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Market potential for electric vehicles in the German commercial passenger transport sector

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Abstract

Commercial transport is often referred to as an early market for plug-in electric vehicles (PEVs). In comparison to private transport, commercial transport with passenger cars is characterized by higher vehicle kilometers traveled (VKT) forming an important factor for a quick pay-off of PEVs. In this paper, we analyze multi-day driving profiles of German passenger cars and light-duty commercial vehicles from the commercial transport sector. These commercial vehicles amount to almost two thirds of the annual vehicle registrations in Germany and thus form an important market segment. Our analysis shows that about 30 % of German commercial vehicles could be economically operated as PEVs in 2020. However, it becomes apparent that energy and battery prices have a high impact on the future market share of plug-in electric vehicles in this segment.

Keywords: market, commercial, transport, PHEV (plug in hybrid electric vehicle), BEV (battery electric vehicle)

1 Introduction

Motorized transport is responsible for large shares in greenhouse gas (GHG) emissions in Germany and worldwide. Using renewable energy sources, plug-in electric vehicles could induce a significant decrease in local and global emissions from the transport sector without losing the advantages of motorized individual traffic [1].
The transport sector can be divided into private and commercial traffic, although there is no common definition for commercial traffic at the moment [2]. We identify three main definitions in the literature:

1. according to the purpose of the trip, i. e. a trip to work or a leisure trip [3],
2. according to the means of transport, i. e. goods or people [3]
3. according to the vehicles weight, when vehicles above 3.5 tons are commercial vehicles [4] or
4. according to their car holder (person or company) [5].

In this paper, we stick to the last definition as this is the statistically most resilient, e. g. for vehicle registrations.[1] Thus in this work a vehicle is considered to be a part of the commercial transport sector if it is registered to a commercial vehicle owner.
Using this definition the private sector embraces 90 % of the overall German vehicle fleet in stock,

[1] We may subdivide the group of commercially licensed vehicles into vehicles only used for commercial purposes (fleet vehicles) or vehicles that may also be used privately (office vehicles). Since there is no statistics publicly available for Germany up to now, we do not go into further detail here.

while the largest part of registration of new vehicles can be ascribed to the commercial sector, which accounts for 60 % of all annual registrations [5, 6]. In table 1 we give more examples about the different characteristics, such as the shorter holding time, the larger motor sizes and the higher amount of vehicle kilometers driven (VKT) during the week and on weekends of commercially licensed vehicles.

Table 1: Privately and commercially licensed vehicles in Germany. Data from [3, 5–8]

criteria	private	commercial
Stock (2010-01-01)	37,645,234	4,242,031
	89.9 %	10.1 %
Registrations (2011)	1,243,759	1,963,684
	38.8 %	61.2 %
Avg. veh. holding time [a]	6.2	3–4
Avg. motor size [ccm]	1,638	1,994
Avg. VKT on weekday [km]	40.1	76.8
Avg. VKT on Sat./Sun. [km]	28.8	29.3

Targeting on a mass market introduction for PEVs in this decade, the commercial sector is particularly important due to the high car registration numbers and the higher amount of driving, as this determines the pay-back-time of an plug-in electric vehicle compared to a conventional one. But the economical advantage of high VKT is also responsible for the high final energy consumption of the transport (of goods) sector which is still rising (24 % in 1990 to 37 % in 2008) and goes in hand with CO_2-emissions [9]. Because of this the commercial transport sector could not only be an early market for plug-in electric vehicles, but also offers large energy- and $mathrmCO_2$-savings potentials.

Many research projects focus on specific examples of commercial transport such as parcel service providers, nursing services or taxis, while this paper aims to determine the potential for plug-in electric vehicles within German commercial traffic sector as a whole. Precedent steps will be to analyze the PEV-potentials of different vehicle size classes and to determine the influence of different factors on the market diffusion of plug-in electric vehicles.

As in earlier works (e. g. [10–14]) we use driving profiles of vehicles for the analysis which are described in section 2. With this data we determine what share of a driving profile of a conventional car can be done by a plug-in electric vehicle (technical analysis) and if this is economically reasonable (economic analysis). The methodology is described in section 2 as well. Section 3 contains the results which will be discussed in section 4.

2 Data and Methodology

2.1 Driving profiles

To analyze the potential PEV market shares in commercial traffic, a relevant number of driving profiles is required. For a large collection of driving profiles in commercial traffic, Motor Traffic in Germany (KiD) is one major German data source collected in 2002 and 2010 [15, 16]. However, the observation period in KiD is only a single day for every vehicle. Since the time horizon of the used data collection has a significant influence on the upscale to VKT as well as on the technical feasibility and potential electric driving share, a single day data base might result in a strong bias (see e.g. [12]). Thus we collected data of conventional vehicles with a time horizon of 21 days in the on-going project "REM2030" [17]. Table 2 shows the main differences of the 2002 data collection of KiD and the REM2030-profiles.

Table 2: KiD2002 vs. REM2030

Criteria	KiD2002	REM2030
Data collection design	Questionnaire	GPS-tracking
Observation period	1 day	18.7 days
Total number of profiles	29,079	348
Avg. VKT per day	49.8 km	69.9 km
Profiles w/ movement	14,545	348
Avg. VKT per day	99.5 km	69.9 km
Total number of trips	56,927	49,331

While the KiD2002 was collected in a questionnaire and people reported all their movements over one day, the REM2030 data is collected with GPS-tracking over 18.7 days on average to not overestimate the PEV-potential (see e. g. [12, 13]). As KiD2002 also contains vehicles without any movements on the day of observation there is only 14,545 of 29,079 vehicles which are weighing less than 3.5 tons that are moved during the day. The average vehicle kilometers traveled per day is 49.8 km if all profiles are considered and 99.5 km for all vehicles with motion. The REM2030-data instead currently contains 348 vehicles with 49,331 trips in total. Here the average VKT per day is 69.9 km. The total number of trips in KiD2002 is about the double of REM2030-trips.[2]

Thus by using the data of REM2030, we may not be representative for all branches in commercial

[2] Regarding the distinction of solely commercially used and partly privately used commercial vehicles, the REM2030 data mainly contains vehicles of company's fleets which are only used for commercial purposes.

transport, but get a better idea of the potential for PEVs with the longer observation period. This will also decrease the error in the technical analysis (see [12]).

2.2 Methodology

With the above mentioned data, we may analyze each driving profile by simulating a battery profile to estimate the technical PEV-potential. This technical PEV-potential delineates whether a battery electric vehicle (BEV) would be able to do the whole driving profile with a fixed battery size or, in the case of a plug-in hybrid vehicle (PHEV), what electric driving share could be achieved. We explained this method in [12] and refer to it for more detail. For this analysis, we assume that:

- Plug-in electric vehicles are only charged overnight with 3.7 kW no matter where they are parked.
- PEVs are only considered for the same vehicle size as the conventional ones in the profiles (no downsizing).
- PHEVs always run in Range-Extender-Mode, i. e. the energy in the battery is used up completely before the conventional propulsion is used.

All parameters for the technical analysis can be found in tables 3 and 4.

In a second step, considering the technical PEV-potential, the economic potential is determined for each driving profile. We do this by calculating each user's total cost of ownership (TCO) for different propulsion systems and assigning the one with the lowest (annual) TCO to the driving profile. The annual total cost of ownership TCO_a consists of capital expenditure a_{capex} and operating expenditure a_{opex}:

$$TCO_a = a_{capex} + a_{opex}$$

We use the discounted cash-flow method without residual values and calculate the investment annuity:

$$a_{capex} = I \cdot \frac{(1+i)^T \cdot i}{(1+i)^T - 1}$$

Here the investment I (here for vehicle and battery) is multiplied by the annuity factor consisting of the interest rate i and the investment horizon T.[3]

[3] Values for these factors are given in tables 3 and 4.

The operating expenditure is calculated as follows:

$$a_{opex} = VKT_a \cdot (s_e \cdot c_{el} \cdot k_{el} + (1 - s_e) \cdot c_{conv} \cdot k_{conv} + k_{O\&M}) + k_{tax}$$

We multiply the vehicle kilometers traveled per year (VKT_a) with the cost for driving in electric mode plus the cost for driving in conventional mode and the cost for operations and maintenance ($k_{O\&M}$). The cost for electric driving consists of the electric driving share s_e, the electric consumption c_{el} in kWh/km and the cost for electricity k_{el} in EUR/kWh. The same holds for the conventional driving where the share of conventional driving, i. e. $(1 - s_e)$, is multiplied with the conventional consumption c_{conv} in l/km and the cost for conventional driving k_{conv} in EUR/l. Finally the annual cost for vehicle taxes k_{tax} in EUR/yr is added. All values for this calculation are given in tables 3 and 4 and all calculations are made for 2020. As investment horizon T we use four years as the average holding time in the commercial transport sector and twelve years as average total car holding time.[4]

Calculating the TCO-minimal propulsion system, summing up all drivers for whom this would be a plug-in electric vehicle and dividing it by the total number of driving profiles, we obtain the share of potential PEV-users in the sample.

3 Results

Using the approach mentioned before, we can determine the technical and economical potential of plug-in electric vehicles in the commercial transport sector.

3.1 Technical potential

Figure 1 shows the results of the technical analysis. In the left panel of the figure, we can see what share of vehicles in the driving profiles may technically be replaced by battery electric vehicles in 2020. The technical feasibility of BEVs is

[4] As we do not regard residual values, the second investment horizon can be considered as a situation with two consecutive car holders where the first one holds the car for four years, sells it with his residual value to the second one who holds it for another eight years until the residual value is zero. The case where T=4 years is more conservative as companies have to pay of there vehicle completely in this time frame. We may regard these two values as upper and lower boundaries of the result.

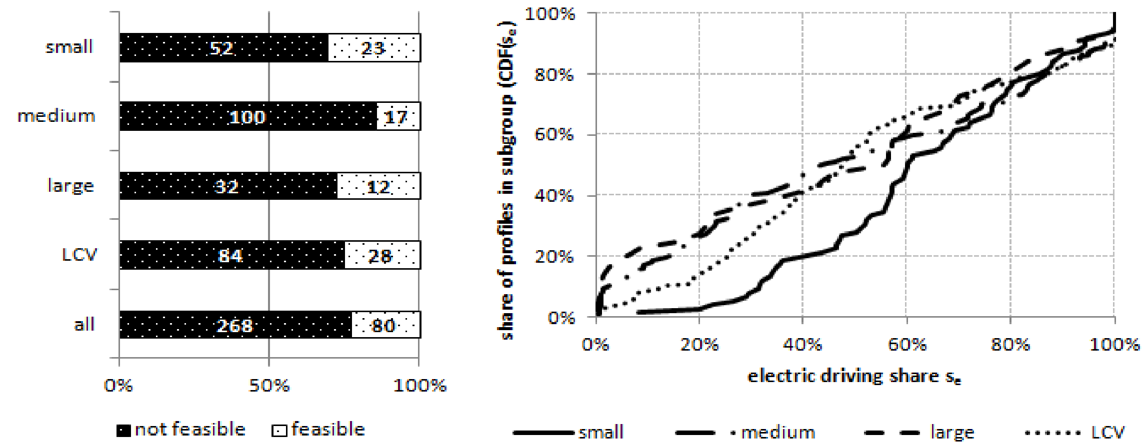

Figure 1: Technical potential of PEVs of driving profiles in 2020. *Left panel:* Technical replaceability through BEVs distinct by vehicle sizes. Non feasible profiles in black with white dots, feasible profiles in white with black dots. Small numbers inside the bars indicate the number of driving profiles in the subsample. *Right panel:* Cumulative distribution $CDF(s_e)$(ordinate) of electric driving shares s_e(abscissa) for different vehicle sizes. Small vehicles in solid black line, medium-sized vehicles in dashes and dots, large vehicles in dashed and light-duty commercial vehicles in black dots. Both axes in %.

almost the same over all vehicle size classes and lies around 20–25 %.

In the right panel of the figure we see the electric driving shares s_e (abscissa) and the share of users that have the same electric driving share in the simulation as cumulative distribution function CDF(s_e). Here vehicle sizes are distinct as well: small vehicles are displayed as black solid lines, medium-sized vehicles as dash-dotted lines, large vehicles as dashed lines and light-duty commercial vehicles as dotted lines. We can see that for small vehicles the curve is further on the right, i. e. there are more users with high electric driving shares. However the vehicle size does not seem to have a significant impact on electric shares of PHEVs, as all other curves have an almost similar shape.

3.2 Economic potential

In Figure 2 we show the economic potential of the four propulsion technologies BEV, PHEV, Gasoline and Diesel for different vehicle size classes in 2020. We use an investment horizon of four years in the left panel and twelve years in the right panel of the figure.

In the left panel where we use the four year horizon, we find hardly any plug-in electric vehicles, about 35 % are gasoline vehicles and more than 60 % diesel vehicles. We can also observe that there is more gasoline engines within smaller car sizes (∼75 % in small vehicles, ∼50 % in medium-sized ones) whereas diesel engines dominate especially the larger vehicle sizes. The ratios of gasoline and diesel engines are a consequence of lower relative difference in investments of diesel and gasoline engines and the higher impact of favorable running costs. The investments for plug-in electric vehicles cannot be paid off in four years.

In the right panel where twelve years of investment horizon are considered, we observe that propulsion technologies for different vehicle size classes in this analysis are still dominated by diesel engines for all car sizes in the year 2020. We find 20 % of vehicles having economic potential to be replaced by BEVs and another 10 % through PHEVs. Except from LCVs where there were no gasoline vehicles in the four-year-analysis, in all vehicle size classes PEVs do mainly reduce the share of gasoline vehicles. This results from the high amounts of annual driving for which diesel vehicles have the lowest TCO. The highest share in plug-in electric vehicles can be found in small-sized vehicles. About 25 % of this vehicle size class in the REM2030 data could be operated as BEVs or PHEVs, followed by medium-sized cars with about 20 %. Only one-fourth of the large-sized vehicles could be operated as plug-in electric vehicles. The segment of light-duty commercial vehicles (LCV) has the lowest share of potential PEVs with about 15 % of the observed driving profiles. The results in Figure 1 show that small vehicles with short trip lengths have the highest PEV-potential in commercial traffic. With an increase in vehicle size class, an increase in vehicle kilometers trav-

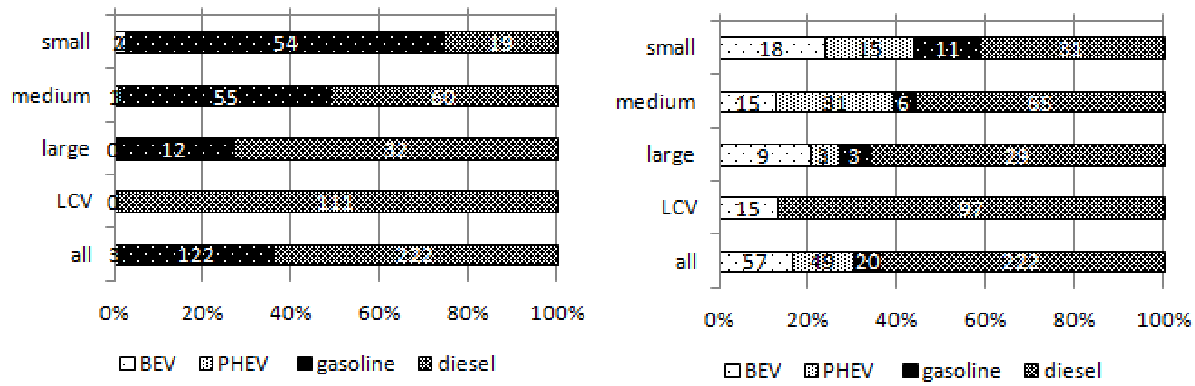

Figure 2: Calculated vehicle market shares for different car-sizes in 2020. Shares for investment horizons of four years *(left panel)* and twelve years *(right panel)*. BEVs in white with few black dots, PHEVs dotted, gasoline in black with white dots and diesel in grey crosses. Small numbers in the bars indicate the number of driving profiles in this subsample.

eled takes place, leading to a decrease in PEV-potential due to inadequate battery capacity and higher battery costs. Furthermore, it becomes apparent that BEVs compete with gasoline vehicles for short-distance trips, while PHEVs rival diesel vehicles for long-distance trips, if they are not too long.

As we analyze four and twelve years, we conduct a lower and an upper boundary for PEV market potentials. We do this because there is yet no knowledge about residual values for electric vehicles. We may also regard the analysis with twelve years as a case with high and the analysis with four years as a case with low residual values. We also have to state that results might differ, if we weigh market shares inside commercial branches with their share of vehicles in commercial transport.

3.3 Sensitivity analysis

Since this analysis is based on several assumptions, changing values for used parameters could lead to different shares of propulsion technologies in the market. Thus, we conducted a sensitivity analysis for gasoline and diesel price as both are dependent on the oil price. The results are shown in Figure 3. We display the market shares of BEVs, PHEVs, gasoline and diesel engines that result from the economical analysis on the abscissa while changing fuel prices can be found on the ordinate. This analysis is done for an investment horizon of twelve years with the values mentioned before, while we used 1.60 EUR/l as diesel price (excluding VAT) and 1.71 EUR/l as gasoline price (w/o VAT) in 2020 in the analyses before.

We observe that the market share of PEVs is highly sensitive to changes in fuel prices. Given a gasoline price of 0.86 EUR/l and a diesel price of 0.8 EUR/l (both excluding VAT of 19 %) the economic PEV-potential is very small and leads to a market share of merely 1.5 %. On the contrary, rising fuel prices to 2.62 EUR/l (gasoline) and 2.48 EUR/l (diesel), could lead to the fact, that almost every second vehicle in commercial traffic could be operated as a PEV in 2020. We can see that even with high fuel prices, there is still a large portion of diesel engines, while gasoline engines seem to phase out with fuel prices over 1.80 EUR/l (1.70 EUR/l) as net gasoline (diesel) price in 2020. While BEVs receive their market shares mainly from gasoline vehicles, their shares are limited due to their technically restricted range. Within favorable market conditions for PHEVs (rising fuel prices), they can take over significant market shares from diesel cars.

3.4 Brief analysis of uncertainty

This calculation is based on several assumptions and uncertainties. While in section 3.2 we discussed the role and uncertainty of holding times and residual values, in section 3.3 we showed the influence of fuel prices. Apart from these two there are several others, such as the influence of the observation period (as mentioned before and discussed in previous works [12]) or the representativeness of the data. Here we want to discuss the uncertainty in the analysis based on a limited sample size. We do this by looking at the economic results for 12 years and define the market shares as the relative frequency inside one

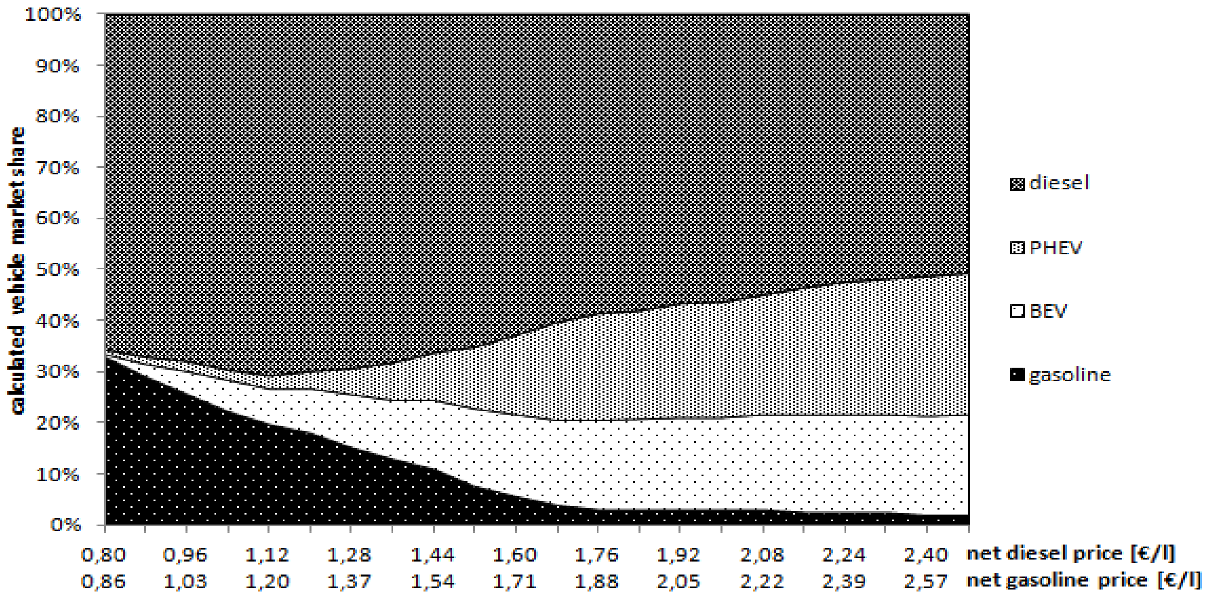

Figure 3: Variation of market share (ordinate) with changing net fuel prices in EUR/l (abscissa). BEVs in white with few black dots, PHEVs dotted, gasoline in black with white dots and diesel in grey crosses. Base prices for 2020: 1.60 EUR/l (Diesel) and 1.71 EUR/l (Gasoline).

vehicle size.[5] We use the following approximation for a binomial distribution to determine the 95-%-confidence intervals (see e. g. [21])[6]:

$$\Delta p \approx 1.96 \cdot \sqrt{\frac{p \cdot (1-p)}{n}}$$

The results for this analysis are given in table 5.

Table 5: Market shares (p) of PEVs with confidence intervals (Δp)

Veh. size	market share
small	44.0 % ± 11.2 %
medium	39.3 % ± 8.9 %
large	27.3 % ± 13.2 %
LCV	13.4 % ± 6.3 %
all	30.5 % ± 4.6 %

We find that the market shares resulting from the economic analysis do have a statistical uncertainty because of the sample size. While for small and medium vehicles the 95 %-confidence interval is about a quarter of the market share, it is about half for large vehicles and LCVs. In general the error of about 10 % in all results is fairly good for the small sample. The total market share over all vehicle sizes of 30.5 % has a 95 %-confidence interval of 4.6 %.[7]

To sum up, we firstly analyzed the technical potential of electric vehicles in section 3.1, finding that about 25 % of all profiles would be feasible as BEVs and a large portion would have high electric driving shares as PHEVs (40 % of all users would have electric driving shares of more than 60 % depending on vehicle size). Secondly we found that about 30 % of all driving profiles could driven with PEVs more economically than with conventional ones in 2020 (using 12 years as investment horizon). Thirdly we analyzed several factors of uncertainty in more detail, i. e.:

- The uncertainty through unknown holding times and residual values (fig. 2) in section 2.2,
- the uncertainty of energy prices in section 2.3 (figure 3) and
- the uncertainty of the limited sample size in section 2.4 (table 5).

We conclude our analysis in the following section.

[5]With s being the size of the vehicle and v_s the vehicles type of size s (e. g. a BEV) the the relative frequency would be the number of vehicle of type v_s divided by the total number of vehicles (of size s): $p_s(v_s) = \frac{n(v_s)}{n(s)}$.

[6]This approximation might be questionable here [22], but is helpful to give a rough idea about the degree of uncertainty.

[7]This error is calculated with a square error propagation, according to: $\Delta f = \sqrt{\sum_i^n (\frac{\partial f}{\partial x_i})^2 \cdot (\Delta x_i)^2}$.

4 Conclusions and Discussion

The aim of this paper is to provide an analysis for the future market potential of plug-in electric vehicles in German commercial passenger transport sector. We use driving profiles for our analysis and find the following:

- About 25 % of all vehicles could be operated as BEVs given the assumptions for 2020, while more than 40 % of all users would have electric driving share of more than 60 % as PHEVs.
- PEVs may reach significant market shares in commercial traffic in 2020, adding up to 30 % in total or 20–40 % depending on the vehicle size class. Furthermore, a tendency of PHEV to compete with diesel vehicles for long-distance trips and BEVs with gasoline vehicles for short-distance trips is observed.
- This potential can be realized if long investment horizons are considered and plug-in electric vehicles can be sold with high residual values about which there is not much knowledge at the moment.
- However, the market share of PEVs strongly depends on future energy prices, which have to rise for a PEV-breakthrough ($>$ 1.28 EUR/l for diesel and $>$ 1.37 EUR/l for gasoline).
- The limited sample size is a factor of uncertainty that has to be taken into consideration ($\pm$5 %).

This analysis depends on several assumptions as explained and stated in section 2. Besides that the economic analysis is based on the assumption that (commercial) users do make their decisions only based on cost. Although there is other factors that influence the buying decision, cost is one of the main factors in companies decision making processes (see e. g. [23]). Besides that, we do remind, that we only describe the market potential, which is not a prognosis for the future. Future analysis could regard if the PEV-potential of commercial traffic is also affected by company- and city sizes besides the vehicle size class. Moreover, a comparison with the PEV-potential of private registered cars and the influence of different industry sectors should be part of further research.

Within the project "REM2030" we will keep on collecting driving profiles to increase the database and get a better understanding for commercial traffic.[8]

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Table 3: Vehicle dependent input parameters 2020 (All prices w/o VAT). Data from [18–20].

Parameter	Veh. size	Gasoline	Diesel	PHEV	BEV
Conv. energy consumption [l/100 km]	small	5.4	4.3	5.8	./.
	medium	6.5	5.3	7.0	./.
	large	8.5	6.6	9.3	./.
	LCV	12.6	9.6	13.8	./.
El. energy consumption [kWh/100 km]	small	./.	./.	18.8	17.2
	medium	./.	./.	20.2	21.1
	large	./.	./.	24.7	24.2
	LCV	./.	./.	37.0	34.3
Battery capacity [kWh]	small	./.	./.	6	15
	medium	./.	./.	10	20
	large	./.	./.	14	40
	LCV	./.	./.	14	40
Net investment w/o battery [EUR]	small	8,563	10,092	9,575	7,955
	medium	19,560	21,560	21,529	18,391
	large	27,475	29,060	30,877	28,362
	LCV	28,640	29,500	32,842	28,467
Operations & maintenance [EUR/km]	small	0.025	0.022	0.025	0.013
	medium	0.025	0.022	0.025	0.014
	large	0.025	0.022	0.025	0.015
	LCV	0.122	0.120	0.122	0.103
Vehicle tax [EUR/yr]	small	24	114	24	7
	medium	114	242	114	8
	large	248	428	248	10
	LCV	132	132	132	10

Table 4: Vehicle independent input parameters 2020 (All prices w/o VAT). Data from [18–20].

Parameter	Unit	Value
Depth of discharge	./.	75 %
Battery price BEV	EUR/kWh	250
Battery price PHEV	EUR/kWh	290
Electricity price	EUR/kWh	0.20
Gasoline price	EUR/l	1.71
Diesel price	EUR/l	1.60
Interest rate for vehicle	./.	3 %
Interest rate for battery	./.	3 %