EVS35 Symposium
Oslo, Norway, June 11-15, 2022

Impact of battery developments on the future of charging infrastructure deployment

Rick Wolbertus[1], Edward Heath[1,] Renee Heller[1]
[1]*Amsterdam University of Applied Sciences, Faculty of Technology, Urban Technology, Energy & Innovation group, Weesperzijde 190, 1097 DZ, Amsterdam, The Netherlands*

Executive Summary

Developments in battery technology have made it able to increase the range of electric vehicles without increasing the price. To combat range anxiety among potential customers OEMs are expected to keep adding range in the near future. It is expected that this also influences the charging needs of these future EV drivers. This paper analyses charging behavior along the line battery sizes of vehicles using a database of more than 19.000 EV drivers and simulates different scenarios in battery size development to assess its impact on charging infrastructure planning. It is expected that increased battery size reduces the need for day-to-day charging and fast charging.

1 Introduction

Continuous improvement on batteries is the driving force behind increased adoption of electric vehicles. Due to these research efforts, prices of batteries have dropped significantly (Nykvist & Nilsson, 2015) which in term leads to longer ranged battery electric vehicles (Nykvist et al., 2019). Charging needs differ depending on the range and charging capacities and home charging opportunities of the electric vehicle driven (Wolbertus et al., 2020). The long-term implications of changes in battery development and policies regarding electric vehicles on the need for and type of charging stations are yet unknown.

Current charging infrastructure planning is based on simulation of charging needs by either translating driving patterns from gasoline vehicles and certain charging assumptions or analyzing charging patterns from current electric vehicles on the road. When defining the charging assumptions, a certain range and charging speed are assumed, but are considered static (often based on the most market offerings). When using charging data from electric vehicles to predict future charging demand it is assumed that the population of cars stays similar. Market announcements from major OEMs throughout the years however have shown an upward trend in EV ranges which likely is to continue into the future (Bloomberg NEF, 2021). Charging infrastructure planning therefore needs to account for differences in charging needs depending on battery size and charging power.

Besides technological improvements, market segmentation of electric vehicles, highly differs between countries. This is the result of different policies for the sales of electric vehicles. Differences include inclusion of Plug-in Hybrid electric vehicles and/or market caps on subsidies. Shift in subsidies can create different market dynamics (Wolbertus & van den Hoed, 2019) which in turn has consequences for charging needs. Policy makers should be able to account for the implications on the charging infrastructure side of EV sales policies.

This paper is the first to simulate different scenarios regarding EV battery development and policies on battery and plug-in hybrid vehicles. Using data on current EV drivers' charging behaviour, the number and type of charging infrastructure is determined for various scenarios.

1.2Literature review

Charging infrastructure planning studies tend to account for different vehicle battery sizes in some form. Many studies however assume a limited set of vehicles (Asamer et al., 2016; Kavianipour et al., 2021) which is presented as given. No substantial analysis of differences for this variable is given and often the publication date determines the type of vehicles that are included. Some studies take a more substantial approach by including all vehicles on the market (Olivella-rosell et al., 2014) but an analysis of the impact of this on the results is missing. Gnann et al. (2018) take a slightly different approach by assuming a single driving range that increases over time. The topic of increasing battery size seems to be noted by modellers, but an impact assessment or sensitivity analysis on this variable is missing.

Charging behaviour review studies tend to include differences between PHEV and FEV drivers (Chakraborty et al., 2019; Vermeulen et al., 2018)but differences in battery size of FEV drivers are missing or only include some models (Idaho National Laboratory, 2015). Early analysis of differences in charging patterns is emerging (Wolbertus et al., 2020), but an impact analysis on charging infrastructure design is missing. This study will be the first to provide a more systemic analysis of this topic.

2 Methodology

2.1 Data Collection

This dataset is charging card data from 19,420 EV drivers in The Netherlands. Data contains all charging sessions in which a charging card is needed to access the charging station in the year 2019. Data on the location, time and volume has been logged anonymously. The data also contains information about home charging stations as some employers would ask their employees to log this data to get a refund for their costs. The data additionally provides information about the type of charging station (private, public, semi-public, fast charging). A total of 1,160,283 charging sessions (94,5% of total) were used for the analysis after filtering for impossible (e.g. negative or >100 kWh) charging sessions or for faulty data (e.g. duplicates of missing time variables). A full description of the dataset can be found in (Wolbertus & van den Hoed, 2020).

Table 1 Data variables and examples

Variable	Example
RFID	60DF4D78
Address	Prinsengracht 767, Amsterdam
Start Connection Date Time	24-04-2015 13:56:00
End Connection Date Time	24-04-2019 17:14:00
Connection Time	2:18:00
Volume	6.73 kWh

The battery size of the EV driver is determined by the maximum charge that an EV driver has completed over the course of the dataset. To exclude any bias on the data due to drivers with a limited amount of data, only charging cards were included which had at least 10 charging sessions in the dataset. Battery size was cut into groups of 0-16 kWh (plug-in hybrid), 16-30 kWh, 30-

50kWh, 50-70kWh & 70+ kWh.

2.2 Scenario development

Scenarios are developed together with relevant stakeholders in the field such as municipal governments and chargepoint operators. Scenarios are developed along two axes , battery size and home charging share. A high and low scenario are used for the battery size developments and three different scenarios are used for home charging (low-medium-high). These are expected to be representative of charging needs in different countries varying from low density to high density urban areas. The specific scenarios can be found in Table 2.

Table 2 Scenarios used for simulation

Scenario	A	B	C	D	E	F
Plug-in hybrid (0-16 kWh)	30%	10%	30%	10%	30%	10%
FEV 16-30kWh (Small)	30%	10%	30%	10%	30%	10%
FEV 30-50 kWh (Medium)	20%	20%	20%	20%	20%	20%
FEV 50-70 kWh (Large)	10%	30%	10%	30%	10%	30%
FEV 70+ kWh (XLarge)	10%	30%	10%	30%	10%	30%
Home Charging availability	75%	75%	50%	50%	25%	25%

To simulate the different scenarios EV drivers are randomly sampled from the entire database according to the distributions within each scenario. Home charging availability is also seen as an attribute of the EV driver and therefore final results of the simulation could show a different distribution of home and away from home charging distributions. To simulate 1.000 EV drivers are sampled from the database of which the charging patterns are analyzed. This limited amount is used to prevent resampling the same users from user groups that are limited in size.

3 Results

3.1 Descriptive analysis

In terms of charging frequency, it can be noted that cars with larger batteries (>50kWh) charge about 0.5 times less a week compared to full electric cars with smaller batteries (< 50kWh) regardless of access to private charging access. The effect is more substantial when comparing PHEV owners with private charging access to FEV drivers with large batteries. PHEV owners charge 1.5 charging sessions more a week.

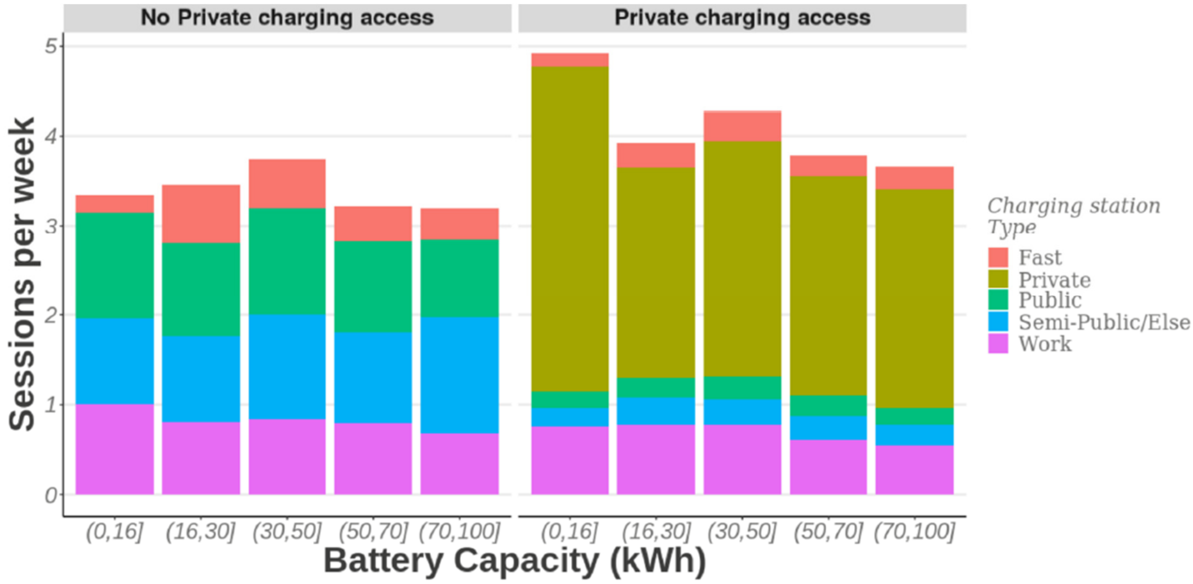

Figure 1 Charging sessions per week for different battery sizes and access to private charging

Figure 1 also shows that the full electric small battery (16-50kWh) vehicle owners are more reliant on fast charging than other car owners. This is especially relevant for owners that do not have private charging access. Charging security and range anxiety are expected to be highly relevant aspects for these drivers. These drivers nearly charge once a week at fast charging stations, while this is only once every 5 to 6 weeks for EV drivers with large batteries and private charging access.

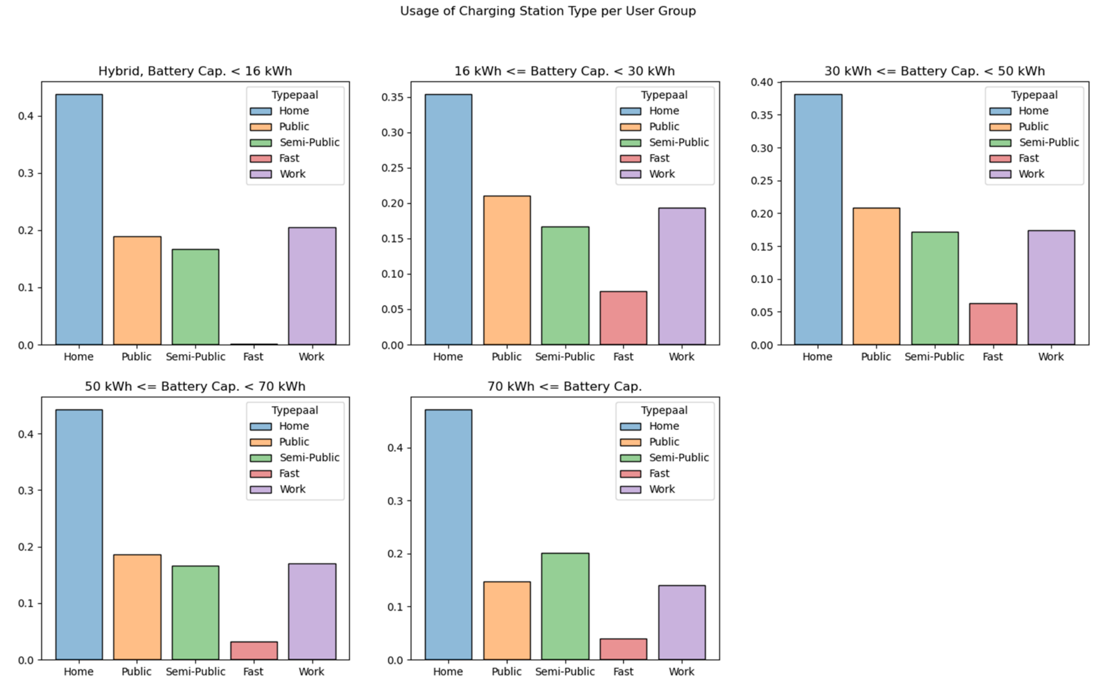

Figure 2 Charging Station Type distribution for different battery size groups

A similar trend can be seen if the charging sessions per charging station are plotted as a share of the total charging sessions (Figure 2). Reliance on other public charging stations besides fast charging is also highly relevant for those driving an electric car with batteries below 50 kWh. This group of drivers also have many more short charging sessions (Figure 3), both at fast charging and (semi-)public stations. Most likely to fill the battery to make it to next locations. Especially drivers with a larger battery only display longer charging sessions, overnight (10-16 hours).

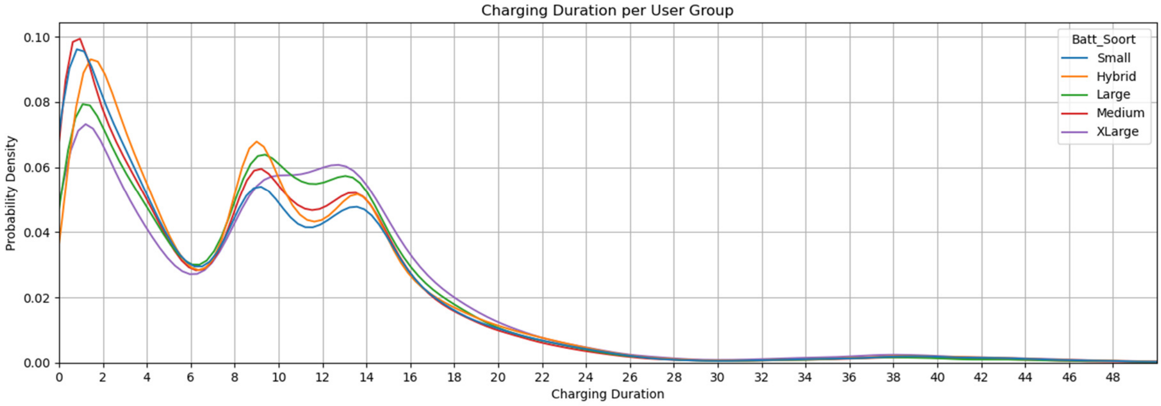

Figure 3 Charging sessions duration for different battery size groups

Analysis of starting times of the different battery size groups in Figure 4 shows that PHEV drivers are highly habitual chargers mainly charging at work (start around 8 AM) and at home (start 5PM-8PM). This could be explained by the fact that they do not have any range anxiety and charging is considered a convenience, done at locations where they know charging points are available. Notable is also the reduction of office charging from EVs with increased battery size. Overnight charging is sufficient for those users with larger batteries. It reduces the need for charging at other locations.

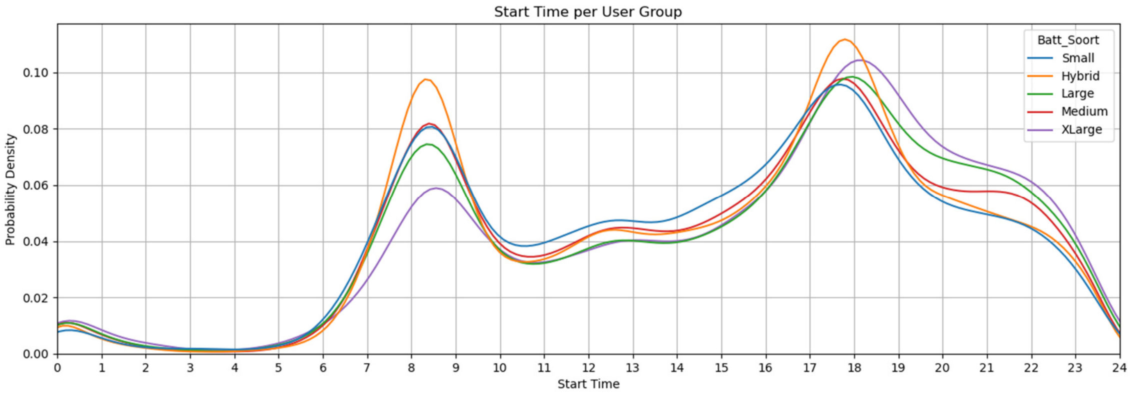

Figure 4 Start time distributions of charging sessions for EV drivers with different battery sizes

3.2 Simulations results

3.2.1. Charging station timing

Each scenario was simulated using 1000 randomly selected EV drivers for each group. Aggregated results for each scenario are displayed in the figures below. Results (Figure 5) show some significant differences between the scenarios on starting time depending on the composition of the fleet and share of home charging. Scenario A (Small batteries, high home charging) & E (Small batteries, low home charging opportunity) show the most striking results as they completely differ on the timing of the charging sessions. A lack of home charging results in a much higher share of office charging (~50% higher). Scenario B, in which home charging opportunities is common, but battery sizes are large shows the reverse effect of increased battery size on office charging. Starting times remain focused at late afternoon and early evening. Overnight charging is not done at private charging stations but is shifted towards public stations near the home location.

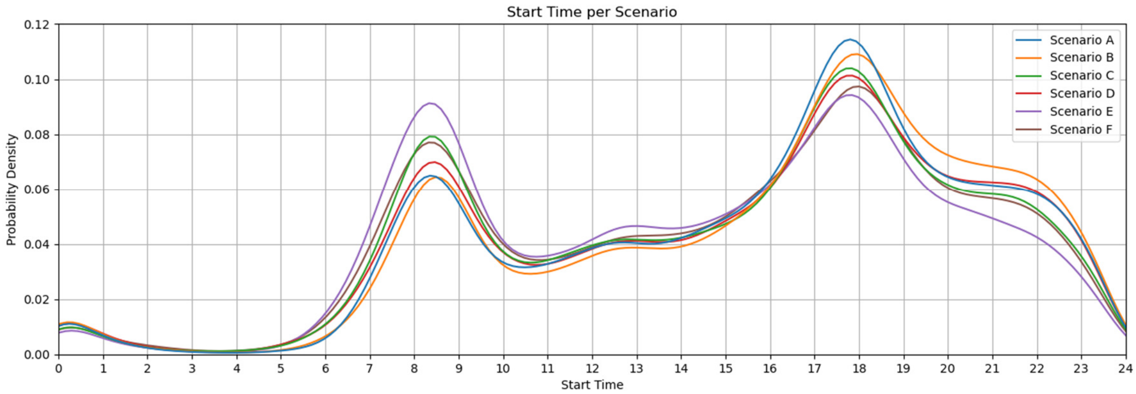

Figure 5 Start Time Distribution per Scenario

These results can also be seen in Figure 6, which shows the distribution of connection times at charging stations. Scenario E shows more charging times 8-10 (office charging) but fewer overnight sessions. Remarkable is that this also results in more very short charging sessions concentrated at fast charging stations.

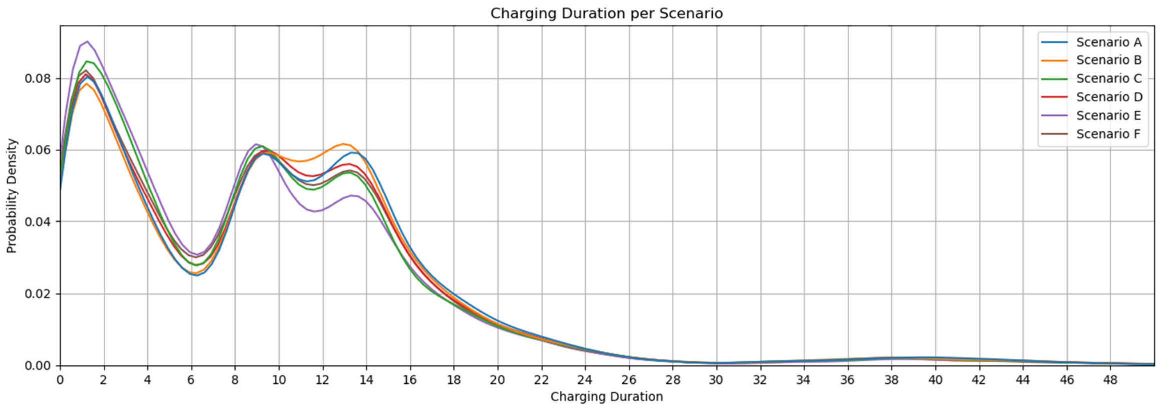

Figure 6 Connection duration distribution per Scenario

3.2.2. Energy

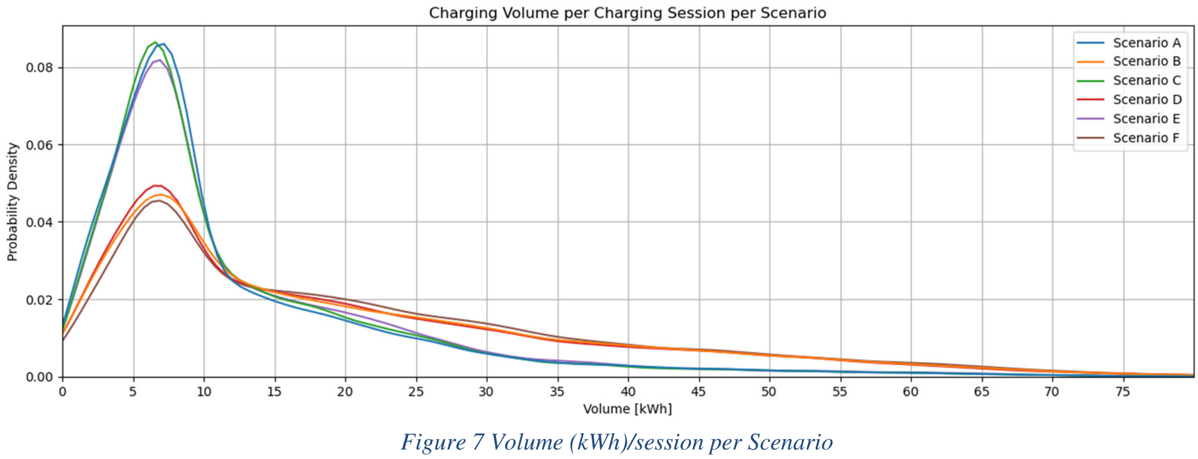

Figure 7 Volume (kWh)/session per Scenario

In terms of volume charged (Figure 7) there is a clear split in scenarios with smaller batteries and those with larger batteries. Especially PHEV vehicles only charge a limited amount of energy per sessions, which results in a clear peak around 5-8 kWh. EVs with larger batteries show a more widespread distribution of energy charged. Perhaps less expected is that the different scenarios also result in different loads on the electricity grid (Figure 8). Scenarios with smaller battery sizes (scenario A/C/E) also charge much slower. This would lead to lower grid peak demand compared to scenarios which larger batteries in which the cars more often charge at 3.7 or 11kW.

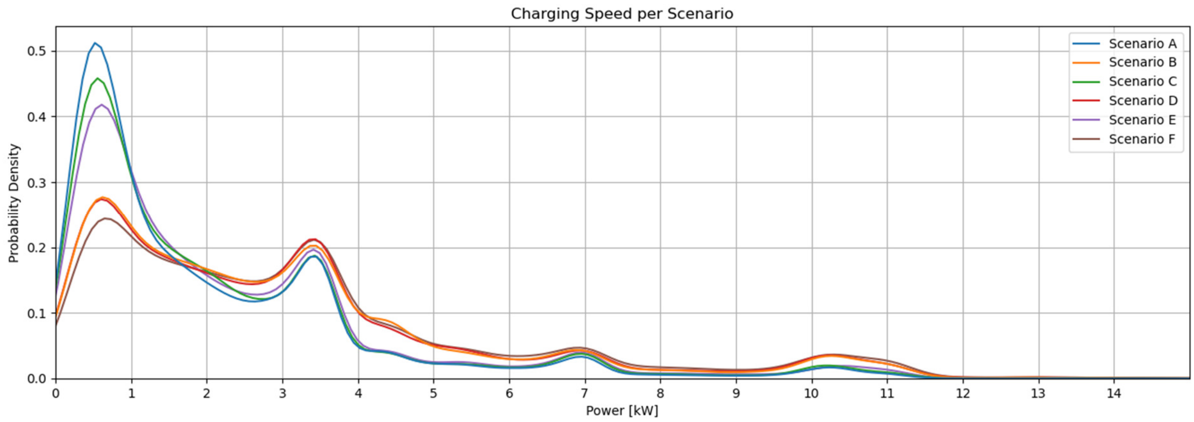

Figure 8 Charging speed distribution per Scenario

3.3.3 Location choice

In terms of location choice, it can be seen that availability of home charging leads to more charging sessions at fewer different charging stations. Increased home charging availability leads to less reliance on other public charging stations. In general, bigger batteries lead to fewer charging stations, but the differences become smaller as home charging availability decreases. Installment of public charging is less needed in countries/locations with a high share of home charging and which have stimulated the sales of cars with large batteries.

Table 3 Location choice results of simulation

Scenario	Sessions/week/user	Share of sessions at most used station
A (Small bat. – High Home)	2.02	74.3%
B (High bat. – High Home)	1.81	72.7%
C (Small bat. – Medium Home)	1.78	68.5%
D (High bat. – Medium Home)	1.66	66.4%
E (Small bat. – Low Home)	1.59	59.9%
F (High bat. – Low Home)	1.53	61.4%

Not only the need for regular (semi-) public charging decreases but also the need for fast charging. For the scenarios with bigger batteries there is a decrease in fast charging demand (60-70%). (Figure 9. In general, the figures show a clear shift away from home charging towards (semi)-public solutions and partly work to replace the opportunity to charge at home. Each of these three solutions about a third of the demand that is otherwise fulfilled by private home charging. As could be seen from figure 5, the timing of charging sessions does not differ as much as the location choice, indicating that a similar use pattern persists (a small shift towards more workplace), but the private home charging station is substituted with public alternatives.

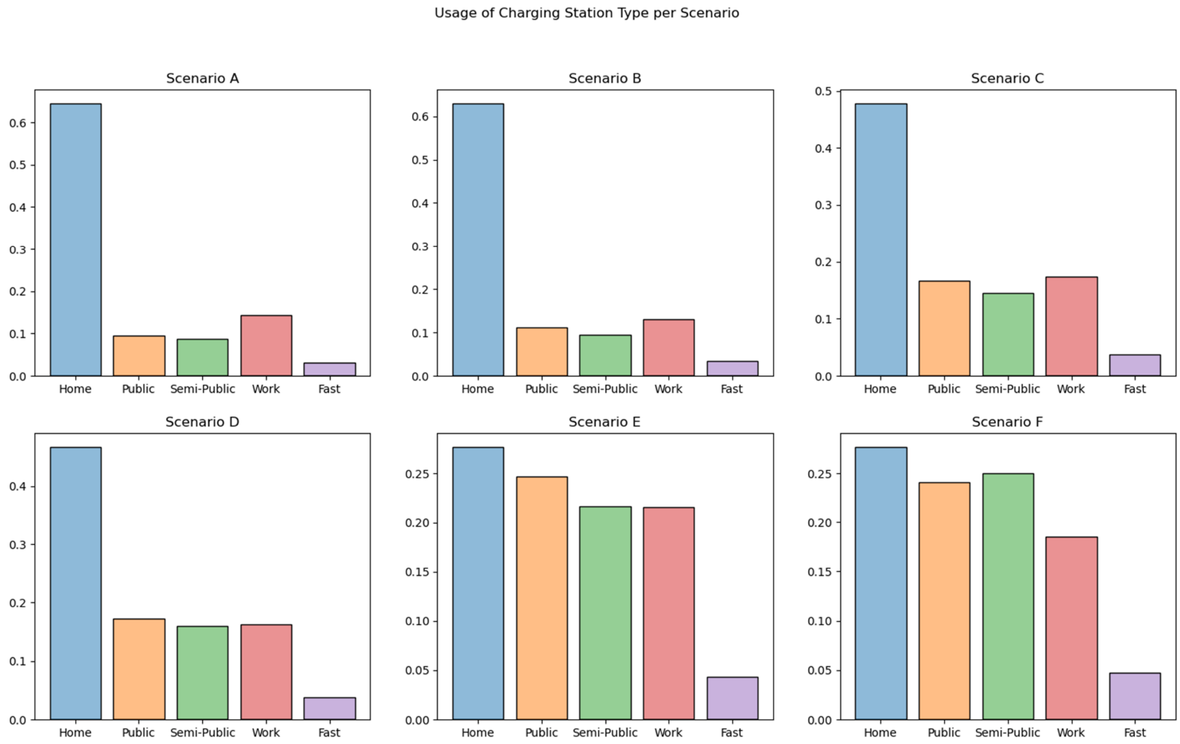

Figure 9 Distribution of charging station use per scenario

4 Discussion & conclusions

Through the simulation of different scenarios on EV battery development and home charging availability this paper has provided insights into different future scenarios and corresponding charging infrastructure needs. It is clear that depending on technological advancements, choices from OEMs and policy decisions these can have very different outcomes.

4.1 Charging infrastructure design

Simulations have shown that home charging availability is the most important drivers for charging infrastructure design. A lack of this availability in more dense urban areas has to be replaced by (semi-)public alternatives and partly by private initiatives at the workplace. A lack of private charging also slightly increases the need for fast charging as charging security at public stations is less than at private.

Increased battery size lowers the reliance on workplace charging, as the charging frequency decreases. A single charge overnight at (semi-)public locations or private is sufficient for EV drivers with a larger battery. A larger focus on PHEVs would increase the number of charging sessions at various locations (with exception of fast charging) and would increase the need for charging points at the workplace. Differences could vary between 10-15% in the total number of charging points needed.

4.2 Charging point operator business case

The composition of the EV fleet can also have implications for charing point operators (CPOs). A shift towards larger batteries could imply a larger transaction per charging sessions, whilst connection time at charging points remains rather similar. As well, due to the decrease in the charging frequency several users could share public charging points which in terms leads to a greater turnover at the same station.

Fast charging operators however need to be careful about this trend as EVs get larger ranges or if a focus on PHEV cars arises. This could substantially reduce the number of charging sessions at these locations and it would only be viable to operate them along routes that are used for long distance travel. CPOs are therefore advised to monitor the market closely and anticipate on policy changes and OEM announcements of cars coming to the market.

4.3 Grid operator consequences

The timing and the average load of the charging session also differ quite a lot depending on the battery size which could have consequences for grid operators. A shift towards larger batteries implicates a higher peak during the late afternoon- early evening period when the grid is already at peak capacity. A shift away from workplace charging would implicate a lower use of solar energy during the daytime. Grid operators should therefore focus on stimulating this charging despite this not fitting current usage patterns of EV drivers with larger batteries or invest in smart charging technologies to make use of idle time during the night time. Additionally, grid operators have to monitor trends of increasing load per vehicle as this also increases with battery size and a switch away from plug-in hybrids.

4.4 Policy implications

Policy makers have to take into account the consequences for charging infrastructure design when proposing sales related measures. Interventions such as focussing solely on full electric vehicles instead of including plug-in hybrids or setting a cap on the maximum price of vehicles will also impact the design on the charging infrastructure. This is also related to the type of area (urban vs. rural) as the availability of home charging is an important mediator. Based on these results it is therefore necessary that policy makers come up with integral plans for the electric vehicle market that includes charging infrastructure.

Literature

Asamer, J., Reinthaler, M., Ruthmair, M., Straub, M., & Puchinger, J. (2016). Optimizing charging station locations for urban taxi providers. *Transportation Research Part A: Policy and Practice*, *85*, 233–246. https://doi.org/10.1016/j.tra.2016.01.014

Bloomberg NEF. (2021). *Electric vehicle outlook 2021*.

Chakraborty, D., Bunch, D. S., Lee, J. H., & Tal, G. (2019). Demand drivers for charging infrastructure-charging behavior of plug-in electric vehicle commuters. *Transportation Research Part D: Transport and Environment*, *76*, 255–272. https://doi.org/10.1016/j.trd.2019.09.015

Gnann, T., Plötz, P., & Wietschel, M. (2018). Can public slow charging accelerate plug-in electric vehicle sales? A simulation of charging infrastructure usage and its impact on plug-in electric vehicle sales for Germany. *International Journal of Sustainable Transportation*, *0*(0), 1–15. https://doi.org/10.1080/15568318.2018.1489016

Idaho National Laboratory. (2015). *Plugged In: How Americans Charge Their Electric Vehicles*. 1–24. https://avt.inl.gov/sites/default/files/pdf/arra/SummaryReport.pdf

Kavianipour, M., Fakhrmoosavi, F., Singh, H., Ghamami, M., Zockaie, A., Ouyang, Y., & Jackson, R. (2021). Electric vehicle fast charging infrastructure planning in urban networks considering daily travel and charging behavior. *Transportation Research Part D: Transport and Environment*, *93*. https://doi.org/10.1016/j.trd.2021.102769

Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. *Nature Climate Change*, *5*, 329–332.

Nykvist, B., Sprei, F., & Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. *Energy Policy*, *124*(September 2018), 144–155. https://doi.org/10.1016/j.enpol.2018.09.035

Olivella-rosell, P., Villafafila-robles, R., & Sumper, A. (2014). *Probabilistic Agent-Based Model of Electric Vehicle Charging Demand to Analyse the Impact on Distribution Networks*. 1–26. https://doi.org/10.3390/en8054160

Vermeulen, I., Helmus, J. R., van den Hoed, R., & Lees, M. (2018). Simulation of Future Electric Vehicle Charging behaviour - Effects of transition from PHEV to FEV -. *Electric Vehicle Symposium 31*, 1–5.

Wolbertus, R., & van den Hoed, R. (2019). Plug-in (Hybrid) Electric Vehicle adoption in the Netherlands: Lessons learned. In M. S. M. Contestabile, G. Tal, & T. Turrentine (Eds.), *Driving Electric Cars - Consumer adoption and use of plug-in electric cars*. Spring.

Wolbertus, R., & van den Hoed, R. (2020). Fast charging systems for passenger electric vehicles. *World Electric Vehicle Journal*, *11*(4), 1–11. https://doi.org/10.3390/wevj11040073

Wolbertus, R., Wolbertus, R., & van den Hoed, & R. (2020). *How do EV drivers adapt their charging behavior to battery size and charging capabilities? A systematic data-driven analysis IDO-laad View project Future Charging View project How do EV drivers adapt their charging behavior to battery size and charging capabilities? A systematic data-driven analysis*. https://www.researchgate.net/publication/341204921

Presenter Biography

Rick Wolbertus is a researcher at Amsterdam University of Applied Sciences (AUAS). He holds a PhD on charging behaviour of electric vehicles. His research topics are charging behaviour, the effect on the electricity grid, and the effect of charging infrastructure on EV sales. He leads the four-year Future Charging research project.

Renée Heller is professor Energy & Innovation at the Amsterdam University of Applied Sciences. She holds a PhD from Utrecht University and has been involved in numerous projects in the field of sustainable energy. Her group is involved in many projects around electric mobility and grid integration.

Edward Heath is a researcher at the Energy & Innovation group at the AUAS. His main topic include energy modelling and grid integration of electric vehicles. He holds a masters' degree from Delft University of Technology during which he researched combining PV and EV charging.