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TCO-Comparison of Fuel and Electric Powered Taxis: Recommendations for Hannover

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Is it economically viable to electrify the taxi fleet?

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1 Total Cost of Ownership (TCO)

The perception that battery electric vehicles (BEV) are more expensive than conventional propelled cars is quite common. This perception may stem from the difficulties for businesses and private consumers to assess and evaluate the long-term operational costs of BEV. In order to comprehensively determine the overall costs of purchasing and operating a vehicle, various total cost of ownership (TCO) models and calculation methods have been applied by several researchers (e.g., Lin et al., 2013, Thiel et al., 2010, Tseng et al., 2013). The total cost of ownership analysis aims to explore the true costs of purchasing and operating a particular good that arise over the entire holding period. Therefore, the calculation of the TCO is equally useful for companies, state authorities as well as private consumers to identify the overall costs associated with a decision to purchase. An exclusive consideration and comparison of the purchase prices of vehicles, excluding long-term cost positions, may cause uneconomical buying decisions resulting in serious financial consequences for businesses and private customers (Hagman et al., 2016).

However, existing studies in this area often neglect to consider specific use cases and hence, cannot provide meaningful recommendations for particular sectors, such as the taxi industry (Wu et al., 2015). Therefore, a closer examination of the specific TCO of BEV for taxi operators seems to be advisable and crucial in order to investigate the economic feasibility of electric taxis. The aim of this chapter is to develop an *Excel*-based TCO model and to compare the total cost of ownership of conventional driven taxi vehicles with that of equivalent BEV. For this purpose, the overall cost positions that arise to the taxi operator due to the vehicle ownership as well as data from the taxi industry in Hannover are used to calculate the TCO values of battery electric taxi vehicles and conventional propelled taxis. The used data regarding the taxi industry in Hannover was obtained and validated through discussions with managing directors of the *Hallo Taxi 3811 GmbH Hannover*, which is responsible for the entire taxi dispatching system in Hannover.

Consequently, the purchase price does not represent the total buying and owning costs of a vehicle. In addition, various operating and capital cost need to be taken into consideration. Capital costs are associated with the vehicle purchase and comprise cost categories, such as depreciation, tax and interest payments. Operating costs on the other hand, are tied with ongoing driving costs, namely: fuel or electricity expanses as well as maintenance and repair costs (Consumer Report, 2012).

The underlying TCO model in this study constist of the following elements visualized in Table 1:

Table 1. TCO elements

Parameter	**Description**
IPC	Initial purchase price
RV	Resale price after the vehicle holding period
I	Interest costs
T	Taxes
FC	Fuel or electricity consumption costs
MR	Maintenance and repair costs
CIC	Charging infrastructure costs
S	Environmental subsidies

The following calculation approach is used for this study:

$$CO = \left(IPC - \frac{RV}{(1+r)^N}\right) + I + \left(T_0 + \sum_{n=1}^{N-1} \frac{T_n}{(1+r)^n}\right) + \left(\sum_{n=1}^{N} \frac{FC_n}{(1+r)^n}\right) + \left(\sum_{n=1}^{N} \frac{MR_n}{(1+r)^n}\right) + \left(CIC_0 + \sum_{n=1}^{N} \frac{CIC_n}{(1+r)^n}\right) - S_0 \quad (1)$$

where TCO is the total cost of ownership of a particular vehicle over the holding period, IPC is the initial buying price of the vehicle and RV constitutes the future resell value after the holding period. Thus, the difference between IPC and the discounted resell price represents the car specific depreciation. N is the vehicle holding period in years. I depicts the total interest expanses over the vehicle holding period (see 3.2 for a detailed presentation of the total interest paid formula). FC stands for the fuel or electricity costs and MR represents the maintenance and repair costs of a vehicle. Further, CIC describes the charging infrastructure costs, whereby both the initial purchasing costs as well as maintenance costs for charging infrastructure are considered. Finally, S displays the environmental subsidy. In order to achieve comparability between the occurring costs, a discounting of all future costs to their present values was performed, as illustrated in the Formula (1) above.

These different cost positions depend on the particular vehicle category, the vehicle use as well as defined general conditions. In the next sections, the vehicle use case (taxi operation), all elements of the TCO model as well as all input variables and assumptions for the TCO calculation are described. The TCO model will be used to compare the total cost of ownership between conventional diesel taxi vehicles and equivalent electric driven taxi vehicles in consideration of the specific conditions and driving data of the taxi industry in Hannover, which will be outlined in the following section.

al., 2015). New tax measures that reduce the relative costs of electricity in comparison to diesel prices could foster the opportunities for middle-class BEV to become also most economical for taxi companies in the near future.

Further, in order to enable a smooth taxi operation with BEV, the taxi dispatching system of the *Hallo Taxi 3811 GmbH* should be adjusted. The current taxi dispatching system of the *Hallo Taxi 3811 GmbH*, with which over 90% of the taxis in Hannover are coordinated, is not suitable for electric taxis, as the characteristics of BEV are not considered. To improve the feasibility of electric taxis, a new dispatching system need to be implemented that takes into account the vehicle specific remaining battery capacity in conjunction with the requested destination of the customers. In addition, the new taxi dispatching system should consider the distance of electric taxis to battery charging stations and their availability, to optimize charging processes during a taxi shift (Lu et al., 2012). Such an adjusted dispatching system constitutes an important prerequisite for the efficient use of electric taxis in Hannover. Complementary, navigation systems with *EcoRouting* should be implemented in electric taxis to prevent wrong battery capacity displays, for example due to a sudden increase in electricity consumption because of steep route sections. *EcoRouting* systems allow a precise forecast of available battery capacity based on the topography of a planed route (Schulz, 2015). As a result, the remaining battery capacity for upcoming taxi rides could be managed more accurately and without misjudgements by the *Hallo Taxi 3811 GmbH* in Hannover. In the next section limitations associated with the analysis will be reviewed in detail.

6 Limitations and Further Research

Some of the cost categories implemented in the TCO model can be predicted with a high degree of certainty and are stable over the vehicle holding period. These includes in particular costs related to taxes, interests as well as maintenance and repair. However, the development of most TCO categories over the vehicle ownership is difficult to predict, such as depreciation and fuel costs. For example, the depreciation of a vehicle depends on many factors that can change unexpectedly and rapidly over the vehicle holding period. Especially in the case of new drive technologies, it is not yet clear how the demand for BEV will develop on the used car market and therefore, makes it even more difficult to estimate the depreciation (Hagman et al., 2016). Hence, it is possible that the depreciation costs of the six sample vehicles will differ from the depreciation costs calculated in this study.

The prediction of fuel and electricity costs is challenging mainly because of two reasons. First, the global fuel market is characterized by high price fluctuations, which make it difficult or even impossible to make a secure assessment of future fuel prices. Second, fuel and electricity consumption data of vehicle manufacturers are determined in an optimized test environment, which lead to fuel consumption specifications that cannot be achieved under real world conditions (Wu et al., 2015). Within the scope of this study, this was addressed by including real world fuel and electricity consumption figures supplied by vehicle owners on an online database. Nevertheless, due to the significant price volatility in fuel markets future consumption costs of the analyzed vehicles may differ from the ones determined in this research study. In summary, it is important to consider that TCO calculations are always subject to uncertainty due to the variety of required assumptions and forecasts.

Further, it must be noted that the calculated TCO results are based on country specifics of Germany, e.g., German fuel and electricity prices, as well as characteristics of the taxi industry in Hannover, e.g., annual mileage and vehicle holding period. Hence, the results of the developed TCO model can vary across different cities and countries, for instance due to higher fuel prices or tax rates. Finally, it must be acknowledged that economic factors, as analyzed in this chapter cannot fully explain buying decisions in the vehicle sector. Additional factors are also responsible for purchasing decisions, such as age, education or housing type. Therefore, this TCO study has focused primarily on an economic factor, which is an important but not the only parameter influencing the vehicle purchasing decision of customers and taxi companies (Axsen and Kurani, 2013).

Future research in this area could use the developed TCO model to investigate the economic feasibility of other alternative drive technologies such as natural gas or fuel cell vehicles and hence, evaluate their suitability for the taxi industry. In addition, various assumptions of the TCO model could be varied in order to analyze the impact of these changes on the vehicle TCO. For example, the average mileage of taxis could be increased and the influence of this change on the TCO of diesel and electric driven taxis could be investigated.