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Where do EVs charge and how long are they parked at different locations? - Logging of EV driving and charging patterns-

Executive Summary

Charging and driving patterns of Electric Vehicles (EVs) are analyzed from on-board logging of 341 EVs in Sweden, in combination with a survey sent out to the EV owners . A better understanding of these patterns will help to estimate the need for public charging infrastructure and the potential for smart charging. The analysis shows that 71% of energy is charged at home, 4% at workplace, and 21% at other locations. The charged energy outside home per EV is largest in July (e.g., 83% more than November). Commuters using car to workplaces park at home 9% shorter and charge 66% larger amount of energy at home compared to non-commuters. However, commuter and non-commuter charge similar amount of energy at public charging stations. For half of the charging events at home and workplace, the charging speed could be slower than 1.1 kWh/h and 2.1 kWh/h, respectively.

Keywords: Electric vehicles; Smart charging; V2H & V2G; Consumer behavior; Customer demand

1 Introduction

In order to limit global warming in line with the Paris Agreement[1], electrification is a key measure to reduce emissions from transportation. The number of electric vehicles (EVs) is increasing worldwide [2]. The number of registered EVs in Sweden, which is the country in focus in this study, has increased dramatically during the last few years, from 9,122 in 2016 to 358,260 in 2024 [3], corresponding to ~7% of the passenger car fleet.

When EVs are parked, their batteries might be used to shift electricity load in time. EVs might also be used as battery storage and to discharge energy back to grid, so-called vehicle-to-grid (V2G) services. However, the drastic increase of EVs can make an negative impact on the electricity grid by charging when the demand for electricity is high. Furthermore, planning and building more public charging infrastructure is needed in order to meet the increasing EV demand. Thereby, studies are needed to estimate: (i) the impact of EVs on the electric grid; (ii) the need for charging infrastructure; and (iii) the potential, and possible benefits, of smart charging and V2G. Such studies require knowledge of the driving and charging patterns of EVs. One also needs to understand the attitudes and motivation of EV owners with respect to the use flexible charging.

To date, only a limited number of studies have been conducted on the charging and driving patterns of passenger EVs. This likely reflects the fact that it is only recently that there has been a dramatic increase in the number of EVs, with the main growth seen over the last few years. Thus, until recently, there were limited numbers of EVs in each region, and most of the passenger EVs were owned by high-income individuals living in the larger cities, so not necessarily representative of the typical EV passenger fleet of a country.

Previous studies on the charging and/or driving patterns of privately owned EVs have typically suffered from different limitations. For example, one EV study derived driving patterns only from travelling surveys including diaries and not using logged GPS [4]. A study by Taljegard et al. [5] collected data with GPS, but only from fossil-fueled vehicles. The study by Duarte et al. [6] include only a low number of EVs and Märtz et al. [7] included only a few EV models. Ziras et al. [8] used data that were collected at chargers which means that driving behavior cannot be acquired. Furthermore, the study by Sellmair et al. [9] did not include privately owned vehicles and the study by Sun et al. [10] only consist of EVs with a low battery capacity, i.e., relatively old EV models. The study by Sun et al. [11] is based on data collected over a short period.

To the best of our knowledge, there are no published studies that have analyzed charging and driving data collected from hundreds of randomly selected EVs for a cross-seasonal period using on-board GPS equipment and taking into account the various models and battery sizes that represent the entire EV market in a country. Thus, there is a need to collect and study real driving and charging patterns, including State of Charge (SOC), for a high number of EVs of various models, located in both urban and rural settings, over a longer time period (such as an entire year).

Therefore, the aim of this study is to analyze the characteristics of charging and driving patterns among a representative sample of EV owners to better understand the needs of charging infrastructure and potential for smart charging. This study quantitatively investigates the following two research questions:

- Where do EVs charge?
- How long are they parked at different locations?

This study uses two types of data:

1. Data on driving and charging patterns from 341 randomly selected EVs distributed across Sweden. The collection of data is performed using on-board GPS equipment plugged into the On-Board Diagnostics (OBD) port. The dataset enables us to draw conclusions about the driving and charging patterns of current EVs, using Sweden as an example.
2. A survey conducted on the same EV owners with the purpose to obtain information on the context of their EV ownership including 51 questions on their driving and charging behavior. This survey result enables us to categorize EVs and EV owners with respect to important attributes, such as if the EV owner is a commuter or not.

2 Method

This chapter is divided into the following subsections: logging data of EVs and survey conducted to the EV owners (2.1); description of analysis (2.2).

2.1 Logging data and survey

Geotab Go is used for logging driving and charging patterns of vehicles. Geotab Go records the data mostly from Control Area Network data through the OBD port and transmit them to a database provided by Geotab. The Geotab database mainly consists of trip data and status data, where the data used in this study is shown in Tables 1 and 2. Trip data is an event recorded when every trip is ended. A trip event is defined as the period the EV is not parked. Parking is defined as the period when the "ignition" is turned off or the driving speed is kept 0 km/h for more than 200 seconds. The status data is the data recorded depending on the change of each parameter. Time of start and end of charging is recorded when they occur, with distinguishing the charging type into alternating current (AC) and direct current (DC). The SOC is recorded for every 0.5 or 1 % change in battery capacity and odometer is recorded every 1-10km depending on the EV model. The energy charged to battery (accumulated value) and charging power to battery are recorded using the Ramer-Douglas-Peucker algorithm.

Two surveys were sent out to the participants, one before and one after the logging of the EVs. For this study, only answers from the survey sent out after the logging is used, which contains 51 questions with the questions used for the analysis in this paper listed Table 3.

Table 1: Parameters of trip data used in this study

Trip data	Unit
Start/end time of a trip event	YY:MM:DD HH:MM:SS
Coordinates at the end of a trip event	(x,y)
Driving distance	km

Table 2: Parameters of status data used in this study

Status data	Unit
Time of start/end of charging	0: End 1: AC 2: DC
SOC	%
Odometer	km
Energy charged to battery	kWh
Charging power to battery	kW

Table 3: Survey questions and alternatives (translated into English here since the original questions is in Swedish)

	Question	Alternatives
Q1	Do you use the electric car participating in the study to commute to work?	• No, I get to work in another way • Retired/not work • Work from home • Yes, but not every week • Yes, once a week • Yes, several times per week
Q2	Have you used the electric car participating in the study to go to a private vacation house?	• Yes • No
Q3	Where is the electric car charged mostly when not having a private charger at home?	• At the destination • On a street near the home • On the road to/home from the destination • In a larger parking lot near the home • Near home • The workplace
Q4	Where is the electric car charged when it is not charged at home or workplace?	• Event parking • Leisure activity • Never used a public charging station • Other private home (e.g., neighbor, friend, etc) • Resting places along the rural and highways • Shopping center/grocery store • Tourist destinations • Urban center (parking along the street) • Urban center (parking space)

The home location of each EV is defined as the location where the EV was parked most of the time during night-time (at 03:00) and that are less than1 km from the address of the EV owner’s residence provided by Statistics Sweden (SCB). The workplace location of each EV is defined as the location other than home location where the EV was parked for the longest in total of the parking events and that occurred during a period where the EV returns home within 24 hours after leaving home. The workplace location is defined only for the EVs owned by the participants who answered “Yes but not every week”, “Yes, once a week” or “Yes, several times per week” to the survey question Q1 stated in Table 3. These EVs are defined as “Commuters” and the others as “Non-Commuters”.

The vacation house location of each EV is defined as the location other than home location where the EV was parked for the longest in total of the parking events which occurred during the period when the EV is away from home 24 hours or longer between the time when leaving home and when returning home. The vacation house is defined only for the EVs owned by the participants who answered “Yes” to the survey question Q2 in Table 3. Parking locations closer than 50 km from the address of the EV owner’s residence are excluded.

The 341 private EV owners in this study were selected by SCB among owners of EVs resident in Sweden. The selection of participants is random, so that the EV owners represent different regions population density (e.g. city size), housing type (detached house or apartment), geographical location in Sweden and EV models. Most of the data used in this study were logged in Year 2023, but the logging period was from

October 2022 to November 2024, as shown in Figure 1a. Figure 1b shows the number of logging days per EV. For more details of participants, see previous study [12].

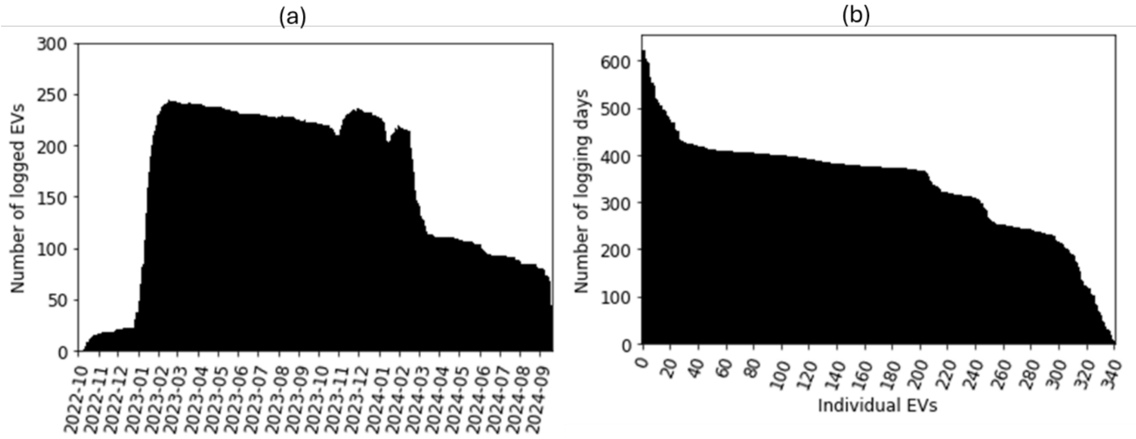

Figure 1: (a) Number of logged EVs on different days during the logging period in this study and (b) number of logging days for each EV. The individual EVs are in descending order according to the number of logging days.

2.2 Definition of concepts

In this study we want to clarify how the parking and charging patterns vary depending on the different locations and attributes of the car/owners. Furthermore, we have divided the EVs in to four categories: commuter and non-commuter with a small battery (50kWh or smaller) or a large battery (larger than 50kWh). Table 4 defines the metrics used in this study.

Table 4: Metrics used in this study.

Metric	**Definition**
Charged energy in a month	February 2023 to January 2024 is selected for the analysis because during this period at least 200 EVs are logged.
Average weekly charged energy	The charged energy of the EVs in a certain period is averaged to a week and one EV, so that the charged energy can be compared between the period with different number of EVs and/or days (e.g. different months) $Ave\_energy = Total\_energy \times 7/(Num\_day \times Num\_ev)$ Where Ave_energy is average weekly charged energy, $Total\_energy$ is the total charged energy of the EVs in the period, Num_day is number of the days in the period, Num_ev is number of EVs in the period.
Large-battery EVs Small-battery EVs	• Large-battery EVs: 54–100 kWh • Small-battery EVs: 16–50 kWh Note that there was no EV with a battery capacity lower than 16 kWh or higher than 100 kWh, and there was no vehicle with a battery capacity between 51 kWh and 53 kWh.
Number of trip events from home to home	The number of trip events made between leaving home and returning home again.
Share of driving distance of a trip to a charging location	This indicator shows how large share of total driving distances between home-to-home that is made before the charging event occur. As an example, if the EV drives 100km from home to home and charge after driving 50 km, this indicator is then 50%, and 50% probably indicates that the location is the destination.
Housing type	The type of house where the EV owner lives is categorized into detached house or apartment. This information is provided by SCB.
Yearly driving distance	The difference of the odometer values from when the logging started to when logging has reached 365 days.

Daily driving distance	The sum of the distances of all trips that started during a day (i.e., within 24 hours). If no trip occurs during a day, the daily driving distance is 0 km. Days with 0 km are not included when calculating the max daily driving distance.

3 Results and discussion

Figure 2 shows the shares of the EVs that are parked at the different locations (i.e., home location, workplace, vacation house and other locations), as well as if the EVs are charging at these locations or driving for an average weekday (a) and weekend (b). Figure 2 also shows the share of EVs charging in an average weekday (c) and weekend (d). As can be seen in Figure 2, the share of EVs that is driven at a certain time of the day is less than 10%, which occurs at 16:40 hours in the weekday (Figure 2a) and 8% in the weekend and national holidays (Figure 2b). In the weekday, two small peaks can be seen in Figure 2a, with one in the morning at around 08:00 and one in the evening at around 17:00 while the weekend does not have a clear peak.

The maximum share of EVs charging at the same time is 14% on average, which occurs at 00:10 hours in an average weekday, i.e., just after midnight (Figure 2c and 2d). From Figure 2, one can also see that the share of EVs parked at the home location without charging is large (see the orange-colored field in Figure 2). At midnight in the weekday, about 90% of the EVs are parked at home. The share of EVs parked at home decreases from 05:00 hours and reaches the lowest values (46-49%) between 11:00 and 15:00 hours in the weekday, as seen in Figure 2a.

The share of EVs parked at workplaces reaches a peak at 11:00 of a weekday at 21% of the EV fleet (light blue- and blue- colored field). In the weekend and national holidays, the share of EVs parked at home is lower, 80%, at midnight but 6% are parked at vacation houses instead (pink-colored field in Figure 2b). Overall, at least 47% and 56% are parked at home during daytime in the weekday and weekends, respectively, on average.

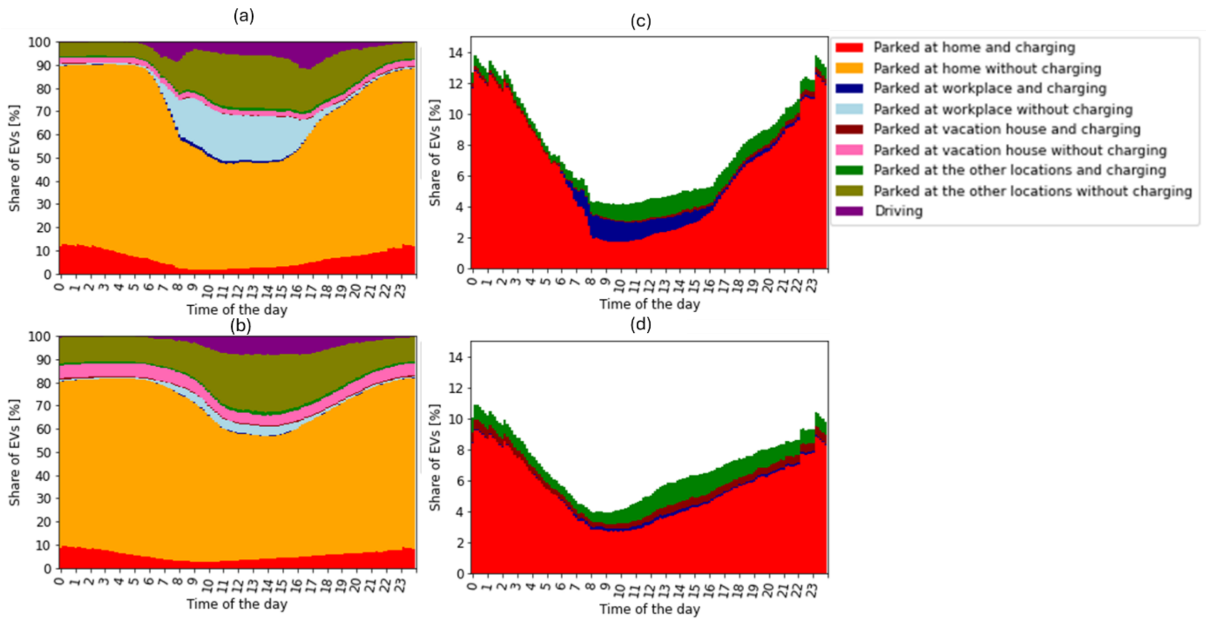

Figure 2:The shares of the EVs that are driving or charging at home location and workspace location at each time of an average (a) weekday and (b) weekend. The share of EVs charging in those locations for an average (c) weekday and (d) weekend. The resolution is 10 minutes. Note the difference in scale on the y-axes (a, b vs c, d)

Figure 3a shows the share of charged energy of all EVs in the logging period. DC and AC charging are plotted separately since DC charging are often possible at other locations than home/workplace. As seen in Figure 3a, 71% of energy is charged at home while the energy charged at workplaces and vacation houses is small (both are around 4%). Furthermore, the category “other locations” corresponds to 21% of the charged energy, where 40% is charged with DC charging (Figure 3a).

According to the results of the survey question Q3 in Table 3, 64% of all participants who do not have a private charger at home answered that they charge on the road between home and the destination. Of these owners 33% answered that they use chargers at the destination of a trip and 12% use chargers near home.

According to answers on survey question Q4 (i.e., use of chargers at other locations than home/work): 65% of the participants use chargers located along the roads or highways; 40% use chargers at shopping center or grocery stores; 29% charge at parking lots in urban areas;18% charge at other private home; and 13% charge at tourist destinations. Thus, “Other locations” could typically be public chargers on the roads or highways on the way to different destinations or shopping centers.

Figure 3a shows the total energy charged for an average EV and Figure 3b shows the average weekly charged energy per EV for different months. The charging behavior differ between seasons as seen in Figure 3b. The lowest charged energy at home is shown in July 2023 while this month also shows the largest amount of energy charged at other locations (34% of charged energy) and at vacation houses (6%). The energy charged at home is highest in November (30% more than July) and at workplaces (2.3 times of the July). As seen in Figure 3b, the energy charged at other locations on July is 83% higher than that of November, especially the energy charged with DC charger is 2.6 times of that of November. Ther reason seems to be because July is the main vacation month in Sweden with vacations typically starting around Midsummer Eve on a Friday between 19th – 25th of June. During the vacation season, the EVs are less often used to commute to work but are more often used for long trips.

The parking and charging patterns also depend on which category the EV belongs to (i.e., commuters/non-commuters and large/small battery size) as seen in Figure 4a. The share of parking duration at home is slightly smaller for commuters (large battery 65%, small battery 71%) than the non-commuters (large battery 73%, small battery 73%) as can be seen in Figure 4a. Figure 4b shows the average weekly charged energy for the same categories as those in Figure 4a. Overall characteristics is that commuters charge more energy (i.e., use more energy) than non-commuters in total, as well as those EVs with a large battery capacity charge more energy than those with a small battery capacity. The obvious reason is that commuters drive more often and those EVs with a large battery capacity is driven longer distances. However, the energy charged at other locations than home/work/vacation house is similar between commuters (large battery 14kWh/week) and non-commuters (large battery 11kWh/week). The average energy charged at home for commuters and non-commuters with large battery is 39kWh/week and 29kWh/week, respectively. This implies that most EVs do not need to charge at the other locations for the daily driving, but need to charge at other locations during long trips.

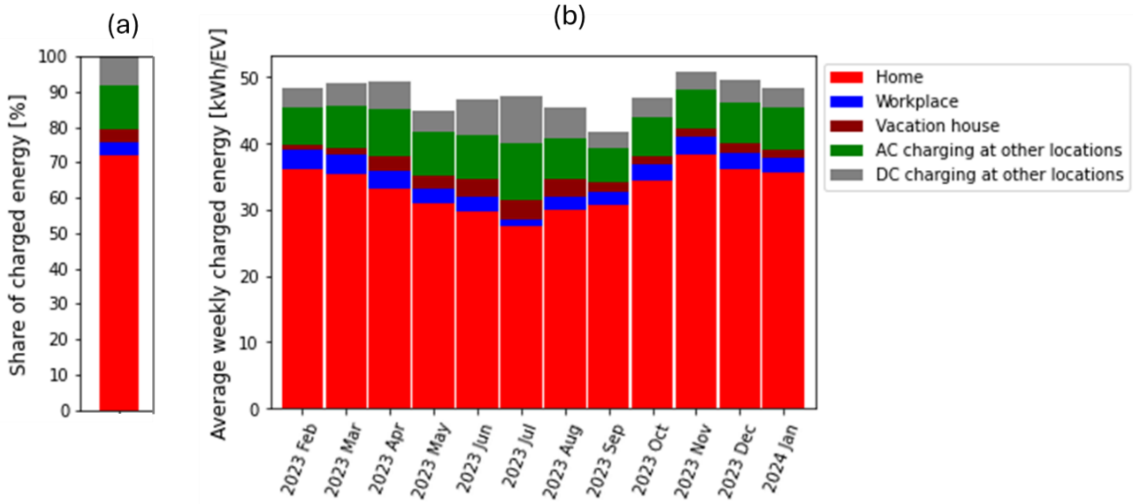

Figure 3: (a) Share of charged energy of all EVs during the whole logging period and (b) Average weekly charged energy per EV in different months during 2023 and 2024.

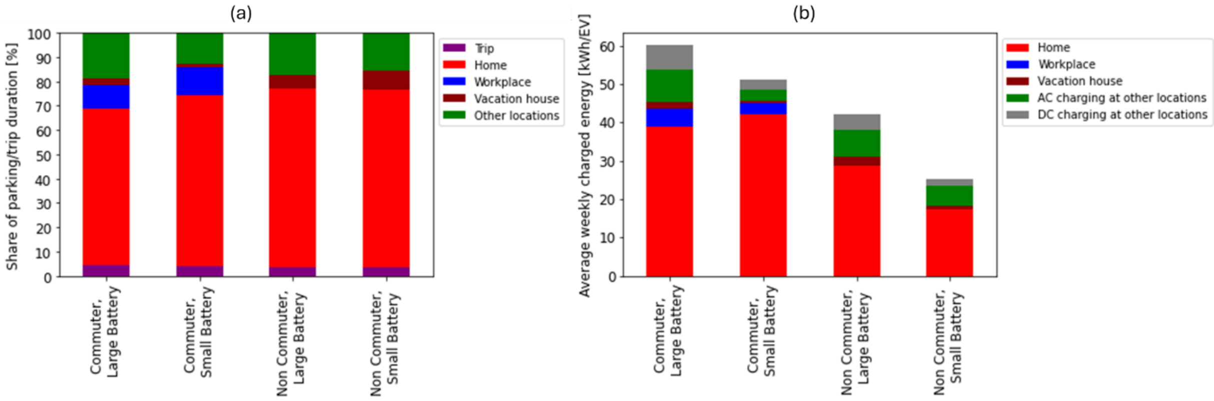

Figure 4: (a) Share of parking and trip duration in different location categories for commuter and non-commuter and small and large battery and (b) the average weekly charged energy for the same categories.

Figure 5 shows the share of driving distance from leaving home to a charged location other than at workplace and vacation house in the total driving distance to arriving home for AC charging (a) and DC charging (b), and the same values for the trips from home to home with 100km or longer driving distance for AC charging (c) and DC charging (d). As can be seen in Figure 5a, the charging locations are concentrated to within half of the driving distance from home, i.e., most vehicles charged at destination before returning home (47% of the charging locations are within 45-55% of the driving distances from home to home). On the other hand, DC charging in Figure 5b shows more widely spread distribution than AC charging in Figure 5a. The share of charging locations in 45-55% of the driving distances from home to home is only 22%, while the share of charging locations in the later part of trips is higher than for the EVs with AC charging (DC:48% and AC:28% for the charging locations in 55-100% of the driving distance). The share of charging locations in the later part of the trip is also higher than the earlier part of trips for DC charger (31% for the charging locations in 0-45%). These characteristics for DC charging are more obvious for the trips from home to home with longer driving distance as seen in Figure 5d. The peak of the histogram for DC charging is lower (18% of charged locations are in 45-55%) as seen in Figure 5d, while the share of charging locations in 45-55% of the driving distance is similar (47%) to the case in Figure 5a, as seen in Figure 5c. These results show that AC charging is mainly used for charging at destination or the trips are made for visiting a charging station, while the DC charging is used on the way, especially from the destination to home although some amount of trips seem to be only to reach a DC charger as the peak of the histogram shows in Figure 5b.

Figure 6 shows share of energy charged with DC chargers by yearly driving distance (a) and max daily driving distance (b) for the EV owners who live in an apartment (orange colored symbols) and those in a detached house (blue colored symbols). As can be seen in Figures 6a and 6b, the highest share of energy charged with DC chargers among the EV owners who live in an apartment is 34%. The average share of energy charged with DC charger is 14% and 5% for the EV owners who live in an apartment and detached house, respectively. This shows that inconvenience to access to a charger at home in an apartment is a reason for charging large amount of DC chargers too some extent. As seen in Figure 6a, the share of energy charged with DC chargers does not have strong correlation with the yearly driving distance (correlation coefficient: 0.05). However, the value has stronger correlation with the max daily driving distance (correlation coefficient: 0.4), especially for the EV owners who live in detached house (correlation coefficient: 0.7) as shown in Figure 6b. This result shows that EV owners who make long trips charge large amount of energy with DC charging.

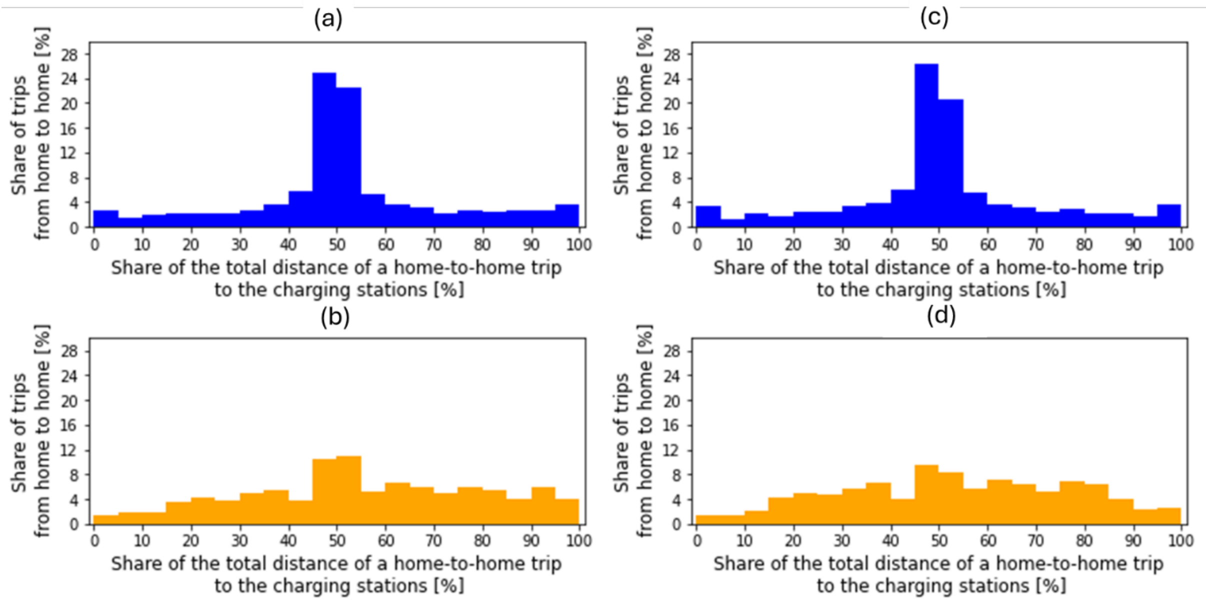

Figure 5: Share of the total driving distance of a home-to-home trip from leaving home to a charging station (other than workplace and vacation house) for (a) AC charging and (b) DC charging, and the same values for the trips from home to home with 100km or longer driving distance for (c) AC charging and (d) DC charging.

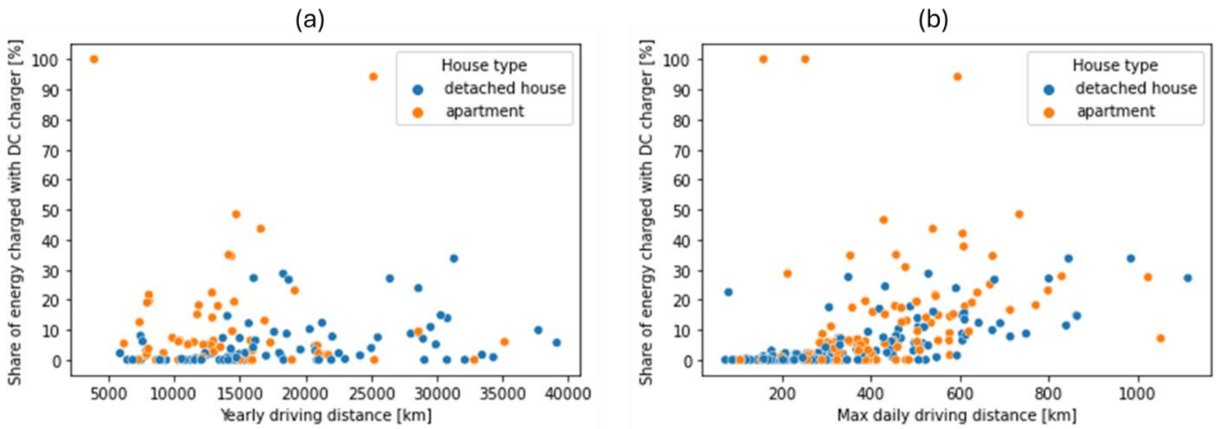

Figure 6: Share of energy charged with DC charger vs (a) yearly driving distance and (b) max daily driving distance for each EV owner by housing type.

From the result it is clear that the EVs are only charged for a fraction of the time they are parked. The time when EVs are parked but not charged can be used for charging flexibility. Figure 7 shows charged energy and parking duration for each parking event for charging at home (a) and at workplace (b). Each blue dot shows each parking event and orange colored line corresponds to charging at 3.0kWh/h. The parking duration at home is concentrated on 10-17 hours, most of which are overnight parking events (97%), while 43% of charging events at workplace are seen in the parking events with a duration for 7-10 hours. As shown in Figure 7a, 88% of the charging events require, theoretically, only 3.0 kWh/h or lower as the average charging speed at home. However, 86% of the EVs are charged at home with 3.0kW or higher, meaning that only a share of the parked time is used for charging. If an EV battery can charge from a charger with 9.0kW (11kW charging and some energy loss) for example, the charging power can be 1/3 of maximum power or the EV owner can choose charging time of 1/3 of the parking duration. Furthermore, half of the charging events (51%) require only 1.1kWh/h or slower average charging speed at home.

As shown in Figure 7b, 75% of the charging events require 3.0kWh/h or slower average charging rate at workplace although 74% of the EVs that are charged at workplace charged with 3.0kW or higher at workplace during the logging period. Furthermore, half of the charging events require only 2.1kWh/h or slower average charging rate at workplace.

From these results, we can conclude that there is a larger possibility for flexible charging time at home compared to workplace, although both places show large potential. The parking events at workplaces also have a large potential of smart charging and can play an important role, such as the storage of solar energy during the daytime, and can contribute to ancillary services.

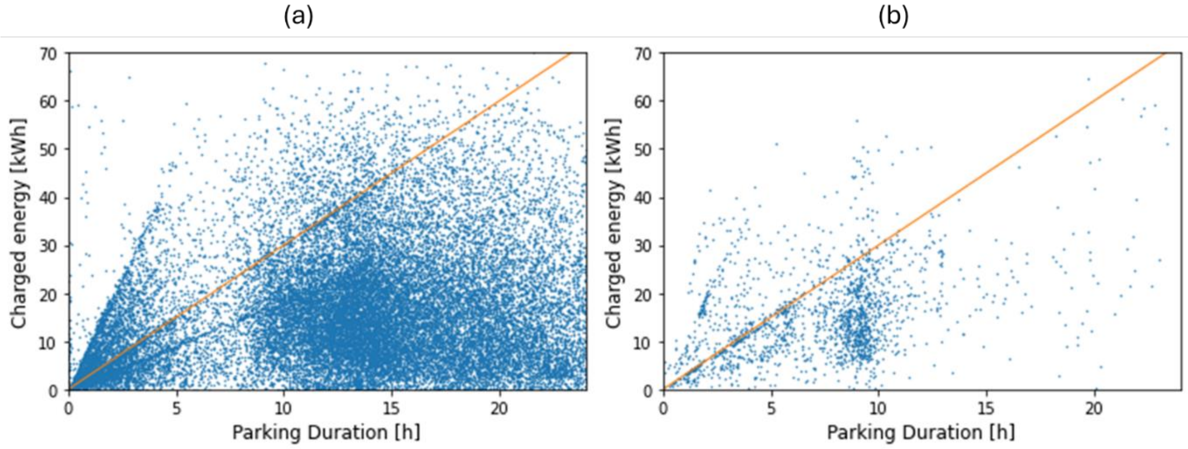

Figure 7: Charged energy and parking duration for each parking event with charging (a) at home and (b) at workplace. Each blue dot shows each parking event and orange line shows the line of 3.0kWh/h.

4 Conclusion

In summary, we conclude the following from the analyses of the measured pattern of driving, parking and charging of the EVs, as well as, from the survey to the EV owners.

- On average, 71% of energy is charged at home location, 4% at workplace, 4% at vacation house and 21% at other locations. According to the survey "other locations" is typically public chargers along roads/highways and in shopping centers.
- The energy charged at vacation houses and other locations than home and workplaces, is highest in July (i.e., double compared to November).
- The EVs belonging to category commuters tend to park at home shorter (9% shorter) and charge larger amount of energy at home (54% more), but charge similar amount of energy at the other locations.
- About half of the charging events with DC charging are, on average, made after driving 55% of distances from leaving home to returning home again.
- In half of the charging events at home and workplace, the charging rate could be lower than 1.1kWh/h and 2.1 kWh/h, respectively.

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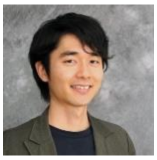
Presenter Biography



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