ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20250415173728

Subject review
Received: 2025-04-15, Accepted: 2025-04-30

Maintenance and Repair of Battery Electric Vehicles in Germany

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Abstract: After a surge between 2019 and 2023, Battery Electric Vehicles (BEV) registrations declined in 2024, with customers facing the expiry of state subsidies. In addition, actual studies showed, that the repair costs of BEVs are considerably higher than that of classic Internal Combustion Engine vehicles (ICEV). This research aims to answer the question, why BEVs require higher repair costs than ICEVs, while having a lower technical complexity drivetrain and requiring less maintenance. Focusing on the research question, a mixed-methods approach is used combining a secondary analysis based on recent studies of insurance companies and road assistances. The study describes the technical differences between BEVs and ICEVs and analyses their maintenance and repair strategy. Regarding practical and managerial implications, the results could help BEV manufacturers to enhance their product and maintenance strategies. This study could support decision-makers to better understand the BEV market.

Keywords: Battery Electric Vehicle (BEV); cost; maintenance; repair

1 INTRODUCTION

Since 2019 registration numbers of Battery Electric Vehicles (BEV) in Germany increased continuously, despite a relatively low range of the early available models and insufficient charging infrastructure. The increase was fired by a growing number of different models on the market and significant state subsidies. This trend came to an end in 2024: after 18,4 % respectively 524.219 BEVs of in sum 2,84 million newly registered passenger cars in 2023, the number declined to 380.609 in 2024 [1].

Generally, the reasons for this decline are mainly seen in the stop of state subsidies and the resulting higher purchasing costs. Nevertheless, there are other reasons, why "Germans continue to struggle with the purchase of electric cars" [2]. In 2024 several car rental and trading companies reduced their BEV fleet not only in Germany, but internationally: "Sixt USA, a subsidiary of Germany-headquartered Sixt SE, and American rental car giant Hertz Global Holdings are slashing their BEV fleets after experiencing expensive repair costs, weak customer demand and a dramatic drop in resale prices for such cars." [3]

During the last years, several studies have emphasized the importance of Total Cost of Ownership (TCO) for the market success of BEV. In 2012 Propfe et al. predicted the cost competitiveness of different propulsion systems for the German auto market in 2020. He concluded, that electric vehicles will profit from lower maintenance and repair costs and a higher expected resale value [4]. Nevertheless, there have been contradictory results from different studies ([5-7]). Some are stating less yearly maintenance and repair costs for electric vehicles in some countries like the USA and some increased costs in other countries, like Turkey ([5-7]).

2 RESEARCH QUESTIONS AND METHODOLOGY

This study is part of an ongoing research program and aims to examine the reasons for BEVs high repair costs and tries to answer the following research questions:
RQ 1: What are the technical differences between BEV and ICEV?
RQ 2: Which strategies are practiced for maintenance and repair?
RQ 3: What are the deriving cost factors for maintenance and repair of BEV?

To address the research questions, a mixed-methods approach is used, which contains a literature analysis and qualitative expert interviews. Targets of the literature analysis are to represent the actual state of research as well as the actual state of practice based on recent studies of insurance companies and road assistances.

3 TECHNICAL DIFFERENCES BETWEEN BEV AND ICEV

The classic vehicle technology has been characterized by internal combustion engine drives based on the petrol or diesel principle, manual or automatic transmissions and mechanical power distribution to the drive wheels. In addition, there were mechanical/hydraulic auxiliary units such as steering, brakes, suspensions and damping. Together with the introduction of electronic safety and comfort systems, these have been successively electrified since the 1980s. Fundamentally, however, the conventional vehicle is still based on the classic mechanical structure.

Electromobility is changing this principle from the ground up: the elimination of mechanical drive components opens up opportunities for new vehicle concepts and mobility systems, depending on the degree of electrification of the drivetrain. The introduction of high-voltage electrical systems into vehicle technology not only changes the drive technology, it also acts as an accelerator for the electrification of the last mechanical or mechanical-hydraulic auxiliary units. Steering and braking signals more and more will be transmitted electronically (steer-by-wire and brake-by-wire). Steer-by-wire and brake-by-wire systems will find their way into the various forms of electromobility as well as into the more advanced conventional vehicles. Together with the further computerization and networking of automobiles, this in turn enables driver assistance systems for the realization of autonomous driving.

The effects of the various electrification concepts on maintenance and repair result from the different technical configurations of electric vehicles compared to conventional vehicles with petrol or diesel engines.

While full hybrid and plug-in hybrid vehicles have an internal combustion engine and mechanical drivetrain in addition to the electric components (electric motor, traction battery, electric drivetrain and, if necessary, a device for external electric charging), range extender vehicles do not have a mechanical drivetrain - the power is mainly distributed to the wheels by the electric drivetrain. In purely battery-electric vehicles, the combustion engine and fuel system are also omitted.

This study focuses on battery electric cars (BEV). Electric motor, power electronics, high-voltage-battery and charging unit are the main parts, which determine the vehicle concept of BEVs (see Fig. 1).

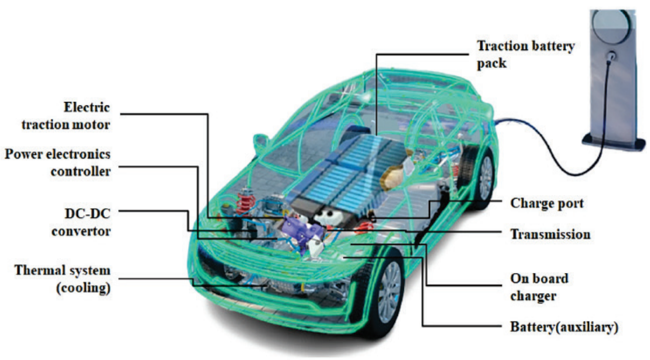

Figure 1 Technical components of BEV [8]

4 CONCEPTS FOR MAINTENANCE OF ICE VEHICLES AND BEV

The internal combustion engine and the mechanical drive train determine the maintenance and repair concepts of conventional vehicles. The energy source is liquid fuel from a fuel tank. The chemical-mechanical energy conversion and mechanical power transmission generate heat, friction and wear in the engine and the entire mechanical drivetrain.
For these reasons, the following maintenance activities must be carried out at certain intervals:

- Oil change including oil filter change,
- coolant change,
- spark plug change,
- air filter change,
- timing belt change,
- fuel filter change and
- brake fluid change.

The most important wear-related repair work and the associated replacement of components are:

- Brake pads and brake disks,
- exhaust system and
- clutch.

Focusing on battery electric vehicles (BEV), all combustion engine components and the mechanical drivetrain are eliminated. An electric motor/generator, a traction battery and the complete electric drivetrain are installed. The high-voltage battery is charged externally using an appropriate charger.

Due to the significantly different technical configurations of BEV vehicles, there are major differences in the maintenance and repair work compared to conventionally powered vehicles [9]. In terms of maintenance, all work associated with the combustion engine and the mechanical drive is eliminated. In addition, the following work must be carried out:

- checking the power electronics
- replacing the dryer cartridge and,
- replacing coolants in the battery and power electronics cooling circuits (depending on the manufacturer and conceptual method).

In the case of wear repairs, not only the clutch but also the complete exhaust system is now no longer required. Furthermore, due to energy recuperation, wear on the brake pads and discs can be expected to be reduced. Nevertheless, tire wear of electrified vehicles is discussed controversially: due to better acceleration in combination with higher vehicle weight compared to conventional vehicles higher tire wear can be expected [10, 11].

The available maintenance and repair cost data on BEVs is limited because of a relatively small number of vehicle models in the market. 2021 Liu et al. compared total cost of ownership of battery electric vehicles and internal combustion engine vehicles [7]. It is observed that the ICEV maintenance and repair cost increases with the vehicle price, while the BEV maintenance and repair cost remains steady and low regardless of the vehicle price variance. This is because BEVs are almost maintenance-free with fewer parts to be replaced and no need to regularly change auxiliary fluids (such as engine oil) during the vehicle's life compared with ICEV [7]. The study "Electromobility – Implication for After Sales" examined the different maintenance costs of BEV in comparison to ICEV in 2014 [11]. The study concluded, that BEVs maintenance labor costs are approximately 13% and wear parts costs 72% under the costs of comparable ICEV [11].

In sum it can be stated, that low maintenance costs are a real advantage of BEV and play a decisive role in the cost-of-ownership calculation.

5 CONCEPTS FOR REPAIR OF ICE VEHICLES AND BEV

When it comes to the repair concept of vehicles, the goal of cost-effectiveness in line with current value, while also taking into account the requirements of the workshop environment, is essential for a successful vehicle concept. This largely determines serviceability, insurance rating and cost of ownership. The repair costs consist mainly of labor and parts costs. Therefore the technical layout of the vehicle, the determination of the spare parts and the repair methods are crucial factors. In addition to that, several safety measurements have to be taken into account when working with high-voltage technology.

In general, for BEV repair the following technical systems are of relevance [12]:

The high-voltage battery is the most expensive part of a BEV. It stores the electrical energy, can be recharged and is responsible for the vehicle's energy supply during operation. Due to its size and weight, the battery is usually installed in the vehicle floor. It consists of individual battery modules containing several battery cells. Depending on the desired range and performance, the batteries differ in the number of modules and therefore in their size. The vehicle layout, the battery design and its protection measures have strong influence on the repair and maintenance costs. In addition, HV lithium-ion batteries are very sensitive to mechanical damage. In case of an accident, the batteries have to be checked according to the OEM rules and even with minor deformation or scratches frequently have to be replaced. Depending on OEM and model the following repair options are available:

- complete replacement with a new HV battery
- replacement with a refurbished battery or
- partial repair with replacement of cell modules.

The thermal management system keeps the vehicle drive within an optimum temperature range. Temperature regulation is particularly important for the electric motor, the power electronics and the battery. To protect the components from overheating, the permissible temperatures must always be maintained in the drivetrain. While the motor and power electronics only need to be cooled, the battery must be cooled or heated depending on the outside temperature. It consists of different cooling circles which need to be checked and the cooling liquids have to be changed on a regular basis. In case of a repair, the cooling system components can be dismantled and replaced.

The On-board-charger and battery management system monitors and controls the entire charging process with an external power source. It ensures safe and efficient energy transfer, which protects the battery cells from overcharging and maximizes charging efficiency. In addition, the on-board charger converts the AC voltage supplied by the external power source into the DC voltage compatible with the vehicle. Together with the charging cable and the charging socket it has to be checked in case of malfunctions in the charging process. In case of a repair, the defect parts ca be replaced.

The power electronics control the electric drive and establish the connection between the electric motor and the high-voltage battery. Both the electric motor and the high-voltage battery are supplied with power by the power electronics. The electric motor is supplied with power during normal driving operation when the motor drives the vehicle forwards or backwards. When the high-voltage battery is supplied with power, the electric motor works as a generator during recuperation and the vehicle's battery is charged by not accelerating. These electric components are quite robust and usually are not repaired but replaced in one spare part.

The high-voltage cables in the vehicle can be identified by their orange color. They are used to allow up to 800 Volts without interference and are consisting of the actual conductor, a primary insulation, a braided shield, a foil shield and a sheath. There is information about damaged HV-cables by weasels, which could not be verified in scientific studies at the time being.

There are several studies and databases, which indicate, that the repair costs of BEV are higher than in ICEV and play a decisive role in the cost-of-ownership calculation. Referring to a comparison of insurance costs between BEV and ICEV the Allianz Center for Technology states, that "the repair costs of electric vehicles are on average 30 to 35% higher than those of comparable cars with combustion engines" (p. 1 in [13]). In insurance cases above 7000 €, the costs of damage of BEV are 18% higher than the costs of ICEV. The reasons are lying mainly in higher spare parts cost and higher labor cost (p. 27 in [14]).

While general spare parts are at the same price level than parts for ICEV, the HV-specific parts are more valuable. The most expensive high voltage spare part of BEV is the traction battery. The second reason are the significantly higher labor costs compared to combustion engines. As a rule, independent workshops at the time being hardly repair on the HV-system of BEV. For this reason, authorized workshops carry out a high proportion of repair work on BEV, for which the hourly rates are significantly higher than at independent workshops. For complex repairs the vehicles even have to be taken to central test centers. All of these reasons are leading to significantly higher labor costs. In addition, the BEV fleet is relatively young (p. 27 in [14]). The high actual value of a BEV also increases the higher repair costs.

6 SUMMARY

It can be stated, that BEV require higher repair costs than ICEV. Mainly because of their technical concept, the cost of maintenance is lower, but the cost of spare parts as well as the cost of labor for repair work are significantly higher than for ICEV. The results of this study may give impacts and recommendations for practice and research.

A reduction of BEV repair costs could be an important aspect to enhance the acceptance of BEV technology and increase sales figures. To reach this task, additional research could investigate the structure of the BEV aftersales system as well as finding improvements of the battery electric vehicle concept. Automotive OEM, suppliers and insurance companies could collaborate to find practical solutions in the field of service oriented construction of the electric drive system. There could be solutions for a better positioning of the HV-parts, improved underbody protection of the HV-battery and optimized reparability of the components.

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