IWI Discussion Paper Series
84 (June 2, 2018)[1]

ISSN 1612-3646

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.

2 Characteristics of Hannover's Taxi Industry

In the state capital Hannover, there exist 248 taxi companies which operate a total of amount of 637 taxis. The number and size of taxi companies in Hannover is illustrated in Table 2 and Figure 1.

***Table 2. Number and share of companies per taxi ownership*[5]**

Taxis per company	Number of companies	Relative share of companies
1	144	58,1%
2	35	14,1%
3	24	9,7%
4	9	3,6%
5	6	2,4%
6	11	4,4%
7	2	0,8%
8	1	0,4%
9	4	1,6%
10	1	0,4%
11	3	1,2%
12	5	2,0%
15	2	0,8%
28	1	0,4%
Total	**248**	**100%**

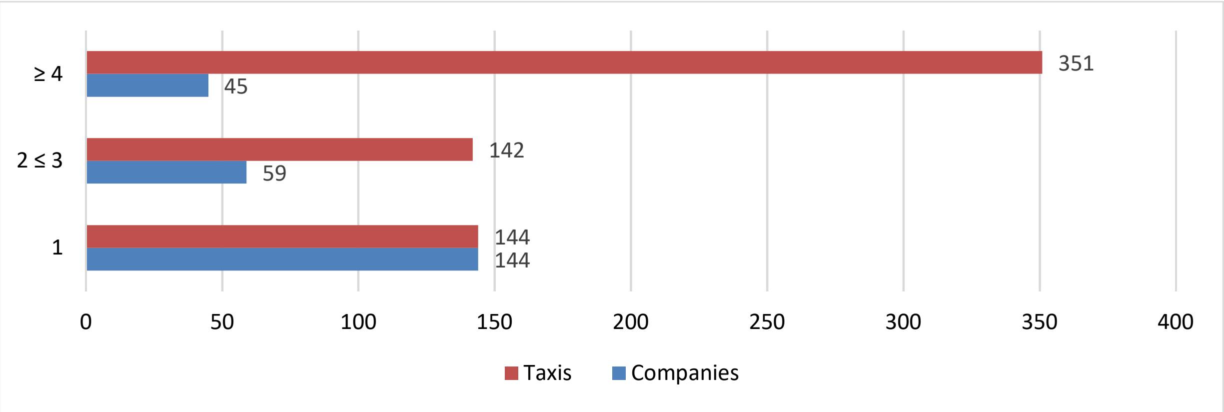

***Figure 1. Companies by size and aggregated taxi ownership*[6]**

About 58% of the taxi operators are companies with only one vehicle, which own 144 (23%) of the overall taxi vehicles in Hannover. The largest taxi company operates 28 taxis (4,4% of all taxis in Hannover) and the average number of taxi vehicles per company amounts to 2,6 vehicles. Regarding the age structure of the taxi companies it is noticeable that a large part of the taxi businesses has only been on the market for

[5] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).
[6] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).

a few years and there exists a relatively high fluctuation level in the taxi industry of Hannover. While only 23% of the companies have started their taxi business before 1995, more than 41% of the current companies have entered the taxi industry since 2008. The average age of taxi companies in Hannover is around twelve years (ISUP, 2015).

Based on 637 taxi licenses in Hannover a taxi-density (TD) of 1,22 taxis per 1000 inhabitants resulted for the year 2014. The TD constitutes a measure of the existing taxi supply and competition in a particular city. The development of the TD in Hannover and other German cities of similar size is provided by Figure 2. The diagram illustrates, that Hannover is characterized by a relatively high TD and that there is a large range of TD between the considered cities. This is mainly due to the specific characteristics of the regional environment, e.g., size of airports or trade fairs (ISUP, 2015).

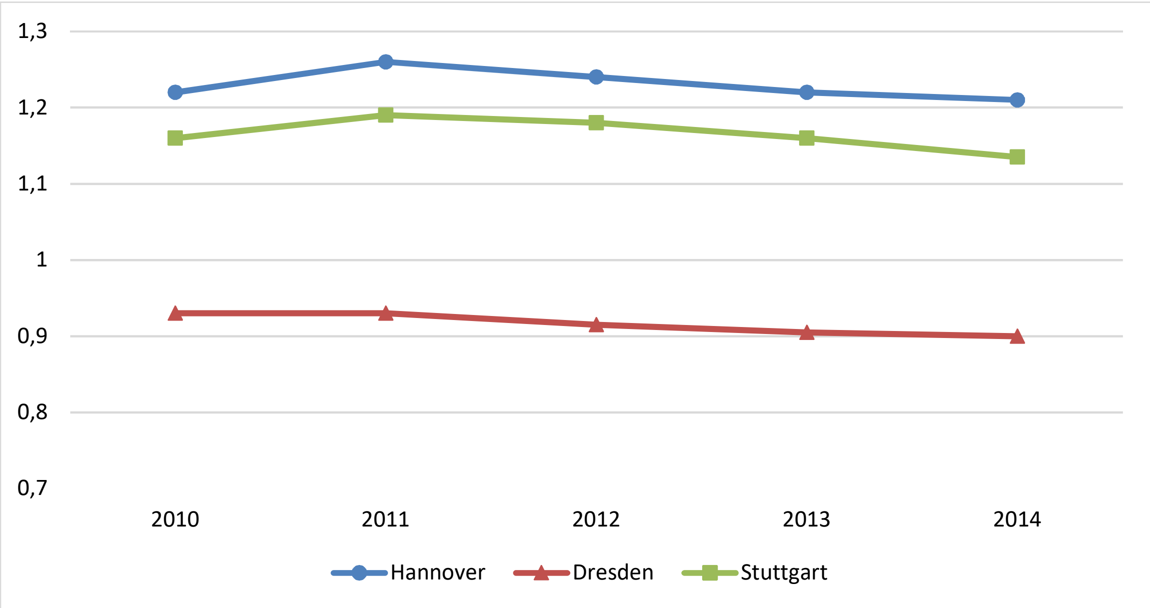

Figure 2. Development of the taxi-density in selected German mid-sized cities[7]

Regarding the vehicle fleet of taxi companies in Hannover it can be stated that vehicles of the brand Mercedes Benz, which are strongly represented in the German taxi industry, are also used in Hannover to a high share. About 46% of the taxi vehicles in Hannover are part of the brand Mercedes Benz. However, the high proportion of taxi vehicles from Volkswagen is remarkable in comparison with other German cities. Approximately 47% of the overall taxis in Hannover belong to the Volkswagen brand, whereas in other cities, such as Regensburg and Potsdam this proportion amounts to merely 17% and 9%, respectively. This high share of taxis from Volkswagen may be explained due to the proximity to Wolfsburg and other production facilities of Volkswagen as well as to the cheaper price compared to vehicles of Mercedes Benz.

[7] Own illustration bason on ISUP (2015).

Furthermore, 6% of the entire taxi vehicles in Hannover are specified as mini-van taxis, which can transport more than five people (ISUP, 2015). Figure 3 depicts the structure of the taxi fleet in Hannover by vehicle manufacturer.

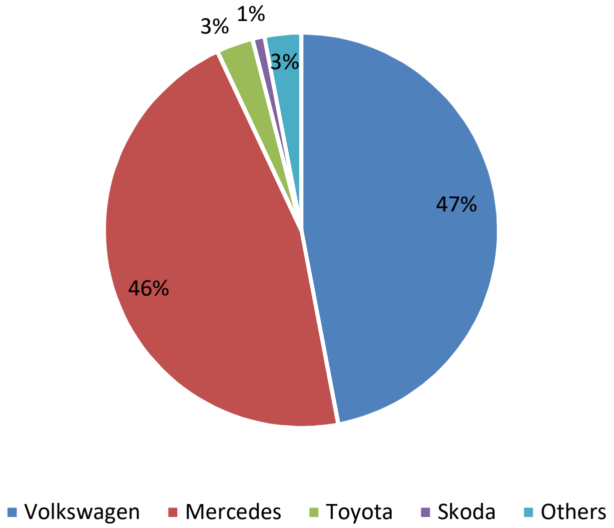

Figure 3. Share of taxi vehicles in Hannover by manufacturers[8]

A recent survey among taxi companies in Hannover indicated that the average operating time of taxi vehicles amounts to 4,3 years. The following Table 3 summarizes the average operating time and vehicle age of taxi vehicles in Hannover by size of taxi companies. According to these figures, an average rounded taxi vehicle holding period of 4 years is assumed for the following TCO calculations.

Table 3. Average vehicle age and operating time per company size[9]

Company size	**Average vehicle age (years)**	**Average vehicle operating time (years)**
1 taxi without employees	3,9	5,5
1 taxi with employees	3,1	4,3
2 ≤ 3	2,8	3,9
≥ 4	3,0	4,2
Average	**3,1**	**4,3**

The average holding period and average vehicle age for companies equipped with only one vehicle without employees (single-driver) exceeds the values for other company sizes due to the lower annual mileage (vehicles are used only by the taxi operator himself). Hence, the lower annual driving distance increases the vehicle holding time

[8] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).
[9] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).

as less vehicle abrasion is caused given a lower mileage. The annual mileage of companies equipped with only one vehicle without employees is on average 19% below that of the multiple vehicle companies in Hannover (ISUP, 2015).

During day and night hours from Sunday to Thursday almost the same amount of taxi rides per hour (1.0 to 1.1) are reached per taxi vehicle in Hannover. Only on Friday and Saturday nights better values of 1,5 taxi rides per hour can be reached due to the more frequent leisure activities of the citizens. The average number of taxi rides per taxi and hour in 2013 is outlined in the following Table 4.

Table 4. Average rides per day and shift[10]

Weekdays	Mon-Thu		Friday		Saturday		Sunday		Average over all weekdays	
Day-/night shift	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Taxi rides per hour [h])	1,0	1,1	1,0	1,5	1,1	1,5	1,0	1,1	1,0	1,3
									1,2	

However, it must be noted that on Friday and Saturday nights mainly short driving distances are demanded by passengers, which are characterized by lower profits in comparison with longer taxi rides (ISUP, 2015). The average driving distance of a taxi ride in Hannover from the customers pick-up location to the customers destination amounted to 6,1km in 2013. Further, the share of empty-trip kilometers per taxi of the total yearly mileage amounted to 53% (ISUP, 2015). Therefore, in Hannover the entire driving distance regarding one passenger transportation by taxi is about an average of 13km (sum of empty-trip kilometers per ride (6,9km), e.g., distance from the taxi rank to the pick up location of the customer and occupied-trip kilometers per ride (6,1km), e.g., the distance from the pick-up location to the customers destination).

Another important taxi data is constituted by the annual mileage of taxi vehicles. Referring to the data provided by the taxi companies, Table 5 shows the development of the average annual mileage per taxi in Hannover for the period from 2012 to 2017 (sum of empty-trip kilometers and occupied-trip kilometers). The values from 2014 to 2017 were determined based on discussions with a managing director of the *Hallo Taxi 3811 GmbH*, under consideration of an annual increase in mileage of approximately 1,5% per year. This is in line with the average increase in mileage from 2012 to 2013.

[10] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).

Table 5. Average annual mileage per taxi [11]

			Prediction			
Year	2012	2013	2014	2015	2016	2017
Annual mileage [km]	60.114	61.021	61.936	62.865	63.808	64.765

As indicated in Table 5, the average mileage per taxi vehicle in Hannover has increased slightly over the last years. Furthermore, it can be deduced that taxi companies of all sizes are equally affected by this development. The average annual mileage of 64.765 km per taxi in 2017 is within the range of annual driving distances of taxis in other German cities with similar size (e.g., Stuttgart 2011: 55.100 kilometers (Linne and Krause, 2013a) and Essen 2011: 65.300 kilometers (Linne and Krause, 2013b)). Survey results among taxi operators in Hannover indicated that taxi vehicles were not used for an average of 57 days in 2013 (ISUP, 2015). Therefore, taking into consideration an average of 308 operating days per year and taxi vehicle in 2017, a daily driving distance of about 210 kilometers per taxi is realized in Hannover. According to this data, an average annual mileage of 64.765 kilometers per taxi will be included in the TCO model and used as a basis for all upcoming calculations. After the basic taxi specific parameters were illustrated, the main elements and input variables of the constructed TCO model will be derived and described in the next section.

3 Total Cost of Ownership Elements

The *Excel*-based calculation model will be used to determine and contrast the TCO of various vehicle models with different drive technologies by taking into consideration the taxi operating characteristics in Hannover. The definition of typical taxi vehicles in the respective conventional and battery electric variant forms the basis for the deduction of specific purchasing and operating costs and therefore, is of crucial importance for the TCO calculation. The TCO is determined among conventional diesel powered and equivalent electric driven car models from Mercedes Benz and Volkswagen, which are primarily used by taxi operators in Hannover (see Figure 3). Additionally, a vehicle model from Tesla Motors was included in this research to enable a TCO comparison between conventional and electric driven premium taxi cars. Premium class vehicles are also widely used in the taxi industry to provide customers with a comfortable driving experience and due to their better resale possibilities. Figure 4 illustrates the key data of the taxi vehicle models, which were considered in this research sorted by drive technology, brand and taxi vehicle class. It must be noted that these are manufacturer specifications. Some of this manufacturer data will be adjusted in this section in order to reflect real world conditions and costs.

[11] Own illustration based on ISUP (2015) and conversations with *Hallo Taxi GmbH Hannover* (2017).

	Conventional Drive Technology	Fully Electric Drive Technology
Middle Class Taxis	Mercedes Benz B 200 d Purchasing price: 31.606 € Consumption (mixed): 4,5 l/100 km (NEFZ) CO_2 emissions: 117 g/km (NEFZ) Horsepower: 136 hp (100 kW) Displacement: 2.143 cm³ Fuel type: Diesel	Mercedes Benz B 250 e Purchasing price: 39.151 € Consumption (mixed): 16,6 kWh/100 km (NEFZ) CO_2 emissions: 0 g/km (NEFZ) Horsepower: 179 hp (132 kW) Electric range: 200 km (NEFZ) Battery capacity: 28 kWh
	Volkswagen Golf VII 1,6 l TDI Purchasing price: 22.200 € Consumption (mixed): 4,1 l/100 km (NEFZ) CO_2 emissions: 106 g/km (NEFZ) Horsepower: 115 hp (085 kW) Displacement: 1.598 cm3 Fuel type: Diesel	Volkswagen e-Golf Purchasing price: 35.900 € Consumption (mixed): 12,7 kWh/100 km (NEFZ) CO_2 emissions: 0 g/km (NEFZ) Horsepower: 136 hp (100 kW) Electric range: 300 km (NEFZ) Battery capacity: 35,8 kWh
Premium Taxis	Mercedes Benz E 350 d Sedan Purchasing price: 55.876 € Consumption (mixed): 5,2 l/100 km (NEFZ) CO_2 emissions: 144 g/km (NEFZ) Horsepower: 258 hp (190 kW) Displacement: 2.987 cm3 Fuel type: Diesel	Tesla Model S 60 Purchasing price: 71.019 € Consumption (mixed): 15 kWh/100 km (NEFZ) CO_2 emissions: 0 g/km (NEFZ) Horsepower: 262 hp (193 kW) Electric range: 400 km (NEFZ) Battery capacity: 60 kWh

Figure 4. Description and key data of the analyzed vehicles[12]

In the following, all cost positions and assumptions will be explained that make up the TCO of taxi vehicles and which were included in the *Excel*-based TCO model.

3.1 Depreciation

The first cost category of the vehicle TCO is represented by depreciation. The initial purchase price less the present value of the resell price of a particular car determines the amount of depreciation. Among the total cost of vehicle ownership depreciation constitutes one of the biggest cost positions and hence, is of vital importance for new car purchasers (Consumer Report, 2012). Depreciation of vehicles is characterized by a high complexity and dependent on various factors, e.g., vehicle equipment, fuel prices, color and brand reputation. Consequently, the amount of depreciation is highly volatile and can vary between drive technologies, car models and brands (Hagman et al., 2016).

Regarding the development of the depreciation value for conventional vehicles there exist various research results. Hence, assuming stable conditions and consumer preferences the depreciation value for conventional vehicles can be assessed and predicted based on these past analysis. Contrary, due to the low sales figures and lack

[12] Own illuastration, data source: Tesla Motors (2017a); Mercedes Benz (2017); Volkswagen (2017).

of BEV in the used-car market, it is not possible today to precisely predict the depreciation of BEV (Schaufenster Elektromobilität, 2016). In the scientific literature various arguments are mentioned justifying either a higher or a lower depreciation rate of electric cars in comparison to conventional propelled vehicles. For instance, arguments supporting lower depreciation rates of electric cars state that used car buyers may have a higher willingness to pay for BEV due to their lower operational costs and the higher attractiveness of modern technologies. In contrast, higher depreciation rates of electric cars are justified by existing uncertainties regarding the battery lifetime and long-term battery capacity (Pfahl, 2012).

In this study, the depreciation costs and rates are calculated based on the depreciation and used-car values determined by the Deutsche Automobil Treuhand (DAT 2017). The depreciation of the vehicles will be determined based on basic purchase prices without considering taxi specific equipment, e.g., costs for the mandatory taxi sign. This is due to the fact that the taxi specific equipment cost the same for both, the electric- and internal combustion engine vehicle version (Mercedes Benz, 2016). The depreciation costs of the sample vehicles (monthly and over the 4-year holding period) are summarized in the following Table 6 and included in the TCO model.

Table 6. Depreciation and discounted resale values[13]

Vehicle models	Depreciation (monthly)	Depreciation (total)	Present value of resale value (discounted)	Depreciation rate (% of initial purchasing price)
MB B 200 d	416 €	21.523 €	10.083 €	32%
MB B 250 e	586 €	29.601 €	9.550 €	24%
VW Golf VII 1,6 l TDI	324 €	16.440 €	5.760 €	26%
VW e-Golf	506 €	25.839 €	10.061 €	28%
MB E 350 d Sedan	758 €	38.988 €	16.888 €	30%
Tesla Model S 60	962 €	49.492 €	21.526 €	30%

3.2 Interest Costs

In Hannover, 85% of the purchased taxi vehicles are financed by bank loans repaid in monthly installments. The remaining 15% of taxi vehicle purchases financed solely with own resources are mainly related to used-cars. The vast majority of the granted bank loans required an average down payment with own resources in the amount of 20% (ISUP, 2015). Therefore, it is assumed that 80 % of the initial purchasing price of a new taxi vehicle in Hannover is financed by a loan with a term of 48 month and an effective interest rate of 3,65% p.a., which constitutes the current interest rate of collateralized loans for consumption in Germany (status February 2017: Deutsche Bundesbank, 2017). This effective interest rate can also be considered as the opportunity cost of

[13] Own representation and calculation based on DAT (2017).

capital and hence, will be used to discount future costs to their present values within the developed TCO model. The occurring interest payments over the loan period of four years will be calculated via the following formulas.

Table 7. Interest payments formulas based on Hagman (2015)

Monthly payment formula		Total interest paid formula	
$c = \frac{r \times P}{1-(1+r)^{-N}} = \frac{P \times r(1+r)^{N}}{(1+r)^{-N}-1}$	(2)	$I = c \times N - P$	(3)
c: Monthly payment		I: Interest paid over the lifetime of the loan	
r: Monthly interest rate		c: Monthly payment	
N: Number of monthly payments		N: Number of monthly payments	
P: Amount borrowed		P: Amount borrowed	

3.3 Vehicle Taxes

In Germany, the calculation of the vehicle tax rates for passenger cars takes into account the engine displacement and the produced carbon dioxide emissions per kilometer. The vehicle tax for light commercial vehicles depends solely on their permissible total weight (Plötz et al., 2013). Against that, fully BEV are currently exempted from vehicle taxation in Germany according to § 3d of the Kraftfahrtsteuergesetz (Generalzolldirektion, 2017). Figure 5 shows the vehicle tax calculation scheme for passenger vehicles in dependence of the drive technology. The calculation of the CO2-dependent cost position for passenger vehicles is based on standardized fuel consumption data resulting from the New European Driving Cycle test procedure (NEDC) and thereof, does not refer to real-world fuel consumption values that will be used for the calculation of the fuel and electricity consumption costs in the TCO-model (see 3.4).

Vehicle tax cost positions	Diesel	Battery Electric Vehicle
Basic tax amount (per 100cm^3 displacement)	9,50 €	0,00 €
+	+	+
CO_2-emission based tax amount (if vehicle exceeds 95g CO_2-Emissions per km)	2,00 € per g/km	0,00 €
=	=	=
Total annual vehicle tax		

Figure 5. Vehicle tax calculation scheme for passenger vehicles based on Plötz et al. (2013)

According to this vehicle tax calculation scheme the following annual tax payments result for the defined vehicles.

Table 8. Vehicle tax payments[14]

Vehicle models	Annual vehicle tax payments	Total vehicle tax payments over 4-years (discounted)
MB B 200 d	253 €	960 €
MB B 250 e	0 €	0 €
VW Golf VII 1,6 l TDI	174 €	660 €
VW e-Golf	0 €	0 €
MB E 350 d Sedan	383 €	1.453 €
Tesla Model S 60	0 €	0 €

3.4 Fuel and Electricity Consumption Costs

Fuel and energy consumption expenses constitute another important cost position of the vehicle total cost of ownership. In order to calculate the vehicle specific consumption cost, assumptions regarding the fuel and energy prices as well as the consumption level have to be made. The average fuel and energy consumption data specified and delivered by the vehicle manufacturers (see Figure 4) are determined according to the New European Driving Cycle (NEDC) test procedure. Recent empirical analysis found that the fuel and energy consumption data based on the NEDC does not match with the real world consumption (Mock et al., 2014). For instance, causes for this deviations may be due to weather-dependent influences, the energy consumption of auxiliary units or type of tires. However, for the determination of the TCO real world fuel and energy consumption values are required and of particular relevance. To address this, a real world adjustment of the fuel and energy consumption data was included in this study. In order to determine the real world consumption figures, time series data of private vehicle owners were analyzed (regarding the sample vehicles included in this study). This time series data sets were obtained from the online data base *Spritmonitor*, which contains real world fuel consumption data of most vehicle models available in Germany (Spritmonitor, 2017a). This fuel and energy consumption data also comprises long-term influences such as seasonal fluctuations and different driving profiles. The analysis of the time series data revealed the following real world consumption figures shown in Table 9, which will be used to calculate the total fuel and energy consumption costs. The real world consumption values represent means from cars that have driven not less than 1.500 kilometers.

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[14] Own illustration and calculation.

Table 9. Real world average consumption figures of the electric and conventional vehicles[15]

Vehicle models	Real world consumption	Difference from consumption based on NEDC test procedure [%]
MB B 200 d	6,68 l/100km	+ 33%
MB B 250 e	23,65 kWh/100km	+ 30%
VW Golf VII 1,6 l TDI	6 l/100km	+ 32%
VW e-Golf	16,66 kWh/100km	+ 24%
MB E 350 d Sedan	7,65 l/100km	+ 32%
Tesla Model S 60	19,80 kWh/100km	+ 24%

As a TCO comparison for a vehicle holding period from 2017 to 2021 is to be performed, projections of future fuel and electricity prices need to be estimated in order to determine realistic fuel and electricity consumption costs. Based on the average diesel price in 2016, the average prices for the years 2017 to 2020 are calculated assuming an annual price increase. According to the calculations on behalf of the Federal Ministry of Transport and Digital Infrastructure (BMVI), an annual increase in fuel prices of 6% in 2017, followed by an annual increase of 1% until 2020 was included as a result of rising crude oil prices and mineral oil tax (SSP Consult, 2017). Table 10 shows the predicted average diesel prices for the years 2017 to 2020 based on the average diesel price in 2016. These predicted diesel prices will be used to calculate the fuel consumption costs for each vehicle holding year and all diesel taxis considered in this study.

Table 10. Predicted average diesel prices for the years 2017 to 2020[16]

		Prediction			
Year	2016	2017	2018	2019	2020
Diesel [€/l]	1,0721	1,1364	1,1478	1,1593	1,1709

The prediction of the electricity prices was carried out as follows. In Germany, the average electricity price for households amounted to approximately €0,29 per kilowatt hours in 2016 (BDEW, 2017). Referring to existing prognosis on behalf of the Federal Ministry for Economic Affairs and Energy (BMWI), the electricity prices in Germany are forecasted to increase for households up to the year 2025 at an annual rate of 1,4% (Schlesinger et al., 2014). Hence, based on the average electricity price in 2016, the average prices regarding the years 2017 to 2020 are estimated in consideration of an annual increase in electricity prices of 1,4%. Due to the high proportion of individual taxi operators in Hannover and the high annual electricity expenditure of at least

[15] Own illustration, data source: Spritmonitor (2017b-g).
[16] Own illustration, data source: SSP Consult (2017).

160 MWh, which is required to obtain industrial electricity tariffs, household electricity prices are used for the TCO calculation (Schaufenster Elektromobilität, 2016). Table 11 summarizes the average electricity prices per kilowatt hour for households in Germany for the years 2016 to 2020, which will be included in the TCO model.

Table 11. Average electricity prices [€/kWh] for households in Germany 2016 to 2020[17]

		Prediction			
Year	2016	2017	2018	2019	2020
Electricity [€/kWh]	0,2900	0,2941	0,2982	0,3024	0,3066

3.5 Maintenance and Repair Costs

Expanses for vehicle repair and maintenance primarily comprise oil changes, car inspections, tire replacement and typical wear-and-tear repairs. Due to the lower share of moving- and wear parts within an electric power train fewer maintenance activities such as filter- and oil changes are needed in comparison with an conventional propelled vehicle (Plötz et al., 2013). Therefore, within this study it is assumed that the maintenance and repair costs for an electric vehicle are reduced by approximately 18%. This value is based on an M&R-cost comparison analysis of electric- and conventional propelled vehicles conducted by the German Aerospace Center in collaboration with the Transportation Technology R&D Center (Propfe et al., 2012). The maintenance and repair costs for conventional driven diesel vehicles are derived from the DAT (2017).

Table 12. Repair and maintenance costs[18]

Vehicle Models	Maintenance and repair costs per month [€]	Total maintenance & repair costs over 4-years (discounted)
MB B 200 d	75 €	3.294 €
MB B 250 e	61,5 €	2.701 €
VW Golf VII 1,6 l TDI	49 €	2.152 €
VW e-Golf	40,18 €	1.765 €
MB E 350 d Sedan	102 €	4.480 €
Tesla Model S 60	83,64 €	3.674 €

[17] Own illustration, data source: BDEW (2017); Schlesinger et al. (2014).
[18] Own illustration and calculation, data source: DAT (2017); Propfe et al. (2012).

Since significant changes of repair and maintenance costs are not expected in the medium term, it is assumed that these values will remain constant during the 4-year vehicle holding period up to 2020. Table 12 illustrates the repair and maintenance costs for diesel vehicles and BEV per month and over the entire vehicle owning period of 4-years. The data includes both, material and labor costs occurring with vehicle maintenance and repair activities.

3.6 Charging Infrastructure Costs

Finally, a well-developed charging infrastructure is required for the operation of BEV. Therefore, charging infrastructure costs can have a significant impact on the profitability of BEV for taxi operators. Consequently, the TCO model is expanded by the costs related to charging infrastructure. It is assumed that with every purchased BEV additional costs arise for the procurement and installation of a battery charging device, e.g., a wallbox. Further, annual maintenance costs are taken into account for each charging device. These battery charging devices could for instance, be implemented either at the company premise of a taxi company, taxi ranks in inner cities or the residence of the electric vehicle purchaser. Due to the high rate of taxi companies with only one driver in Hannover, it is likely that the majority of charging devices will be initially installed at the residence of the taxi operators. Hence, for a BEV purchase in 2017, investment costs of 553€ for a wallbox will be considered in the TCO model (Tesla, 2017b). In addition, charging device maintenance costs of 50€ p.a. will be included (Schaufenster Mobilität, 2016).

3.7 Subsidies

In Germany, companies and private individuals who purchased or ordered a BEV as of 18.06.2016 are entitled to receive a state- and industry funded environmental premium. The condition required for obtaining this premium is that the net list price (price exclusive 19% value-added tax) of the electric vehicle does not exceed 60.000€. All BEV considered in this study are defined as eligible for funding by the German Federal Office for Economic Affairs and Export Control (BAFA). For fully BEV the purchase subsidy amounts to 4.000€ and will be included in the TCO calculation model (BAFA, 2018).

3.8 Insurance Costs

The insurance costs consist of the monetary contributions for compulsory motor vehicle insurance as well as the costs of fully- or partial coverage insurance. However, as the amount of insurance contributions is not based on the type of drive technology but rather on the vehicle model and individual characteristics of the driver (e.g., age and accident frequency), the insurance costs are not included in the TCO model (Plötz et al., 2013).

4 Total Cost of Ownership Analysis

Table 13 presents the calculation results based on the developed TCO-*Excel* model and input variables derived in the previous. All costs are displayed in Euro and the values in brackets indicate the percentage share of the particular cost category in relation to the TCO of each vehicle. The TCO outcomes are calculated for a vehicle purchase time in 2017 and under consideration of a 4-year long vehicle holding period.

Table 13. Total cost of ownership calculation results[19]

TCO model results						
	MB B 200 d	MB B 250 e	VW Golf VII 1,6 l TDI	VW e-Golf	MB E 350 d Sedan	Tesla Model S 60
Depreciation	21.523€ (47%)	29.601€ (61%)	16.440€ (44%)	25.839€ (67%)	38.988€ (56%)	49.492€ (72%)
Interest costs	1.929€ (4%)	2.390€ (5%)	1.355€ (4%)	2.191€ (6%)	3.410€ (5%)	4.335€ (6%)
Tax costs	960€ (2%)	0€ (0%)	660€ (2%)	0€ (0%)	1.453€ (2%)	0€ (0%)
Consumption costs	18.258€ (40%)	16.824€ (35%)	16.400€ (44%)	11.852€ (31%)	20.910€ (30%)	14.085€ (21%)
M&R-costs	3.294€ (7%)	2.701€ (6%)	2.152€ (6%)	1.765€ (5%)	4.480€ (6%)	3.674€ (5%)
Charging infrastructure costs	0€ (0%)	736€ (2%)	0€ (0%)	736€ (2%)	0€ (0%)	736€ (1%)
Subsidies	0€ (0%)	-4000€ (-8%)	0€ (0%)	-4000€ (-10%)	0€ (0%)	-4000€ (-6%)
TCO	**45.964€**	**48.251€**	**37.007€**	**38.383€**	**69.241€**	**68.321€**
TCO / month	958€	1.005€	771€	800€	1.443€	1.423€
TCO / km	0,177€	0,186€	0,143€	0,148€	0,267€	0,264€

The Mercedes Benz E 350 d Sedan has the highest TCO of the sample vehicles, followed by the Tesla Model S 60 and the middle-class taxi vehicles from Mercedes Benz. Both middle-class taxis from Volkswagen have the lowest TCO of the entire investigated vehicles. The computed results show, that the TCO of electric driven middle-class taxis is higher than that of equivalent conventional driven middle-class taxis. The Mercedes Benz B 250 e as well as the Volkswagen e-Golf have a TCO disadvantage over the vehicle holding period compared to the equivalent diesel

[19] Own illustration and calculation.

powered models. The TCO of the Mercedes Benz B 250 e is 2.287€ larger than that of the Mercedes Benz B 200 d and the TCO of the Volkswagen e-Golf exceeds that of the Volkswagen Golf VII 1,6 l TDI by 1.376€. Only among the analyzed premium-class taxi vehicles a TCO advantage of the battery electric model was determined. The TCO advantage of the Tesla Model S 60 in comparison to the Mercedes Benz E 350 d Sedan amounts to 920€ over the 4-year vehicle holding period.

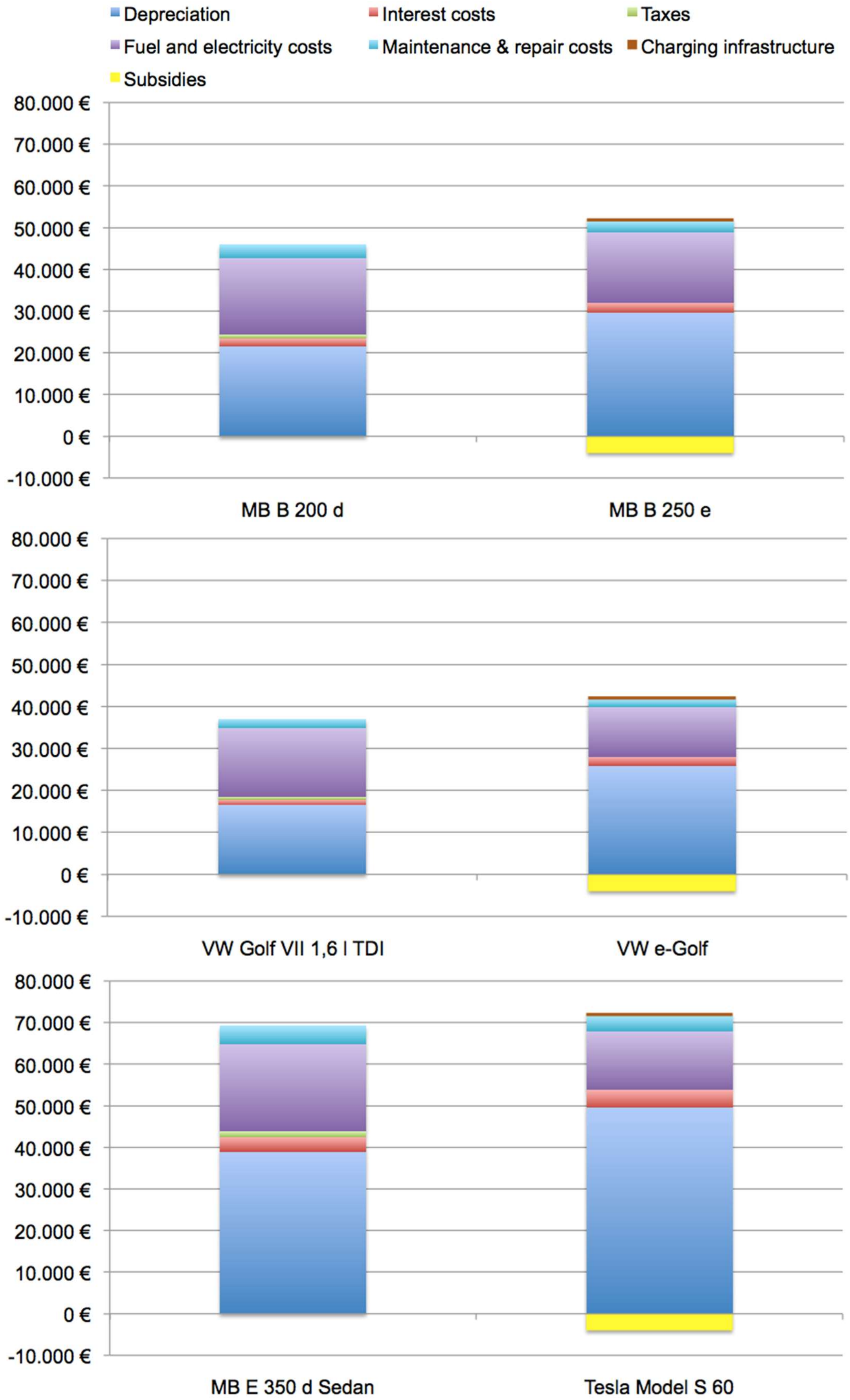
These figures indicate a discrepancy between the purchasing price and the TCO in the area of premium-class taxi vehicles. Although the Tesla Model S 60 has a significantly higher purchasing price than the Mercedes E 350 d Sedan, the TCO of the Tesla is lower in comparison to the Mercedes Benz premium-class taxi. This result demonstrates the importance of a holistic TCO comparison for taxi companies to make cost-efficient purchasing decisions. Despite the considerably higher purchasing price of the analyzed model from Tesla, the analysis results show that the overall costs over the 4-year owning period for this vehicle are lower than that for a Mercedes Benz E 350 d Sedan. Hence, taxi companies in Hannover can benefit from using a Tesla Model S 60 instead of conventional driven premium-class taxis.

The TCO values of each vehicle comprise seven main cost categories and were visualized in the following Figure 6. The diagrams show the proportion of the different cost categories that make up the TCO for every investigated vehicle. The bar graphs clearly point out the diversity of the cost structures of BEV and diesel driven vehicles. As can be seen in Figure 6, the TCO advantage of the Tesla Model S 60 is mainly based on the lower electricity consumption costs compared to the fuel costs of the Mercedes Benz E 350 d Sedan. The bar graphs in Figure 6 show that the depreciation represents the largest cost factor for both drive technologies. It can be concluded that vehicles with high purchasing prices are affected by high absolute depreciation costs. Therefore, for BEV, the absolute depreciation is significantly larger than for conventionally driven vehicles due to their higher purchasing prices. On average, the depreciation is responsible for 67% of the TCO of BEV, while for conventional diesel vehicles it is responsible for only 49% of the TCO.

Table 13 further depicts that BEV are subject to higher interest payments. Due to the higher purchasing prices of BEV the loan amount borrowed for buying a BEV is larger, resulting in higher total interest payments over the vehicle holding period. However, interest payments constitute a relatively small part of the TCO for vehicles of both drive technologies because of the current low-interest phase in Germany and other developed countries.

With regard to the costs associated with vehicle taxes, the results indicate that taxes have a small impact on the TCO of diesel vehicles. As shown in Table 13, vehicle taxes account for only 2% of the TCO of diesel vehicles. Hence, the tax exemption for BEV granted by the German government does not support the TCO performance and competitiveness of new drive technologies sufficiently.

Figure 6. TCO structure of the analyzed sample vehicles



The computed values indicate that fuel and electricity consumption costs represent the second-largest cost position of the TCO for both drive technologies. However, as can be seen in Figure 6 the fuel consumption costs are significantly higher for all analyzed diesel vehicles than for the equivalent BEV. The greatest difference in consumption expenditures over the vehicle owning period can be observed between the investigated premium-class taxi vehicles. The fuel consumption costs over the 4-year holding period for the Tesla Model S 60 are more than 6.800€ below those of the Mercedes Benz E 350 d Sedan. On average, the fuel consumption costs are responsible for 38% of the TCO of considered diesel vehicles, whereas for the analyzed BEV the electricity consumption costs account for only 29% of the TCO. Therefore, it can be concluded that fuel and electricity consumptions costs contribute most to the TCO competitiveness of BEV.

Maintenance and repair costs constitute another relevant cost category and make up 5 to 7% of the TCO of the analyzed vehicles. Further, the calculated values in Table 6 show that the maintenance and repair costs of diesel vehicles exceed those of BEV by approximately 18%. The largest absolute difference regarding the maintenance and repair costs exists between the Tesla Model S 60 and the Mercedes Benz 350 d Sedan and amounts to 806€ over the entire vehicle holding period.

As visible in Figure 6, costs related to the charging infrastructure do not have a major impact on the TCO of the examined BEV. Overall, the infrastructure costs are responsible for only 1 to 2% of their TCO and amount to 736€ per vehicle. Due to advances in the field of charging technology it can be assumed that the importance of this cost position will be further reduced in the near future.

Finally, the results illustrate the importance of the environmental subsidy for the TCO of BEV. As shown in Table 13 and Figure 6, the subsidy reduces the TCO of BEV by 6 to 10%. Since the environmental subsidy for each eligible electric vehicle amounts to 4.000€, independent of the purchase price, it has the greatest relative influence on the TCO of BEV with low purchase prices. In this study, the Volkswagen e-Golf has the lowest purchase price among the analyzed BEV. Consequently, the environmental subsidy has the greatest relative influence of -10% on the TCO of the Volkswagen e-Golf.

5 Discussion, Implications and Recommendations

From the TCO differences between the analyzed BEV and equivalent diesel driven ones, several recommendations for the taxi industry, especially the companies in Hannover, can be derived. Further, policy recommendations can be extrapolated based on the analysis results.

The aim of this research was to investigate the economic feasibility of electric taxi vehicles in Hannover. For this purpose, an *Excel*-based TCO model was developed and used to calculate the TCO of three conventional driven taxi vehicles and three equivalent BEV taxis. The results enhance the understanding regarding the cost structure of conventional and BEV for taxi companies and indicate, which electric driven taxi model is more cost efficient than an equivalent conventional taxi vehicle. The calculation results of the developed TCO model reveal, that the TCO of electric and conventional driven taxi vehicles are strongly dependent on the vehicle class. Only among the analyzed premium-class taxi vehicles a TCO advantage of the BEV was determined. The TCO of the investigated electric middle-class taxis is still above that of conventionally driven ones. The computed values show that the TCO advantage of the electric driven Tesla Model S 60 in comparison to the diesel driven Mercedes Benz E 350 d Sedan amounts to 920€ over the 4-year vehicle holding period. In summary, it can be stated that BEV have advantages in terms of operating costs compared to diesel vehicles, especially in the field of fuel consumption expanses.

According to the results, taxi operators in Hannover should first switch from conventional driven vehicles to BEV in the area of premium-class taxis in order to save costs. An expansion of the taxi fleet with the analyzed electric driven Tesla Model S 60 can improve the economic situation of taxi companies in Hannover. The Tesla Model S 60 has a range of approximately 400 kilometers and hence, is suitable for driving the average daily mileage of a conventional taxi in Hannover without recharging.

In addition to the economic advantages of using an electric driven premium-class taxi, further advantages arise. Due to the high annual mileage, the carbon dioxide emissions of taxis are comparatively large. For example, in Tokio, taxi vehicles are responsible for 20% of the total quantity of carbon dioxide emissions, although they contribute for only 2% of the overall vehicles in Tokio city (NBC, 2010). Thus, the increased use of BEV taxis can be crucial for the improvement of the overall air quality. Moreover, BEV enable a more pleasant and comfortable taxi ride for customers, as they are characterized by less vibrating and quieter engines (Wang & Cheu, 2012). The use of electric taxis can also improve the image of a taxi company and hence, offers additional potential to increase the number of customers.

Although the Volkswagen e-Golf has a TCO disadvantage over the vehicle holding period compared to the equivalent diesel powered Golf VII, the TCO gap is not that high and hence, offers potential for the use of middle-class BEV in the taxi industry. Therefore, an economic efficient use of electric middle-class taxi vehicles in the near future can occur, e.g., by a further drop in battery production costs. However, in order to enable the use of electric driven middle-class taxis in the near future, which do not have such large battery capacities, sufficient battery charging time windows during a taxi shift and charging possibilities for electric taxis in Hannover constitute an important prerequisite. It is often stated that the time needed for battery charging reduces the operating time of taxi vehicles and hence, diminishes the potential revenues (Dutta, 2014). The following Table 14 displays the average daily standby and waiting time of taxi vehicles in Hannover.

Table 14. Share of unproductive standby and waiting time within an 8-hour taxi shift[20]

Weekdays	Mon-Thu		Friday		Saturday		Sunday		Average over all weekdays	
Day-/night shift	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Standby and waiting time [%])	59%	68%	57%	51%	65%	44%	70%	74%	63%	59%
									61%	

The share of unproductive standby and waiting time without a driving order within an 8-hour taxi shift amounts to an average of 61%. The illustrated figures clarify that an significant part of the daily operating time is not fully utilized and consists of long waiting periods due to the existing lack of sufficient demand for taxi services in Hannover. Thus, within an 8-hour shift in Hannover a taxi spends around 4,9 hours waiting without a driving order. During night hours from Monday to Thursday the unproductive standby and waiting time without driving orders is even higher. From this figures it can be deduced, that sufficient time windows for battery charging processes is available within one working shift of a taxi driver in Hannover.

To ensure a sufficient range of electric middle-class taxis with small battery capacities for customer requests, an appropriate taxi specific charging infrastructure must be installed. Due to the long waiting times of taxis at taxi ranks (see Table 14), it would be a worthwhile option to install a battery charging infrastructure in this areas. As of September 2014, there exist 131 taxi ranks in Hannover with approximately 540 parking spaces. The taxi ranks are spread over the entire city area, in consideration of the demand structure. Hence, the taxi ranks are placed primarily near the railway station, hospitals and shopping centers (ISUP, 2015). After a customer transport, taxi drivers in Hannover almost always return to central taxi ranks in order to increase the chance of a new driving job. Consequently, central taxi ranks, e.g., near the central station of Hannover, would be particular suitable for the expansion of a battery charging infrastructure, which would be well utilized by various taxi vehicles. Recharging during waiting times at taxi stands can be one of the main possibilities to overcome the current range deficits of electric driven middle-class taxi vehicles. As a result, even the analyzed middle-class BEV with smaller battery capacities than the Tesla Model S 60 would be feasible for the taxi operation in Hannover. Nevertheless, the determined current TCO disadvantage of electric middle-class taxi vehicles in comparison to equivalent diesel taxi vehicles must be considered. In order to improve the operating cost efficiency of electric middle-class taxis and hence, increase their TCO performance, tax reductions induced by politics could represent a suitable way (Wu et

[20] Own illustration based on conversations with *Hallo Taxi 3811 GmbH* (2017); ISUP (2015).

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.

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