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# Transportation Research Part D

journal homepage: [www.elsevier.com/locate/trd](http://www.elsevier.com/locate/trd)

## A consumer-oriented total cost of ownership model for different vehicle types in Germany



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### ARTICLE INFO

#### Keywords:

Electric vehicles  
Consumer-oriented total cost of ownership  
Cost drivers  
Battery second use  
Battery second life

### ABSTRACT

In Germany, market penetration by alternative powertrains has been generally processing at a slow pace. Therefore, reaching the 2020 target of one million registered electric vehicles (EVs) is a major challenge. We analyze the German market by advancing and refining existing consumer-oriented total cost of ownership (TCO<sub>C</sub>) models and demonstrate the validity of our model by comparing the cost-efficiency of EVs and internal combustion engine vehicles (ICEVs) including the battery resale value for second use and second life. The TCO<sub>C</sub> model was calculated for the ten most frequently registered battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) and compared with ICEVs in the same vehicle segments. The results are further validated through applying three typical annual mileage driver profiles and by Monte Carlo simulations under various scenarios. Results reveal that only a few BEVs and HEVs are economical without subsidies when compared with ICEVs in all considered scenarios. The subsidies only barely change the results. The mini and the medium vehicle segment remain uneconomical in all tested scenarios. Overall, we conclude that subsidies support the competitiveness of BEVs, but fail to lead to favorable TCO<sub>C</sub> within several vehicle segments and several tested annual mileages.

## 1. Introduction

### 1.1. Background

Electric vehicles (EVs) are expected to significantly change the entire automobile industry (Dudenhöffer, 2016), due to their long-term sustainability and cost-efficiency. First, battery electric vehicles (BEVs) or fully hybrid vehicles (HEVs) reduce environmental impacts, in particular when the electricity comes from renewable energy sources (Frahm and Pander, 2017). In order to further reduce the environmental impact of BEVs, the option to reuse BEV batteries as second-life storage devices for renewable energies and to recycle the batteries after their useful lifetime should be considered. For example, the world's largest second-life battery storage pilot project in Germany involves a 13 megawatt hour memory operating with 1,000 old batteries (Specht, 2016). After the batteries' secondary life, the resources from old EV batteries can be recycled to extract metals like cobalt, lithium, and nickel, and thus to achieve the recovery quota of 50% required by EU legislation (European Commission, 2014). For example, the Belgium market leader in the disposal of lithium-ion batteries has developed a ultra-high temperature process in which residues of less than one percent remain after disposal of the batteries (Schwarzer, 2015). In summary, with the rapidly advancing alternative powertrain technologies the environmental balance will be improved, and with the rising EV market demand a comprehensive infrastructure for the two environmental pillars – reuse and recycling of lithium-ion batteries – will become necessary in the future.

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<http://dx.doi.org/10.1016/j.trd.2017.09.007>

Second, EVs in the traffic sector might be already cost-efficient over their comparable ICEVs, but the cost-benefits are mostly non-transparent to consumers. One reason is that EVs require a high initial investment (purchasing price) compared to ICEVs, which represents a major obstacle for the market penetration by EVs (Contestabile et al., 2011; Egbue and Long, 2012; Oliver and Rosen, 2010; Rousseau et al., 2015). Another reason is that consumers are not aware of the operating expenditure savings of alternative powertrains. For instance, over half of all consumers underestimate the considerable cost advantages in energy consumption (Krause et al., 2013; Lane and Potter, 2007; Zhang et al., 2011). In order to increase the EV market share, the German government provides purchase-based policy measures to decrease the purchasing price as well as the fixed costs. BEVs up to a net purchasing price of 60,000 EUR are currently subsidized with a financial incentive of 4,000 EUR and a vehicle tax exemption for a duration of ten years until 31.12.2026 (BMVI, 2016; Bundesregierung, 2016). As a result, EVs have become economically more attractive. However, the overall cost-benefits are not clear when EVs are compared with ICEVs, which still dominate the German car market.

As consumers face new costs for the battery (including reuse and recycling) and new savings for the ownership of an EV, precise information about the total cost of ownership (TCO) can help consumers to make more profound purchasing decisions and can reduce decision complexity (Carr and Ittner, 1992; Ellram, 1995, 1994; Ellram and Siferd, 1998, 1993). Therefore, we develop a modified TCO method which includes battery-related costs and revenues, and we apply the method to the most relevant models and market segments in the German car market.

## 1.2. Literature review

The TCO method allows consumers to directly compare all costs that are associated with the ownership of a product during its useful life (Bickert and Kuckshinrichs, 2011). The studies by Bubeck et al. (2016) and Wu et al. (2015) provide a comprehensive literature overview assessing the general TCO for different powertrain technologies and vehicle classes in various countries. However, the TCO method can be applied in two ways, namely via a consumer-oriented approach or via a society-oriented approach (Lebeau et al., 2013). Consumer-oriented TCO (TCO<sub>C</sub>) models usually include the purchasing price as well as all costs related to actually receiving and using the item which are borne by the consumer (Carr and Ittner, 1992; Ellram, 1995, 1994; Ellram and Siferd, 1998). By contrast, the society-oriented TCO (TCO<sub>S</sub>) considers, in addition to capital and operating expenditure, environmental costs such as carbon dioxide (CO<sub>2</sub>) emission costs (Lebeau et al., 2013). A variety of studies consider the TCO<sub>S</sub> method for different products (Delucchi and Lipman, 2001; Nurhadi et al., 2017). As our aim is to analyze costs that are borne by the consumers and to derive conclusions for the future market development, we concentrate on the consumer-oriented TCO in the following. Consequently, we consider all direct monetary effects for consumers which are crucial for the purchasing decision on new vehicles (Dumortier et al., 2015; Lebeau et al., 2013).

In spite of the large amount of studies comparing EVs with ICEVs, several cost drivers are not yet fully integrated in the existing literature. First, the literature outlines that different ownership cost categories are used in the TCO<sub>C</sub>. As illustrated in Table 1, the cost drivers of capital expenditure such as the purchasing price and battery costs, as well as of operating expenditure, such as energy consumption, maintenance, and repair, are mostly used in the TCO<sub>C</sub> method. Several other essential costs that are associated with ownership, such as resale value, insurance, and vehicle tax, are often ignored in the TCO<sub>C</sub> (Hellgren, 2007; Offer et al., 2010; Van Vliet et al., 2010). For example, Bubeck et al. (2016) do not include the vehicle's resale value, and Wu et al. (2015) ignore additional costs for the replacement of batteries in the TCO<sub>C</sub>. As a result, the findings that BEVs are cost-efficient in specific vehicle classes contradict each other in Germany. Bubeck et al. (2016) state that BEVs are more likely to become competitive for the medium size class (compact, large, and executive vehicles) in the near future. Contrastingly, Wu et al. (2015) find that BEVs are more likely to become economical for the small size class (mini and small vehicles) compared to ICEVs in the near future. In addition, the findings of Schücking et al. (2017) show a high discrepancy in the annual driving distances in which BEVs are currently cost-efficient from 20,000 km to 30,400 km in Germany. These contradictions can be largely explained by the consideration of different ownership cost categories in the TCO<sub>C</sub> in addition to other aspects, such as vehicle models, country-specific aspects, or driving behavior in the form of annual mileage and holding period.

Second, the literature reveals that the battery resale value for second use and for the battery's second life has not been integrated yet in the TCO<sub>C</sub>. Recently, Bubeck et al. (2016) developed a TCO model including the purchasing cost and the operating cost of a new vehicle. The authors consider a battery replacement factor but do not assess the battery resale value for second use, as they assume a maximum mileage of 250,000 km for the battery of a BEV. So far, only Hou et al. (2014) and Faria et al. (2013) have considered the used battery reserved value and/or disposal at the end of the battery's lifetime in a BEV but did not incorporate other essential ownership costs. While Hou et al. (2014) did not consider the vehicle's purchasing price, maintenance and repair, insurance, and vehicle tax, Faria et al. (2013) did not include the battery resale value at the end of use in the TCO<sub>C</sub>. We therefore suggest a comprehensive TCO<sub>C</sub> approach that includes the battery resale value for second use and other relevant cost drivers. In particular, we show that the battery resale value can potentially offset parts of the initial investment costs for the vehicle.

Table 1 summarizes the TCO<sub>C</sub> literature on EVs sorted by publication date. The table shows relevant papers and it outlines the existing research gap of often ignored second use and second life costs of batteries in the literature. These research gaps become even wider when the TCO<sub>C</sub> calculations are not based on the "average driver" but when specific driver profiles are taken into account. We demonstrate the modified TCO<sub>C</sub> approach for the German market, which will change drastically over the course of the next years (Dudenhöffer, 2016). For this purpose, the present study attempts to answer the following questions:

- What is the TCO<sub>C</sub> of vehicles with an alternative powertrain (BEVs, HEVs) with regard to the use of batteries in relation to comparable ICEVs in different usage scenarios and what is the most cost-efficient option from the user perspective?

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