dependent on driving style as well as the vehicle's operating profile. Frequent fast charging of the BEV can significantly shorten its lifetime. Overall, BEVs show great potential for the decarbonization of passenger transport. While traditional ICVs hardly experience any new developments, the efficiency of BEVs is rapidly improving. Theoretically using the potential of renewable energies (Wind energy) and assuming 2 g CO_2 equivalent / km (Tab.7) for the operation, the LCA graph for the micro vehicle is as follows:

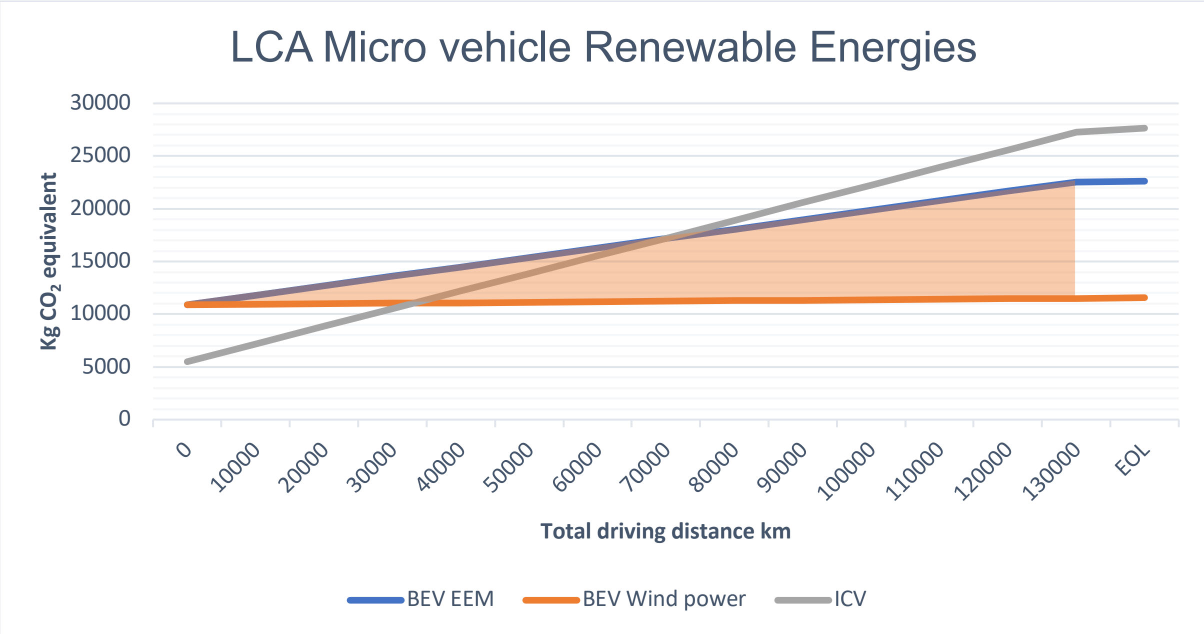

Figure 11 *Potential CO_2 savings operation*

The orange integral shows the savings in CO_2 emissions when using renewable energies for operation and demonstrates the great potential of the energy mix. Compared to the BEV powered by the EEM, the BEV with renewable energy has about 51% less lifetime CO_2 emissions this way. The answer to the first research question can consequently be answered with yes: BEVs and HEVs can contribute significantly to the decarbonization of passenger transport in Germany. As long as no other scalable alternative drive concepts are available on the market, the BEV remains the only possible zero-emission operation vehicle currently available. For a climate-neutral vehicle, however, assumptions must be made that do not yet exist in reality. Although relatively large amounts of CO_2 are still emitted for the production of BEVs, for a small LIB this is quickly put into perspective during the operation phase. For long-distance or performance vehicles, however, an electric drive concept is not very sustainable. The large LIB generates such high emissions that they can hardly be amortized during the vehicle's lifetime. The general political decision in favor of BEVs must therefore be critically evaluated. In urban areas or for small vehicles, the promotion of BEVs would certainly make ecological sense. For long-distance vehicles or the existing fleet, more research into biogenic fuels is needed instead. On the question of potential improvements, many points overlap with the problems of BEVs: 1.) Sustainable production: supply chains must become more transparent and the energy for production must come from sustainable sources. 2.) Energy mix: Even though the share of renewable energy is increasing, the expansion must be accelerated in order to achieve the climate protection goals. In addition, a significant increase in electricity demand can be expected. 3.) Charging infrastructure: Especially in the qualitative study, the lack of charging infrastructure was mentioned several times. Although new registrations for BEVs are increasing rapidly, there will be problems if the charging infrastructure does not grow at the same rate. 4.) End of life: Existing second life applications must be further expanded and a final scalable disposal concept (recycling) for LIBs must be developed. Due to the high R&D efforts of manufacturers, solutions to many of these problems can be expected in the near future. No one can say with certainty what mobility will look like in the future. All that is certain is that alternatives to the fossil fuels used to date will have to be found. BEVs and HEVs provide one available technology for this purpose, and will further shape the market for passenger vehicles in the future. In Europe, no more combustion vehicles are to be sold in the near future. However, the global market and the existing vehicle fleet, which will still be running for a long time, remain. Other concepts will have to be developed for this, e.g. biogenic fuels, biogas or hydrogen. With BEVs alone, it will be difficult to stop climate change and meet the EUs targets. An expansion of local public transport and a rethinking of people's attitude towards mobility are further necessary.