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Article

Driving Profiles of Light Commercial Vehicles of Craftsmen and the Potential of Battery Electric Vehicles When Charging on Company Premises

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Abstract: This paper examines the extent to which it is possible to replace conventional light commercial vehicles in the heating, ventilation and air conditioning and plumbing trade with battery electric vehicles with an unchanged usage profile. GPS trackers are used to record the position data of 22 craft vehicles with combustion engines from eleven companies over the duration of one working week. Within this paper, various assumptions (battery capacity and average consumption) are made for battery electric vehicles and the charging power on the company premises. The potential of battery electric vehicles is evaluated based on the assumption that they are charged only on company premises. Using the collected data and the assumptions made, theoretical state of charge curves are calculated for the vehicles. The driving profiles of the individual vehicles differ greatly, and the suitability of battery electric vehicles should be considered individually. Battery capacity, vehicle energy consumption and charging power at the company have a substantial influence on the suitability of battery electric vehicles. Furthermore, there are differences between vehicles that can charge on the company premises at night and those that cannot or can only do so on some days.

Keywords: battery electric light commercial vehicles; charging strategy; charging on the company premises; potential of battery electric vehicles

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1. Introduction

In order to achieve the environmental policy targets, all newly registered passenger cars and light commercial vehicles (LCVs) in the EU must significantly reduce their CO_2 emissions in the medium term. Local emissions from newly registered passenger cars and light commercial vehicles are to be reduced by 100% by 2035 [1].

Many of today's craft vehicles belong to the LCV class. These vehicles should therefore also achieve the aforementioned targets when they are newly registered from 2035. Electrified drives, such as battery-powered electric vehicles (BEVs), are a potential solution for achieving this objective.

The suitability of vehicles with electric drivetrains in relation to the charging infrastructure has been and continues to be a research topic with numerous published studies. Some examples of studies are listed below to provide an overview.

Zhang et al. looked at various charging scenarios for plug-in hybrid vehicles [2]. They also analyzed charging infrastructure requirements and operating costs for plug-in hybrid electric vehicles and battery electric vehicles [3].

Furthermore, Dong and Lin [4] and Zhang et al. [5,6] investigated the feasibility of BEVs based on different charging scenarios.

Past research has also focused on medium and heavy-duty vehicles.

Forrest et al. investigated the technical feasibility of electric vehicles (EV) for the medium and heavy-duty sectors (class 2b-8) in California [7]. The feasibility of BEVs and fuel cell electric vehicles (FCEVs) was assessed. The study also examined the influence of the infrastructure. For BEVs, a distinction was also made as to whether charging only takes place at the home base or at all stops.

Link and Plötz investigated the technical feasibility of heavy-duty battery electric trucks for urban and regional delivery in Germany [8]. They have identified a particularly high potential for the electrification of 18-ton and 26-ton rigid solo trucks and tractor-trailers.

Research has already been conducted in the field of battery electric light-duty vehicles/light commercial vehicles.

Smith et al. have already investigated the driving profiles of light-duty vehicles of commuters in Winnipeg, Canada [9]. The study examined battery sizes as they relate to different charging scenarios.

Klauenberg et al. looked at the potential of commercial vehicles in Germany and Austria [10]. The study included the analysis of available data, an online survey and data collected using GPS. Within the study, the potential was determined on the basis of daily mileage of the vehicles in different sectors.

Christensen et al. conducted a study for Germany and Denmark in which the potential of BEVs also was assessed on the basis of daily distances driven [11]. Different commercial sectors were also evaluated.

Furthermore, Figenbaum used GPS data from 115 vehicles from 7 different craftsmen and service companies over a period of 2 weeks to investigate the extent to which battery electric light commercial vehicles would be suitable [12]. The basis for this was the range of available BEVs in Norway and the recorded data.

In addition, Tsakalidis et al. carried out a holistic analysis of electric LCVs, looking at economic and environmental aspects [13].

The studies of Klauenberg et al. [10], Christensen et al. [11] and Figenbaum [12] looked at the potential of battery electric LCVs based on the daily distances of the vehicles and the range of BEVs. Technological progress has since led to the availability of new vehicles with longer ranges. This study is therefore intended to supplement the existing literature by evaluating the potential of battery electric light LCVs with a view to the actual standing and charging times on company premises with different vehicle assumptions for BEVs. Within the scope of this study, the focus is on the potential for a specific user group of LCVs. Vehicles from the heating, ventilation & air conditioning (HVAC) and plumbing trade are analyzed.

The potential of battery electric vehicles for this user group is interesting and non-trivial, as the usage profiles differ within the user group. There are vehicles that are mainly used for installation activities, resulting typically in longer standing times at customer sites, vehicles that tend to be used for shorter service activities and vehicles that are used in a mixed manner. In addition, the craft vehicles differ in that some of the vehicles are parked on the company premises at night and some of the vehicles may continue to be used by employees after work, for example, for the journey home. The intention is to investigate the extent to which BEVs are suitable when real usage profiles are considered. Therefore, this study does not compare the kilometers driven daily with the range of available BEVs. Instead, this study considers the actual standing times on the company premises with an assumed charging power there and various assumptions for the battery capacity and consumption of BEVs.

In order to evaluate this potential of BEVs, the following research questions are considered within the paper:

1. How much do the driving profiles of craft vehicles differ within a defined user group?

2. Is there a correlation between the number of routes and the kilometers driven by the vehicles?

3. What is the potential for battery electric LCVs among the user group under consideration if they are solely charged on company premises and are not or only partially located there overnight?

4. What is the potential for battery electric LCVs among the user group under consideration if they are solely charged on company premises and are also located there overnight?

2. Materials and Methods

In this field study, GPS devices are being used to record the position data of craft vehicles. The following summarizes the procedure for recording, processing and evaluating the data. The procedure for calculating the linear state of charge (SOC) curves is also explained below.

2.1. Recording the Position Data of Craft Vehicles

In this study, the position data of vehicles from eleven different companies are recorded during one working week (data collection in the time between June and September 2023). Between 1 and 4 vehicles are recorded per company, resulting in a total of 22 vehicles with a total of 110 recorded days. The companies are all based in southern Germany in the Ulm region. A corresponding data protection concept exists to ensure that the study complies with data protection regulations [14].

In order to determine comparable data for a specific user group, all companies of the vehicles recorded are active in the HVAC and plumbing trade. All of the vehicles examined are light commercial vehicles such as high-roof station wagons, vans and transporters with a gross vehicle weight of less than 3.5 tons. In the context of this paper, therefore, those vehicles that HVAC and plumbing trade employees use to carry out their work are referred to as craft vehicles. The vehicles are used, for example, to drive to customers and transport the relevant materials and tools. The vehicles examined are all powered by conventional internal combustion engines (ICEs).

Trackers from GPSTek, which contain u-blox M8 GNSS chips, are used to determine the position data. The trackers are placed in the vehicles at the start of the working week on Monday mornings and removed from the vehicles the following Friday.

The trackers record position data at a frequency of 1 Hz, except when the vehicle is stationary, in which case the data are only recorded once per minute to conserve battery life and reduce data generation. If the vehicle resumes movement after coming to a stop, a motion detector senses it, and the devices resume recording position data at a frequency of 1 Hz. Therefore, the trackers may not record the first few seconds of a journey, as they are still searching for signals. However, the trackers also send position data once a minute when stationary, which significantly reduces the time required to search for signals once the journey has restarted.

The position data are sent to a server on which the software traccar [15] is installed. Another software traccar2gpx [16] is used to filter the position data and save them locally as a GPX file. For instance, the software eliminated redundant points.

Before the data are analyzed, all recorded data are carefully checked. Vehicles with too much missing data are completely sorted out before the analysis. This results in the verified data records for the 22 vehicles. Minor errors, such as incorrectly recorded points, are then manually removed from the data set using the RouteConverter [17] software. Faulty points can be recorded by recording position data when the vehicle is stationary or due to certain causes of a faulty signal connection. Causes of a faulty signal connection can be, for example, roofs above the vehicle, high buildings or tunnels.

For a better understanding, the following important terms are defined in Table 1 in the context of this paper.

Relevant information is calculated from the recorded position data. This information is documented in tables in the form shown in Table 2. It shows a fictitious example data set for 24 h. The data are processed in such a way that the associated standing time is calculated for each location. Furthermore, information is included for each location as to whether a particular location is within the home zone or not. In addition, essential information about the routes between the respective locations is calculated. These are the driving time and the distance since the last location.

Table 1. Definition of terms.

Term	Meaning
Distance	The distance between two points is calculated on the basis of latitude and longitude. If there are several points, the term distance is used for the sum of the individual distances.
Location	If a vehicle is at a place for more than 15 min, this place is defined as a location.
Route	A route is the total of all points between two locations.
Home zone	A location is within the home zone if the location is less than 100 m from the company location.

Table 2. Example data set of the research data for 24 h.

Location	Standing Time at the Location in h	Location within the Home Zone	Driving Time Since Last Location in h	Distance Since Last Location in km
1	8	1	0	0
2	2	0	1	38
3	0.65	0	1.2	50
4	0.9	1	0.45	15
5	1.05	0	0.35	10
6	8	1	0.4	10

The trackers are always placed in the vehicles and removed from the vehicles at the company premises. The calculation assumes that the vehicles are on the company premises on Mondays before the start of the measurement and on Fridays after the end of the measurement. Journeys made on Mondays before the installation of trackers, and on Fridays after their removal, as well as journeys made on weekends, are not included in this analysis and are therefore counted as standing time on the company premises. The determined tables of the vehicles therefore amount to a duration of 120 h (5 times 24 h) each.

2.2. Procedure for Approximating the SOC Curve

The aim of this study is to determine how well the recorded vehicles with combustion engines can be replaced by battery electric alternatives. The assumption here is that the usage profile of the vehicles should not be changed. This paper analyzes the suitability of BEVs for exclusive charging on company premises. It is therefore assumed that there are no charging facilities at any locations outside the company and that no public charging facilities are used. To assess suitability, theoretical linear SOC curves are determined from the collected data, which are available in the form of Table 2.

Additional variables are required to determine the SOC curve of the collected data. These are the average consumption and the battery capacity of the vehicles and the charging power at the company location. Assumptions are made for these variables in the study. The battery capacities and consumptions of battery electric LCVs already available on the market today vary greatly and therefore cannot be generalized. Battery electric vehicles available on the market can be viewed in corresponding databases [18] or directly from the vehicle manufacturers. For this reason, assumptions are made for five different cases for the calculation in this paper, which are shown in Table 3. The assumptions range from optimistic for BEVs in case 1, with comparatively high battery capacity and low average consumption, to pessimistic for BEVs in case 5, with low battery capacity and high average consumption. To cover the entire range between the five cases, the battery capacity was gradually reduced (−15 kWh/case) and the energy consumption was gradually increased ((+2.5 kWh/100 km)/case).

Furthermore, additional factors such as outside temperatures [19–21], driver characteristics [22], payload [23], as well as additional power consumers [24] have an influence on the actual range of the vehicles. At this point, reference should be made to further literature on this subject.

Table 3. Defined cases of battery electric light commercial vehicles.

	Case 1	Case 2	Case 3	Case 4	Case 5
Battery capacity:	100 kWh	85 kWh	70 kWh	55 kWh	40 kWh
Average consumption:	25 kWh/100 km	27.5 kWh/100 km	30 kWh/100 km	32.5 kWh/100 km	35 kWh/100 km
Calculative range	400 km	309.09 km	233.33 km	169.23 km	114.29 km
Case A: Average charging power:	11 kW	11 kW	11 kW	11 kW	11 kW
Case B: Average charging power:	22 kW	22 kW	22 kW	22 kW	22 kW

In Germany, the charging powers of wallboxes are typically 11 kW or 22 kW (typically AC charging). For this reason, the cases in this study are each calculated with these two charging powers. The different charging powers are examined, for example, by Yasko et al. with regard to future workspace EV charging [25].

The times for plugging in and unplugging the charger are neglected in this analysis.

SOC curves are calculated from the data, which are available in the form of Table 2.

The calculation of the SOC curves is based on the simplification that the SOC curves are linear. The consumption is determined from the kilometers driven and the charged energy from the standing times. These linear SOC curves have the advantage that they provide a vehicle-unspecific, driver-unspecific and therefore comparable overall picture of the driving profiles and thus allow an initial estimate of the potential of battery electric LCVs for the vehicles in the data set collected. The calculation of the SOC curves is based on the linear equation:

$$y = m \cdot x + c$$

When calculating the linear SOC curve, the respective SOCs at the start and end of the locations and at the start and end of the routes are calculated.

If the vehicle is parked on company premises ("1" in column 3 in Table 2), the SOC at the end of the standing time is calculated from the charging power and battery capacity of the respective case and the duration of the standing time (column 2 in Table 2). If the SOC reaches 100% before the end of the standing time, the time at which the SOC reaches 100% is calculated using the linear equation and added to the data set accordingly. The SOC remains at 100% until the start of the next route. If the vehicle is stationary outside the company ("0" in column 3 in Table 2), the SOCs at the start and end of the respective stationary time are identical. If the vehicle is driving, the SOC at the time of the end of the route is calculated on the basis of the kilometers driven (column 5 in Table 2), the average consumption taken from the corresponding case and the battery capacity taken from the corresponding case.

It is assumed that the vehicles have an SOC of 100% at the start of the measurement at the company premises. Figure 1 shows a calculated SOC curve based on the sample data from Table 2.

The calculation of the SOC curve is based on the assumptions from case 3.B. Routes with the corresponding average consumption of 30 kWh/100 km in case 3.B can be recognized in the figure by negative gradients. Locations at the company cause the SOC curve to rise with a charging power of 22 kW up to a maximum SOC of 100%. Corresponding locations outside the home zone can be recognized by constant SOC sections. The minimum SOC of the calculated example is approx. 56% and is marked with a red circle in the figure.

This procedure is used to calculate the weekly SOC curves for all vehicles with the parameters of all cases. The respective weekly minima of the SOC curves are then summarized and classified in pie charts. If there is a theoretical minimum with an SOC of less than 0%, this is classified as SOC = 0%. In this case, the vehicle would not have been able to drive through the driving profile as a BEV with the respective assumptions.

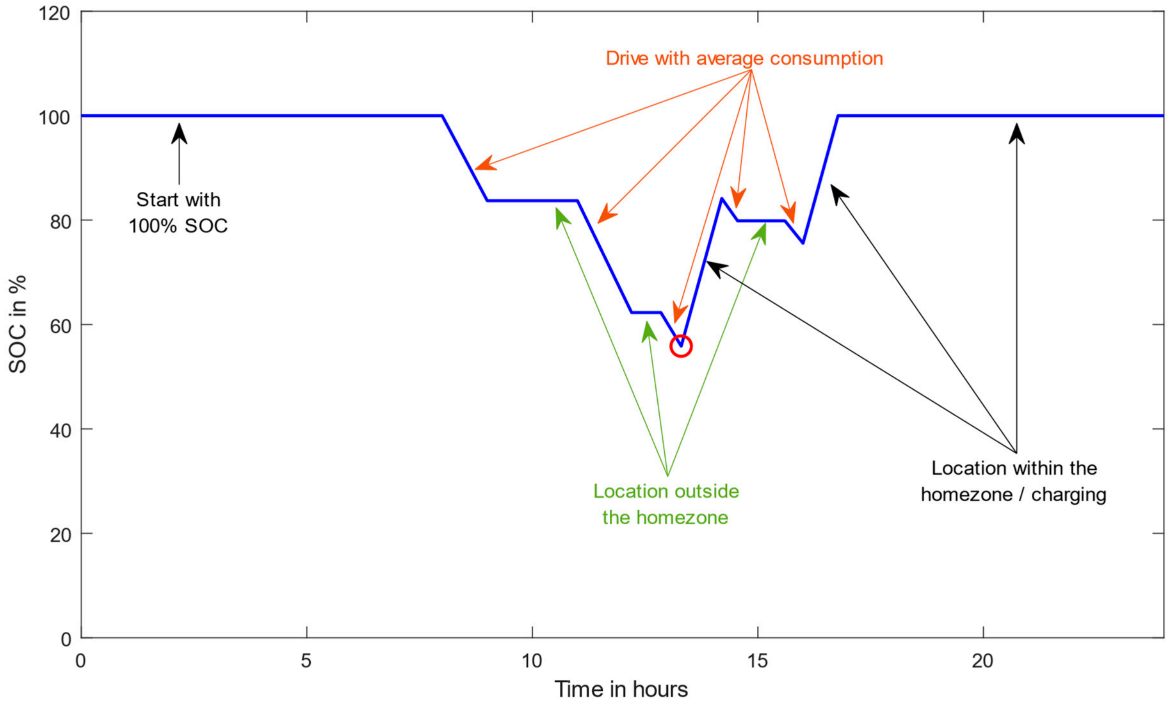


Figure 1. Exemplary SOC progression of a day based on the assumptions of case 3.B.

3. Results

The results of the investigation are presented below. First, a general overview of the data collected in the study is given. Then, the correlation between the daily number of vehicle routes and the total distances traveled by the vehicles each day is examined. Finally, the suitability of BEVs is considered using the theoretically calculated SOC curves of the different cases.

3.1. General Overview of the Collected Data

Figure 2 shows the lengths of the individual routes of the 22 vehicles recorded. The vehicles are plotted on the abscissa and the lengths of the routes in kilometers on the ordinate. The routes of all five measured days are shown for each vehicle, whereby one day of a vehicle typically contains several routes. Furthermore, some statistical values of the recorded routes of the vehicles are quantified in Table 4.

Figure 2 shows that the maximum route lengths of the vehicles vary up to a length of 113.65 km. However, 20 of the 22 vehicles examined did not cover any routes with a total length of more than 55 km during the measurement period. Two of the vehicles covered routes longer than 100 km. The median of the measurement data (shown in red) ranges from 1.45 km to 24.30 km. It should be noted that the medians of the two vehicles with route lengths of over 100 km, at 5.86 km and 7.89 km, tend to be in the medium range of the vehicles considered, and the majority of the routes covered by these vehicles tend to be shorter. The arithmetic mean (shown in green) of the route lengths of all vehicles considered is between 2.51 km and 26.36 km. The quartiles are shown in blue and the respective limits (all data included, no outliers excluded) in black.

Table 4 also shows the number of routes that the vehicles completed during the working week. The vehicles typically completed several routes in one day. The table furthermore displays the total distance covered by the vehicles during the working week. During the measurement, the individual vehicles covered a total distance of between 55.13 km and 632.60 km.

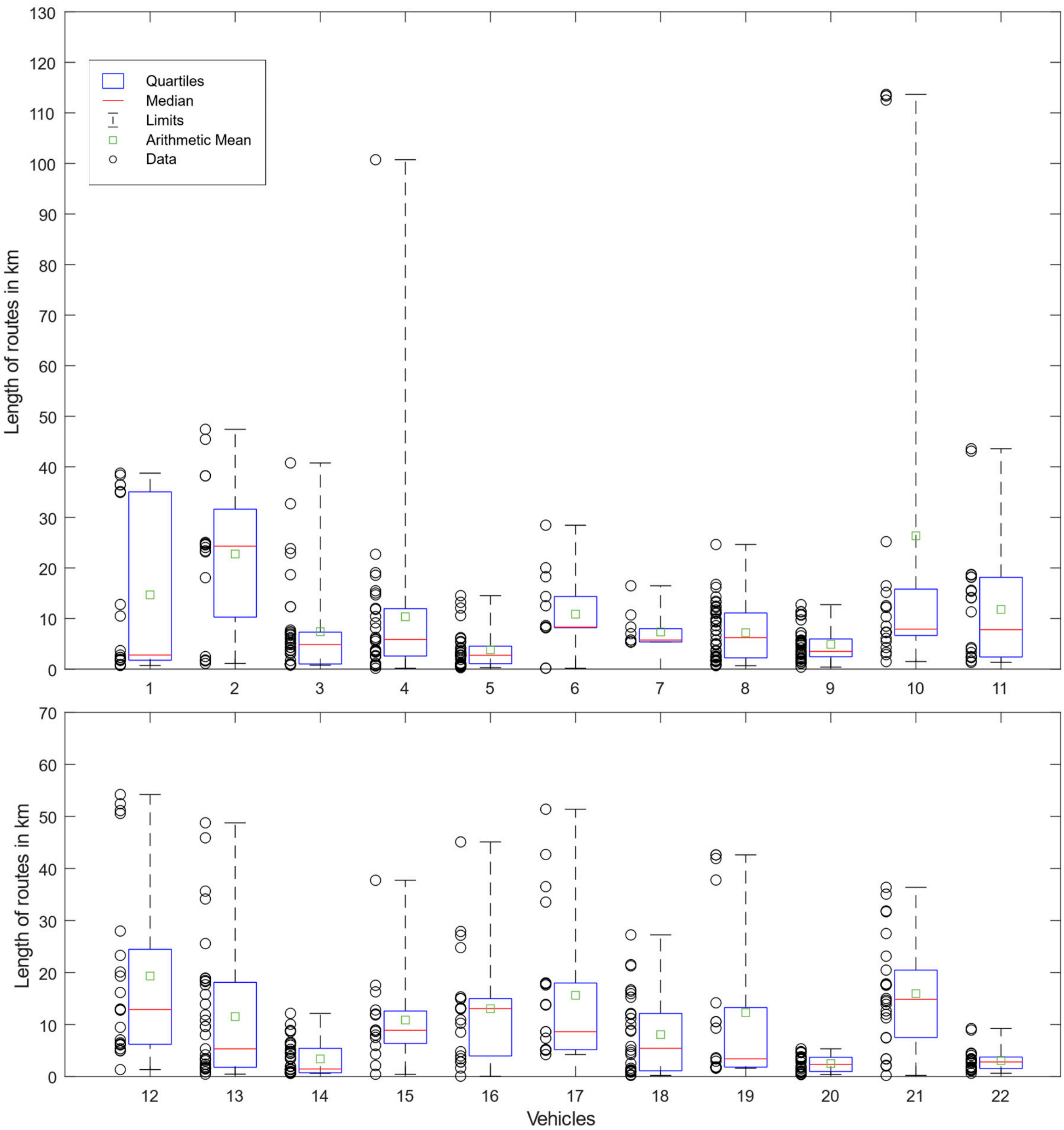


Figure 2. Length of routes per vehicle.

Table 4. Statistics of the recorded routes of the vehicles.

Vehicle	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Number of routes	-	23	16	37	31	33	14	11	42	41	24	22
Minimum	km	0.72	1.11	0.76	0.16	0.27	0.16	5.36	0.67	0.38	1.48	1.33
Maximum	km	38.75	47.42	40.77	100.74	14.52	28.46	16.47	24.64	12.74	113.65	43.58
Median	km	2.77	24.30	4.84	5.86	2.73	8.30	5.73	6.22	3.49	7.89	7.79
Arithmetic mean	km	14.68	22.75	7.40	10.36	3.81	10.86	7.34	7.19	4.89	26.36	11.80
Standard deviation	km	16.39	15.07	9.19	17.85	3.72	7.53	3.47	5.54	3.28	40.00	12.23
Sum	km	337.58	364.06	273.94	321.05	125.76	152.03	80.79	302.11	200.40	632.60	259.51
Vehicle	**Unit**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Number of routes	-	21	35	37	15	22	21	30	19	22	26	24
Minimum	km	1.34	0.46	0.62	0.43	0.07	4.22	0.22	1.61	0.38	0.22	0.63
Maximum	km	54.22	48.77	12.15	37.73	45.10	51.39	27.23	42.61	5.33	36.37	9.24
Median	km	12.87	5.33	1.45	8.90	13.07	8.63	5.44	3.41	2.36	14.84	2.81
Arithmetic mean	km	19.32	11.53	3.39	10.87	13.04	15.62	8.06	12.29	2.51	15.94	3.08
Standard deviation	km	17.63	12.94	3.21	8.81	10.66	13.90	7.60	15.84	1.61	10.30	2.18
Sum	km	405.70	403.46	125.50	163.06	286.81	327.92	241.87	233.44	**55.13**	414.37	73.94

3.2. Correlation between the Number of Routes and the Kilometers Covered by the Vehicles

The correlation between the daily number of routes and the daily distances traveled by the vehicles is examined below. Figure 3 shows the scatter plot of the total daily distance covered over the number of daily routes. The figure shows particularly high total daily distances of some vehicles on three days. These three conspicuous data points are marked in red. As the journeys at these three data points actually took place, these points are not sorted out as measurement errors but are also considered separately in the following correlation analysis.

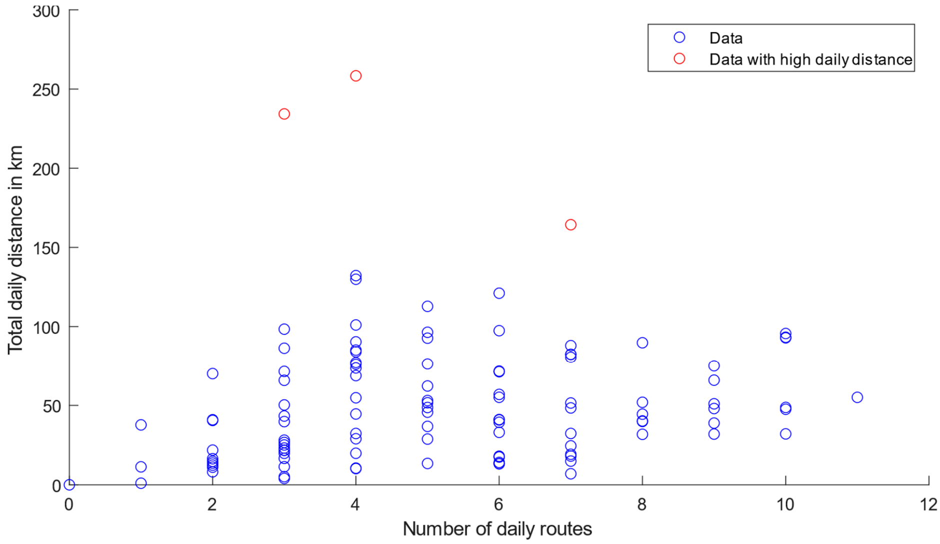


Figure 3. Scatter plot of kilometers driven over the number of routes.

The Pearson correlation coefficient is calculated to assess the connection between these variables.

- Pearson correlation coefficient with all data included: r = 0.1497
- Pearson correlation coefficient without the three marked values: r = 0.2573

As can be seen in the data in the scatter plot in Figure 3 and can be read from the calculated correlation coefficients, only a weak correlation, if any, can be found between the daily distances traveled and the number of daily routes.

3.3. Potential for Electrification of the Vehicles Examined

For each of the 22 vehicles, the SOC curves of the different cases are calculated according to the procedure described in Section 2.2. For the suitability of BEVs, the weekly minima of the individual theoretical SOC curves are considered in this paper.

All of the 22 vehicles considered have longer standing times on the nights between Monday and Friday. Some of the vehicles are located on the company premises (within the defined home zone). Other vehicles, on the other hand, are at a different location during the night (outside the defined home zone). It makes sense to consider these two groups separately. For this reason, the 22 vehicles are grouped as follows:

- Vehicles that are parked on the company premises during the nights between Monday and Friday (9 vehicles)
- Vehicles that are not parked on the company premises during the nights between Monday and Friday or only on some days (13 vehicles)

The calculated SOC curves for case 3.B with the respective weekly minima are shown in Figure 4. Within the figure, a distinction is made between those vehicles that are always on the company premises on the nights between Monday and Friday and those vehicles that are not or only partially on the company premises between Monday and Friday. For each vehicle, the respective weekly minimum is marked with a red circle and quantified.

The figure shows that the vehicles parked overnight on the company premises between Monday and Friday could always have been fully charged by the next day under the assumptions made. These vehicles with the charging power of 22 kW assumed in case 3.B already have an SOC of 100% for a large part of the standing time at night. Therefore, a lower charging power, which would lead to flatter gradients of the SOC curves in Figure 4, would be sufficient to fully charge the vehicles overnight.

If the SOC curves of those vehicles that are not or only partially on the company premises at night between Monday and Friday are considered, it is noticeable that the standing time on the company premises is often not sufficient to fully recharge the vehicles to an SOC of 100% every day. For these vehicles, the assumed charging power has a much greater influence on the minimum SOC of the week.

Furthermore, the respective weekly minima of the recorded vehicles are marked and quantified in the figure. Under the assumptions made, those vehicles that can charge in the nights between Monday and Friday all have a minimum SOC that is greater than 40%. Four of the vehicles even have a minimum SOC of greater than 90%.

The other 13 vehicles, which are not or only partially on the company premises during the nights between Monday and Friday, mostly have minimal SOC between 20% and 80%. It is also noticeable that two vehicles have a calculated SOC of less than 0%. This should be interpreted as meaning that these vehicles would not have been able to drive through the driving profile as a BEV under the assumptions made.

The SOC curves shown in Figure 4 represent only one of the ten cases calculated (case 1 to case 5, each with 11 kW and 22 kW charging power). When calculating the other cases, the different assumptions for charging power, energy consumption and battery capacity result in different weekly SOC minima. In order to present all calculated cases in a comparable manner, only the respective minima of the calculated SOC curves are shown below.

These respective weekly minima of the theoretical SOC curves are summarized and classified in pie charts in Tables 5 and 6. If a vehicle has a calculated SOC curve with a minimum SOC of less than 0%, it is classified as SOC = 0%. The two tables differ in the assumed charging power at the company location. Table 5 shows the pie charts with an assumed charging power of 11 kW (case 1.A to case 5.A) and Table 6 shows the pie charts with an assumed charging power of 22 kW (case 1.B to case 5.B).

To provide an overview of the data, the results of cases 1, 3 and 5 are briefly described below. The vehicles that are always on the company premises during the nights between Monday and Friday are discussed first, followed by those vehicles that are not or only partially on the company premises during the nights between Monday and Friday.

Vehicles parked overnight in the home zone between Monday and Friday:

When comparing Tables 5 and 6, it is immediately apparent that the weekly minimum SOC of the nine vehicles is identical for the respective cases between 11 kW and 22 kW charging power. When describing the individual pie charts of these nine vehicles, it is therefore not necessary to differentiate between 11 kW (case A) and 22 kW (case B).

- Case 1: All vehicles have a minimum SOC of over 60%. Four vehicles even have a minimum SOC of more than 90%.
- Case 3: The distribution of the minimum SOC is quite similar to case 1. All vehicles have a minimum SOC of more than 40%. Four vehicles have a minimum SOC of greater than 90%. The results from the pie chart of case 3.B can be compared with the minima of the SOC curves from Figure 4.
- Case 5: Two vehicles are classified with a minimum SOC of 0%. These two vehicles would not have been able to complete the driving profile under the assumptions made in case 5. One vehicle has a minimum SOC of between 10% and 20%. All other vehicles have a minimum SOC of greater than 40%. One vehicle even has a minimum SOC of over 90% in case 5.

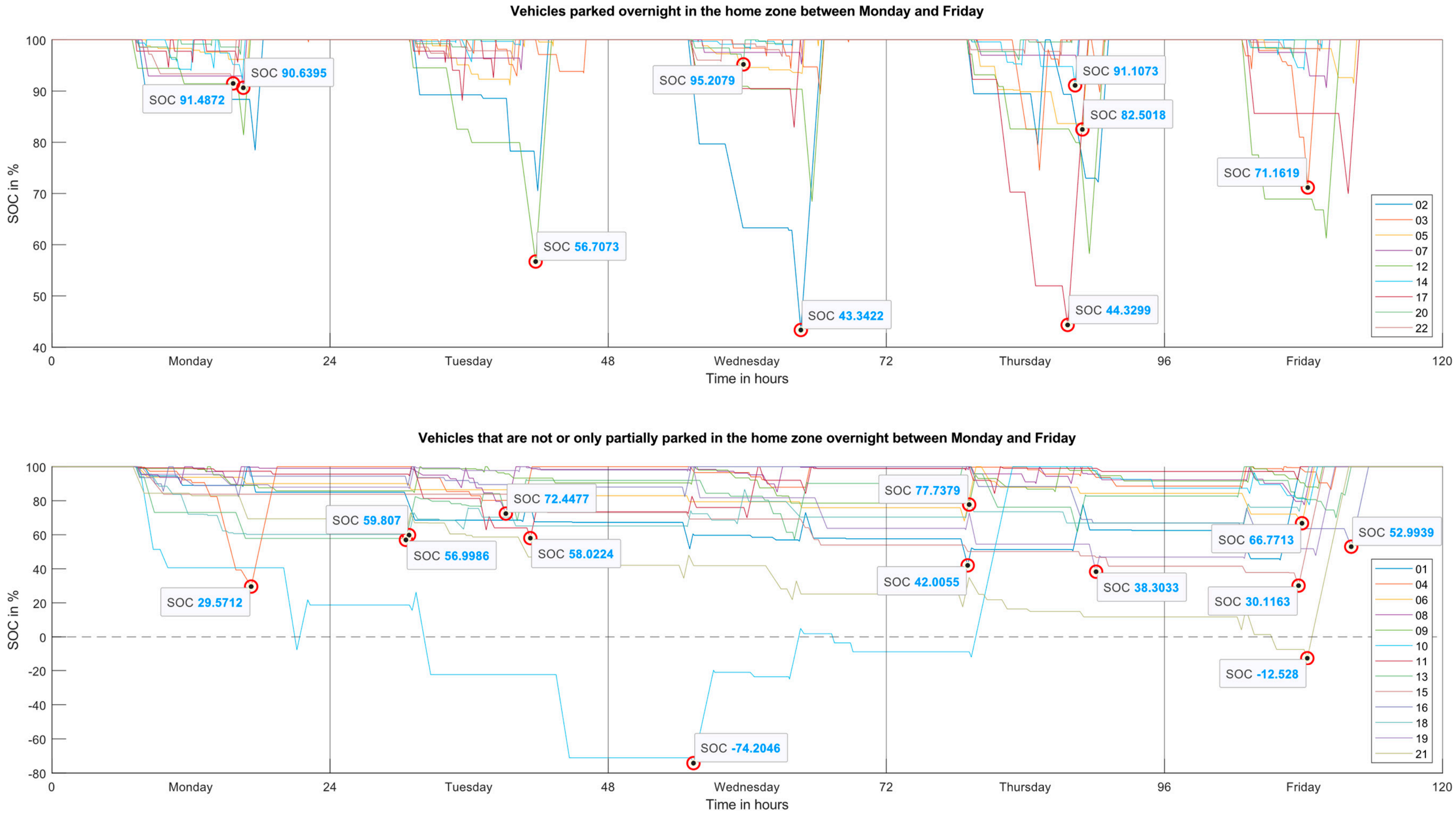


Figure 4. Calculated SOC curves for each vehicle including its minimum over the course of the week with the assumptions from case 3.B.

Table 5. Weekly minima of the theoretically calculated SOC curves with separation of the locations overnight and 11 kW charging power.

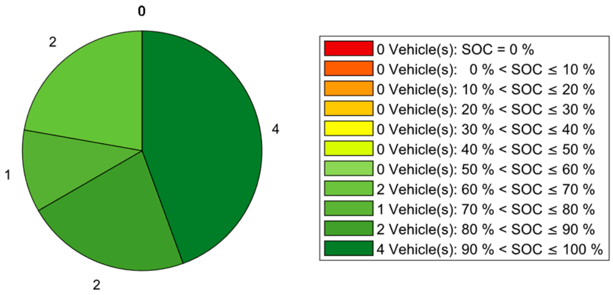
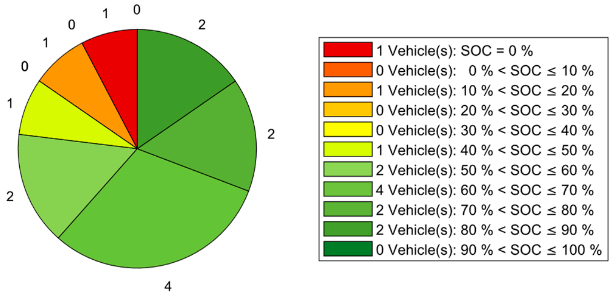
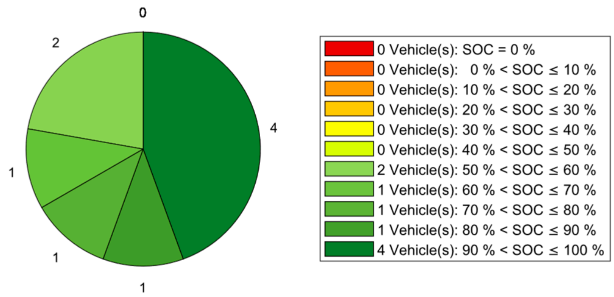
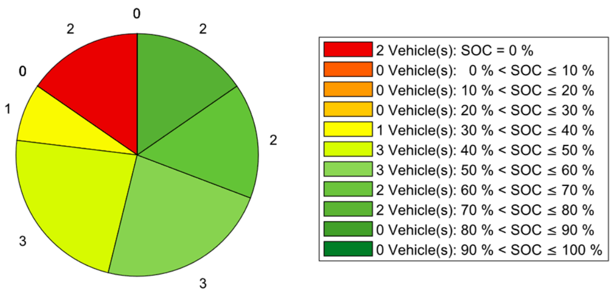
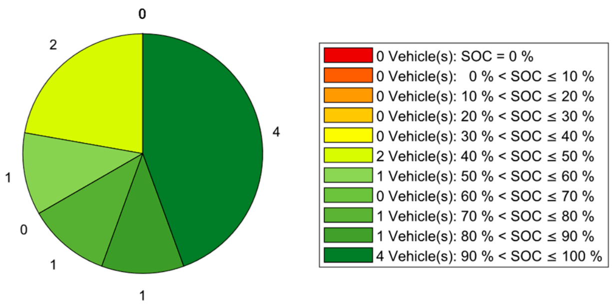
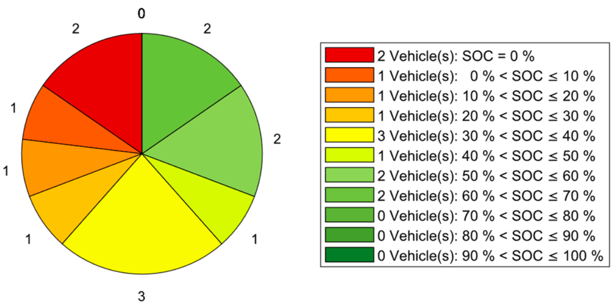
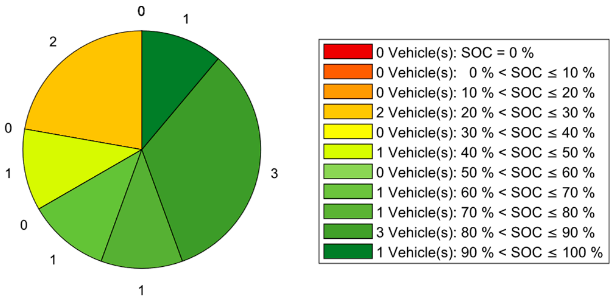
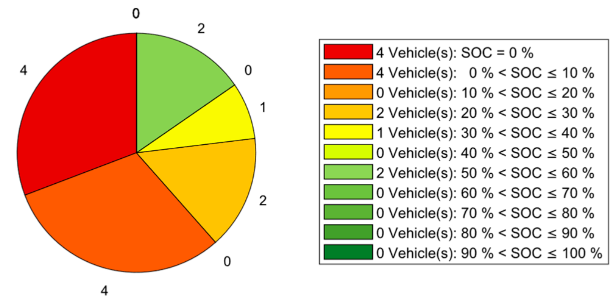
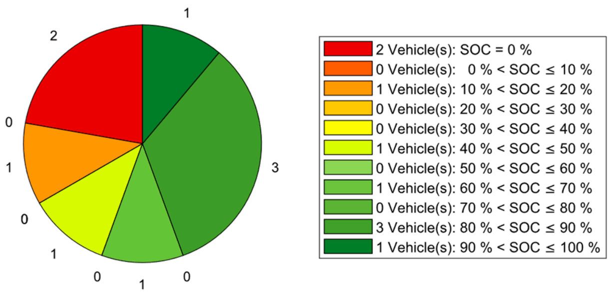
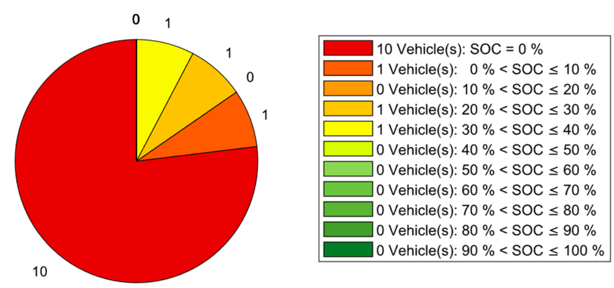
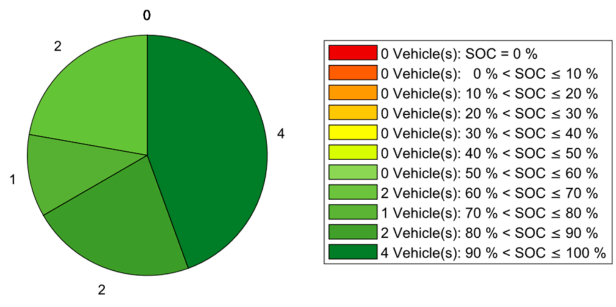
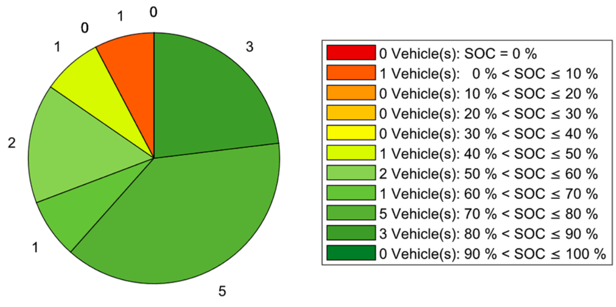
A: 11 kW	Vehicles Parked Overnight in the Home Zone between Monday and Friday	Vehicles That Are Not or Only Partially Parked in the Home Zone Overnight between Monday and Friday
Case 1.A		
Case 2.A		
Case 3.A		
Case 4.A		
Case 5.A		

Table 6. Weekly minima of the theoretically calculated SOC curves with separation of the locations overnight and 22 kW charging power.

<table>
<tr><th>B: 22 kW</th><th>Vehicles Parked Overnight in the Home Zone between Monday and Friday</th><th>Vehicles That Are Not or Only Partially Parked in the Home Zone Overnight between Monday and Friday</th></tr>
<tr><td>Case 1.B</td><td>
</td><td>
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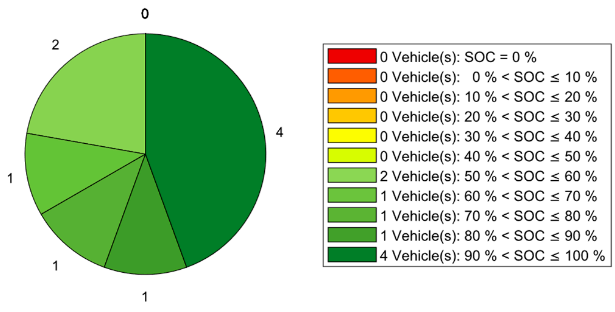
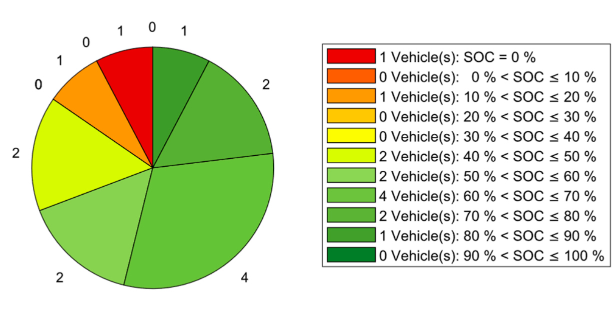
<tr><td>Case 2.B</td><td>
</td><td>
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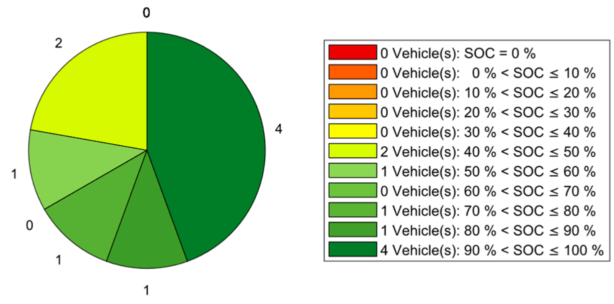
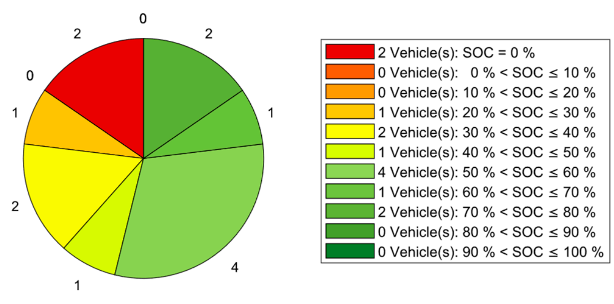
<tr><td>Case 3.B</td><td>
</td><td>
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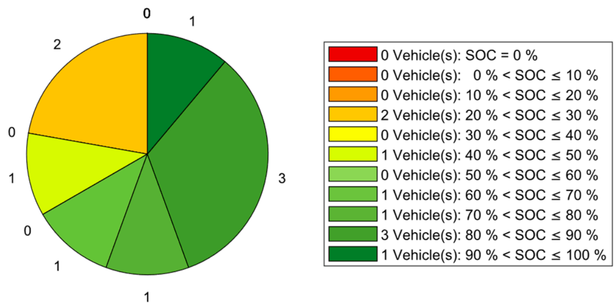
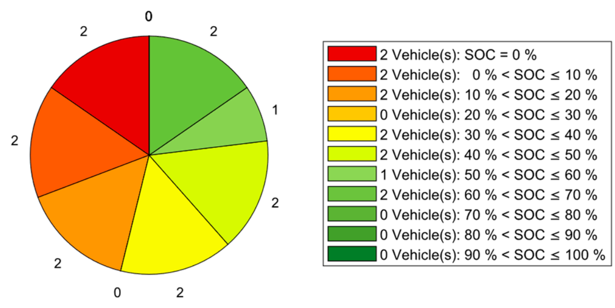
<tr><td>Case 4.B</td><td>
</td><td>
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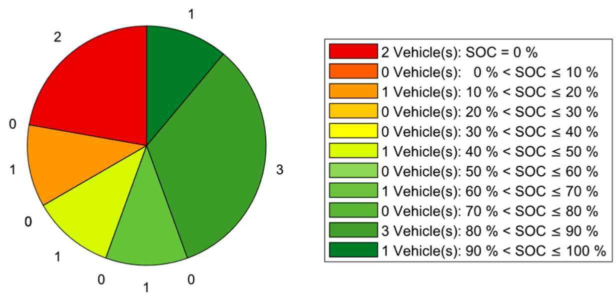
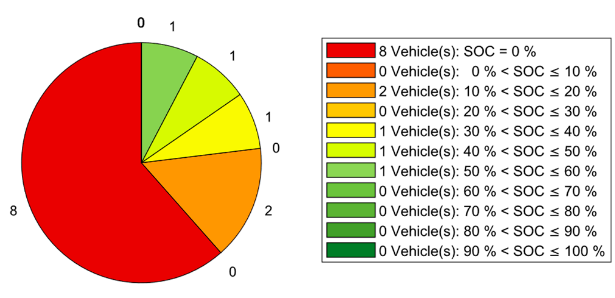
<tr><td>Case 5.B</td><td>
</td><td>
</td></tr>
</table>

Vehicles that are not or only partially parked in the home zone overnight between Monday and Friday:

When looking at the data of the vehicles that are not or only partially on the company premises during the nights between Monday and Friday, it is noticeable that the values of the weekly minimum SOC differ depending on the charging power on the company premises. For this reason, the values from Table 5 (11 kW) and then the values from Table 6 (22 kW) are described separately below.

- Case 1.A (11 kW): One vehicle is classified with a minimum SOC of 0% and another vehicle has a minimum SOC of between 10% and 20%. The rest of the vehicles (11 of 13 vehicles) have a minimum SOC of between 40% and 90% under the assumptions made.
- Case 3.A (11 kW): Two vehicles are classified with a minimum SOC of 0%. Three other vehicles have a minimum SOC of less than 30%. The remaining vehicles have a minimum SOC of between 30% and 70%.
- Case 5.A (11 kW): The majority of the vehicles considered (10 of 13 vehicles) are classified with a minimum SOC of 0% and would not have been able to drive through the driving profiles under the assumptions made in case 5.A. Only three vehicles have a minimum SOC between 0% and 40%.
- Case 1.B (22 kW): All vehicles have a minimum SOC of greater than 0%. One vehicle has a minimum SOC between 0% and 10%. The other vehicles have a minimum SOC of between 40% and 90% under the assumptions made.
- Case 3.B (22 kW): Two vehicles are classified with a minimum SOC of 0%. The remaining vehicles have a minimum SOC of between 20% and 80%. The results from the pie chart of case 3.B can be compared with the minima of the SOC curves from Figure 4.
- Case 5.B (22 kW): More than half of the vehicles (8 out of 13 vehicles) are classified with a minimum SOC of 0%. Two vehicles have a minimum SOC of between 10% and 20%. The three remaining vehicles have a minimum SOC of between 30% and 60%.

4. Discussion

Basically, the results of this paper must be viewed in the context of the data size recorded and the assumptions made in the paper. The driving profiles of 22 vehicles are recorded over a period of five days in each case. The companies of the vehicles studied are located in Ulm and the surrounding area.

With regard to the first research question, an important result of this paper is that the recorded driving profiles of the vehicles from the HVAC and plumbing trade are very different and show a large variance. There is a wide range in the total distances covered during the measurement, from 55 km to 633 km. The lengths of the individual routes taken by the vehicles also vary. General statements on the potential of BEVs are therefore difficult and should be considered individually for each vehicle.

Another finding of this paper is that no strong correlation can be identified between the daily number of routes and the daily kilometers traveled. Therefore, the number of daily routes traveled should not be used to determine the distances traveled by the vehicles.

To answer the research question of how high the potential of BEVs is if they are charged exclusively on company premises, the weekly minima of the calculated SOC curves are considered. Assumed average consumptions, battery capacities and charging powers are used to calculate the theoretical SOC curves. As these values vary for the vehicles already available on the market today (vehicles are often also offered with different battery sizes), these values are assumed within five cases. The values range from optimistic for BEVs to pessimistic for BEVs. Furthermore, many usage-specific parameters such as the payload, outside temperatures, auxiliary consumers or driver behavior have an influence on the range of the vehicles, which are not represented within this study beyond the assumed cases. It should also be noted that further improvements such as larger batteries and lower consumption due to increased efficiencies in the area of battery electric LCVs are to be expected as a result of technical progress. For example, the current Mercedes-Benz eSprinter is available in different battery variants with a battery size of up to 113 kWh, which even exceeds the assumptions from case 1 [26].

The results should be seen in the context that the optimistic assumption is made for all vehicles that they will start on Monday morning with an SOC of 100%. This is the case if the vehicles are parked on the company premises over the weekend and can charge. The assumption helps to make the results comparable, but in reality, there are of course vehicles that are not on the company premises over the weekend and could not start with an SOC of 100%. It should also be noted that the total assumed capacity is always used in the calculations. In reality, however, very low SOC levels, such as an SOC of less than 10%, must also be considered critical. In addition, it makes sense not to always charge and discharge the battery over the full range but to keep the SOC within a certain range in order to increase the service life of the battery [27].

Looking at the results of Figure 4 and the pie charts in Tables 5 and 6, the following findings can be made with regard to the research questions on the potential of battery electric vehicles. It can be seen that, depending on the selected assumptions, a large proportion of the recorded driving profiles can be carried out with BEVs, especially if they are on the company premises at night and can be charged. For example, there are several vehicles that do not fall below an SOC of 90% in the calculated SOC curve under the moderate assumptions of case 3. If vehicles can be fully charged at night on the company premises, they logically only need to have a sufficient range for the daily distance. In the present data set, it makes no difference whether the vehicles that are on the company premises during the nights between Monday and Friday charge with an assumed charging power of 11 kW or 22 kW. This relationship can be observed not only in the identical results of the pie charts for 11 kW and 22 kW but also in Figure 4. Under the assumptions of case 3.B, the figure shows that even significantly lower charging powers (which would lead to flatter positive gradients of the SOC curves) would be sufficient to fully charge these vehicles overnight.

However, if the other group of vehicles is considered, which are not or only partially on the company premises during the nights between Monday and Friday, it can be seen that the charging power at the company has an influence on the potential of BEVs. The greater influence of charging power on the potential of BEVs for these vehicles can also be seen in Figure 4. The standing times on the company premises and thus the possible charging time during the day are often not sufficient to compensate for the energy consumed during the routes driven. The vehicles would therefore often start with a lower SOC than the day before.

With a charging power of 22 kW, a higher minimum SOC compared to a charging power of 11 kW is often observed, which is due to the fact that more energy can be supplied during the day when the vehicles are on the company premises.

It should also be noted that the vehicles differ in their driving mileage. The vehicles that are not or only partially on the company premises at night have higher average mileages, as shown in Table 7. The vehicles of the two groups can be found in Figure 4. The corresponding distances driven are listed in Table 4.

Table 7. Driving distances of the recorded vehicles.

	Unit	**Vehicles Parked Overnight in the Home Zone between Monday and Friday**	**Vehicles That Are Not or Only Partially Parked in the Home Zone Overnight between Monday and Friday**
Vehicles	-	02, 03, 05, 07, 12, 14, 17, 20, 22	01, 04, 06, 08, 09, 10, 11, 13, 15, 16, 18, 19, 21
Average weekly driving distance	km	203.64	303.71
Average daily driving distance	km	40.73	60.74

The kilometers traveled by the vehicles have a direct influence on their calculated SOC curves with the associated minima. However, due to the data size of the present data set, no general statements can be made about the usual driving distances for vehicles that park at the company overnight and those that do not. Nevertheless, a possible explanation for the longer driving distances of the vehicles, which are not or only partially parked on the company premises on the nights between Monday and Friday, could be the additional routes for the "way to work" and the "way home" of these vehicles.

Based on the results of the present data set, the following recommendations are derived for the light commercial vehicles of companies in the HVAC and plumbing trade in particular:

- If the vehicles can be charged overnight on the company premises and the range of the BEVs exceeds the usual daily mileage, these BEVs are suitable. It is also expected that a charging capacity of 11 kW is sufficient.
- If the vehicles cannot park and charge on the company premises at night, or can only do so partially, the driving profiles and idle times of the vehicles must be considered individually and evaluated to determine whether the charging times at the company are sufficient for the usual daily mileage of the vehicles. In addition, this study shows that the charging power has a greater influence on the potential of BEVs of these vehicles, which is why the higher charging power of 22 kW is recommended for these vehicles in case of doubt.

Some of the recorded driving profiles cannot be covered by BEVs under some of the assumptions made, even if it is assumed that the vehicles start with an SOC of 100%. However, this does not mean that these driving profiles cannot be represented by climate-neutral alternatives. In addition to the assumptions considered, the following further assumptions and climate-neutral alternatives are conceivable, for example:

- The vehicles may be able to charge at other locations outside the company, for example, on employees' private properties or public charging points in the immediate vicinity of the locations.
- It is also conceivable that public fast-charging stations could be used if the SOC is correspondingly low. However, this would have an impact on the usage profile of the vehicles and would entail corresponding waiting times for employees at the charging station. In addition, a correspondingly dense and available infrastructure of public fast-charging stations would have to be in place for this to happen.
- Another alternative could be climate-neutral vehicles based on a different type of fuel, such as hydrogen. Vehicles with fuel cells or hydrogen combustion engines would have comparatively short refueling times and could therefore be used without major changes to the usage profile. However, this would require a correspondingly dense infrastructure of hydrogen filling stations.

Furthermore, the recorded data are a snapshot of the respective vehicles for one week at a time, which can give an impression of the potential of BEVs. However, the recorded data of the individual vehicles should not be projected onto a whole year without further ado, as a weekly fluctuation in the driving profiles of the individual vehicles can also be assumed.

Further studies are planned to evaluate various climate-neutral drive technologies for light commercial vehicles. Representative driving cycles of light commercial vehicles will be derived from the collected data to provide a holistic view. Additionally, the infrastructure of public charging stations and hydrogen filling stations will be evaluated from the perspective of light commercial vehicles in the craft sector.

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O.H., B.B. and A.F.; supervision, U.S., M.S. and A.C.K.; project administration, O.H. and M.S.; funding acquisition, M.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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