Exploring electric vehicles owner's preferences and experiences with controlled charging: a mixed-method case study in the Netherlands

Author(s)
Gardien, Lotte; Refa, Nazir ; Tamis, Milan

DOI
10.5281/zenodo.4023309

Publication date
2020

Document Version
Final published version

Published in
33rd World Electric Vehicle Symposium & Exposition (EVS33) Peer Reviewed Conference Papers

EVS33 Symposium
Portland OR, USA, June 14 - 17, 2020

Exploring electric vehicles owner's preferences and experiences with controlled charging: a mixed-method case study in the Netherlands

Lotte Gardien[1], Nazir Refa[1], Milan Tamis[2]

[1]*ElaadNL,Utrechtseweg 310 B42, 6812 AR Arnhem, Netherlands, lotte.gardien@elaad.nl*

[2] *Amsterdam University of Applied Sciences, Weesperzijde 190, 1000 BA Amsterdam, Netherlands*

Summary

Controlled charging of electric vehicles (EVs) can be used to avoid peaks in the power grid by limiting, and shifting the EV power demand during peak hours. This paper presents results on user preferences and experiences regarding controlled (or smart) charging of EVs via home chargers. Data is derived from a controlled charging demonstration project, in which 138 Dutch households participated. With the availability of an override button, households were assigned either a static or dynamic charging profile. Using surveys and interviews, data was collected on three topics: (1) controlled charging, (2) the override button and (3) financial motivations.

Keywords: smart charging, user behaviour, case-study, charger, power management

1 Introduction

We define controlled charging as a charging profile where charging speed for an EV is adjusted by the aggregator on behalve of the grid operator. Controlled (or smart) charging can be used by the grid operator to avoid energy peaks in the grid by curbing electricity demand of private EV charging points [1] , avoiding costly grid investments, as the overall electricity demand rises with every new EV. Charging speed is adjusted through Home Energy Management Systems (HEMS) connected to the private charging points. The research presented here is derived from the demonstration project with controlled charging called "Flexible charging behind the meter''. The project is a joint initiative of organizations *Maxem* (HEMS developer), *Enpuls* (concept developer), *Enexis Netbeheer* (grid operator) and *ElaadNL* (smart charging innovation centre), with user/behavior research conducted by the Amsterdam University of Applied Sciences.

The demonstration project consisted of 138 households with a private charging point and either a Battery Electric Vehicle (BEV) or a Plug-in Electric Vehicle (PHEV). The experiment with controlled charging lasted a year and households were assigned one of the controlled charging profiles: a static profile or a dynamic profile. The static profile adjusted charging speeds between 17:00 and 22:00, resulting in slower charging during evening peak hours. The dynamic profile adjusted charging speeds based on the predicted available capacity of the grid, which could result in reduced charging speeds even outside of the evening peak.

Users from both charging profile groups were able to "override'' the controlled charging by making use of the emergency button within the app connected to the energy management system, overriding any active charging profile and immediately charging the vehicle at regular charging speeds. This override was automatically reset after 12 hours. Aditionally, half of the participants received a financial reward for providing flexibility to the grid operator. This reward depended on the use of the override function to temporarily cancel charge management. Each participant in the incentive-group was given a budget of €50. They could use the override function twice a month without financial consequences. With every third or more overrides, €1 per override would be deducted from their budget. This allowed researchers to study the influence of a financial incentive on user behavior.

This paper examines fundamental user preferences and user experiences with controlled charging technology systems. The aim of the consumer research was to explore the experience and user preferences of controlled charging within the setting of the demonstration project and collect user information on how the controlled charging system coud be improved upon. Insight into user preferences and user experiences with controlled charging technology systems is a prerequisite for upscaling, as user experiences and preferences influence the effective use of the technology as a solution for grid alleviation. Using a mixed-method approach, user preferences and experiences are explored within the context of this demonstration test on three different topics: (1) controlled charging, (2) the override button and (3) financial motivations. Additionally, on a quantitative level, user intention to make use of controlled charging after the demonstration experiment was measured.

2 Literature review

Consumer research is essential for developing charging programmes aimed at optimizing grid stability while simultaneously satisfying EV owners' charging needs, whether this is done through smart charging, controlled charging or vehicle to grid [2]. Essential with these charging programmes is ensuring the EV has a minimum charge based on user preferences [3, 4]. Although some research has been done on incentivizing EV drivers for utility-controlled charging [3], which could be done through cost incentives, very little research has been conducted on user preferences and experiences with demonstration projects that tests controlled charging. Therefore, in this paper we focus on practical research rather than literature research.

3 Methodology

For the behavioral research a mixed-method research approach was used, utilizing two surveys and 20 interviews to collect data. The two surveys were distributed to all 138 participating households. The first measurement was sent prior to the start of the experiment (August 2018) and resulted in N=91 responses. The aim of the first measurement was to collect demographic information, as well as collect self-described driving and charging behaviour. Additionally, motivations (to drive electric and participate in the experiment), expectations (of controlled charging) and attitude (towards controlled charging and a (hypothetical) financial incentive) were measured. The second measurement was sent a few days after the termination of the experiment (September 2019) and resulted in N=89 responses. This measurement recollected information on the attitude (towards controlled charging and a financial incentive), as well as information on experience with controlled charging during the experiment and the intention to keep making use of controlled charging. Additionally, respondents who did not fill out the first measurement were asked to provide some demographic information in the second measurement. In total, demographic information was collected for 103 respondents. Halfway through the experiment (March and April 2019), interviews were conducted over the phone with 20 respondents in total, 10 from each charging profile. Interviews focussed on the respondents' current experience with controlled charging, usage of the override button, the extent to which peak and off-peak hours where taken into account when charging and the attitude towards controlled charging.

For a better understanding of the total demonstration project it is useful to briefly look at the broader research design and method. To investigate the impact of charge management on the network, the charge points of the participants in each group were controlled throughout one year. During this period, the degree of constraint of the charge points was changed regularly by varying the 'business as usual' available network capacity. This enabled researchers to study the influence on the peak load and the extent to which the peak load could be reduced without causing inconvenience for the end user.

To determine the impact of charge management on the network, the researchers compared the network load with and without charge management. This reveals the extent to which the network's peak load is reduced. To achieve this, the researchers measured regular domestic electricity consumption and the electricity consumption of each charge point separately at 15-minute intervals for each household. Adding all individual measurement data per group enabled the researchers to simulate the total load of the (virtual) network.

When charge points are constrained, this reduces the peak load of the network. For each charge point, it is possible to estimate the amount of energy that was curtailed (the "avoided" or "shifted" energy). This is the specific amount of energy with which the network would have been loaded if no constraint had been applied. Knowing this enables us to estimate the peak load of the network *without* constraint and compare it to the electricity consumption that has been measured *with* constraint. This reveals the extent of peak reduction caused by charge management. Fig. 1 illustrates this principle.

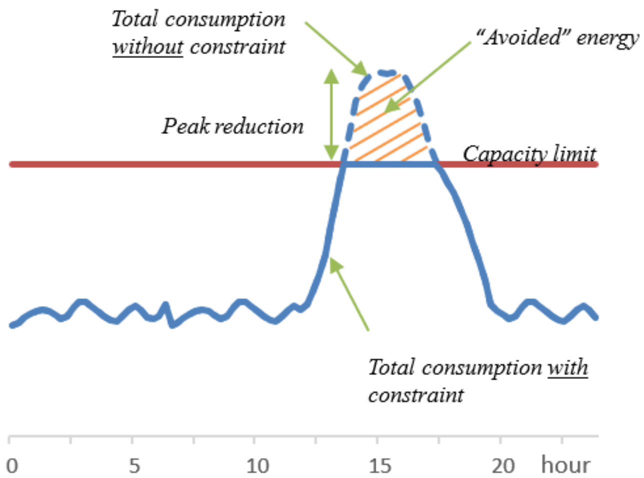


Figure 1: Determining how charge management reduces peak load

4 Results

4.1 General description of the participants and charging behavior

Demographic information was collected of 103 respondents: 98 men and 5 women. Their average age is 49 years, with the youngest respondent being 25 and the oldest 79. Respondents mainly work in IT (30%) and healthcare (15%). To a lesser extent, respondents work in consultancy (7%), the financial sector (5%), construction (4%) and the energy sector (4%). Half of the respondents live in a detached house (50%), followed by a semi-detached house (28%) or a terraced house (17%). 69 households (67%) have solar panels on their own home, and 19 households (18%) have a heat pump. These 19 households also all have solar panels.

100 respondents drove a BEV (versus 3 with a PHEV), with 79 driving either a Tesla Model S or Model X. The reasons for purchasing an electric vehicle are mainly sustainability (82x), financial benefits (75x), interest in innovation (74x), preparation for the future (25x) and driving characteristics (64x). Respondents could indicate multiple answers.

The average mileage per year was 30.601 kilometers. This is more than twice the national average in the Netherlands: in 2017 an average Dutch passenger car drove 13,000 kilometers. Most respondents drive their EV seven days a week. On average, the EV is used six days a week. Respondents' vehicles were mainly bought through business purchase structures (54%) or business lease structures (34%). Private purchase (10%) or private lease (3%) are less common.

EVs were on average charged 4 times a week. Once connected to the home charger, EVs were on average connected for 9,7 hours, usually overnight. 94 of the 103 respondents regularly charge elsewhere, mostly at (Tesla) fast chargers, charging points at work or public charging points at destinations. When asked at what time respondents start a charging session at home on average, five categories could be identified based on the answers (N=89). Fig. 2 gives an overview. 28% of the respondents mention that they start a charging session during the evening peak hours (17:00 - 20:00). 56% of the respondents start their charging session after the evening peak hours. Only 3% indicates they start a charging session before the start of the evening peak hours. 12% of the respondents reported charging at home at varying times.

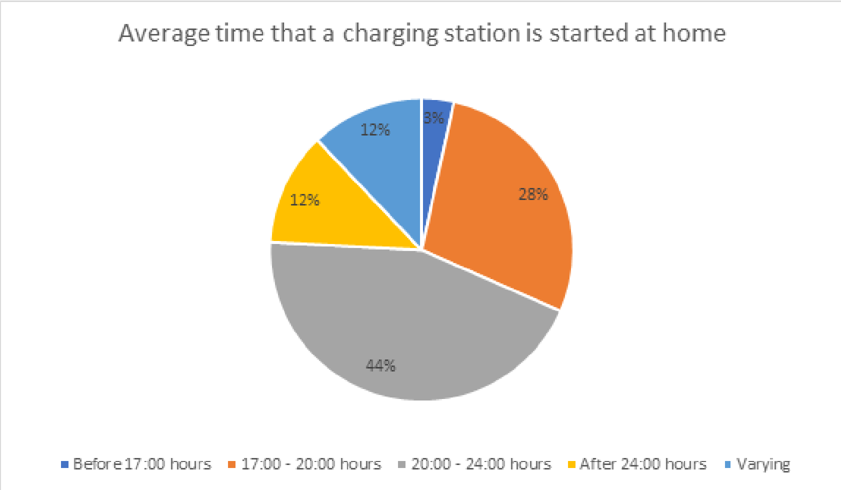


Figure 2: Average time that a charging session is started at home

16% (14 respondents) point out that they have changed their charging behavior since the start of the pilot with charge management. These respondents charge more often in the evening or night, charge more often at work, on the road or at other locations or charge more often during the day.

4.2 Participants on charge management

The research (N=89) reveals the following findings: 52% (46 respondents) noticed that charge management was applied. Of the respondents who did notice charge management, 59% were in an experiment group with a static control profile, 35% were in an experiment group with a dynamic control profile, and for 7% the control profile is unknown. Respondents mentioned that they mainly noticed charge management during the EV's charging session. They noticed the EV charging more slowly or taking longer to charge, or they noticed that the EV was charged with less power. 7% of the 46 respondents indicated that the vehicle occasionally stopped charging or that several charging sessions took place in one night.

55% noticed the charge management especially in (and at the beginning of) the evening, but also during the day (17%), in the afternoon (15%), in the night (7%) or in the morning (4%). 14% sometimes encountered problems because the vehicle was insufficiently charged due to charge management. Respondents mostly reported using the override function when this occurred. Additionally, one respondent charged at a Tesla supercharger, another respondent charged at the destination. Three respondents encountered problems due to technical reasons.

To measure the attitude towards charge management, respondents in both surveys responded to eight statements about charge management, such as: "Charge management of electric vehicles is a suitable solution for preventing an overloaded energy network" and "I feel the need to contribute to a stable energy network." Respondents rated these statements on a Likert scale from 1 (fully disagree) to 7 (fully agree). The average scores of the first and second survey were respectively 5.5 and 5.3. The difference between the scores is so small that no conclusion can be reached. The average score means that there is a predominantly positive attitude regarding charge management. Notably, the statement "I want to be able to interrupt the charge management at all times, so my electric vehicle can charge at regular speed" clearly scores the highest (6,25) and shows that respondents consider the possibility of interrupting charge management to be very important.

No significant differences were found in the attitude towards charge management between the four experiment groups.

29% of the 89 respondents of the second survey wanted to receive more information about charge management during the pilot. Information that respondents found lacking during the demonstration project was information on when and to what extent controlled charging had been applied.

When we complement these findings with the acual data results, we see the following. Fig. 3 shows the relative peak load reduction during the period with maximum constraint (April/May 2019). The relative peak load reduction has been ordered from high to low, resulting in a duration curve. For the dynamic signal groups, a peak load reduction of up to 40% has been achieved, and for the static signal groups, even up to 50%. A stricter constraint had no further effect on the peak load, because during this pilot, the charge points were given a guaranteed minimum available capacity of 6 ampere (A). That is because current standards between charge points and EVs do not allow for a charging current below 6 A. Values below 6 A cause the EV to stop charging, which causes an inconvenience to the end user.

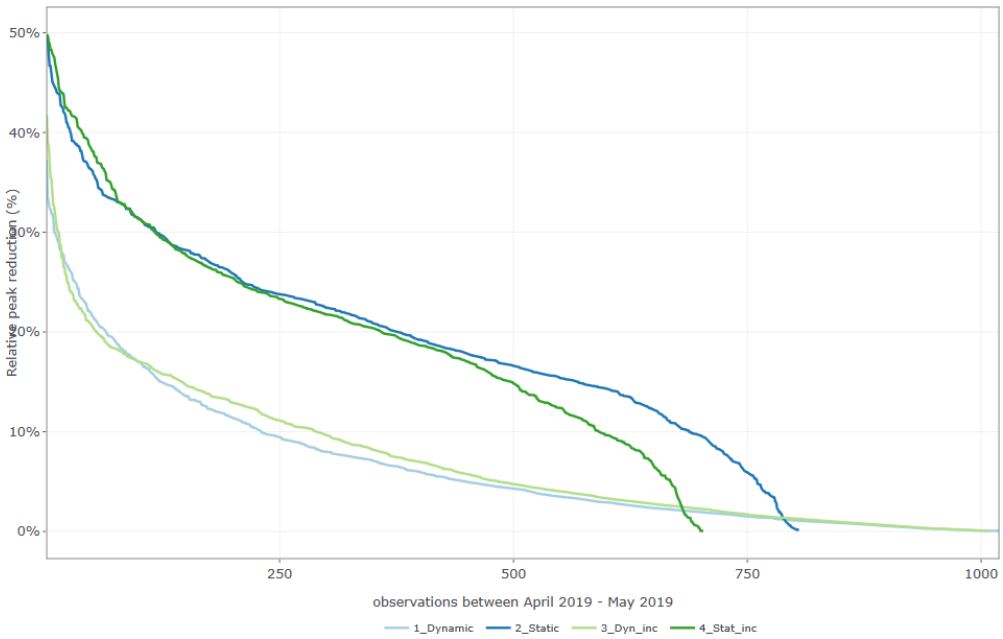


Figure 3: Duration curves of relative peak load reduction with maximum constraint

The results in Fig. 3 suggest that charge management for the static signal groups is more effective than for the dynamic signal groups, because the peak load reduction of the static signal groups is larger. However, a constraint applied between 17:00 and 22:00 does not actually lead to a reduction of the peak load. In that scenario we see a certain reduction of the load for the static signal groups, but the *peak* load is not affected, or it could even be increased by shifting energy from the constrained to the unconstrained time period.

4.3 Participants on the override button

The degree of use of the override function, to cancel charge management for a maximum of 24 hours, can be seen as a sign of the potential inconvenience caused to the pilot participants and of the level of acceptance of charge management. It would seem logical that the stricter the constraint, the higher the number of overrides. However, as Fig. 4 shows, for the dynamic signal groups there is no significant correlation between the number of overrides and the value of the setpoint. The same was observed for the static signal groups.

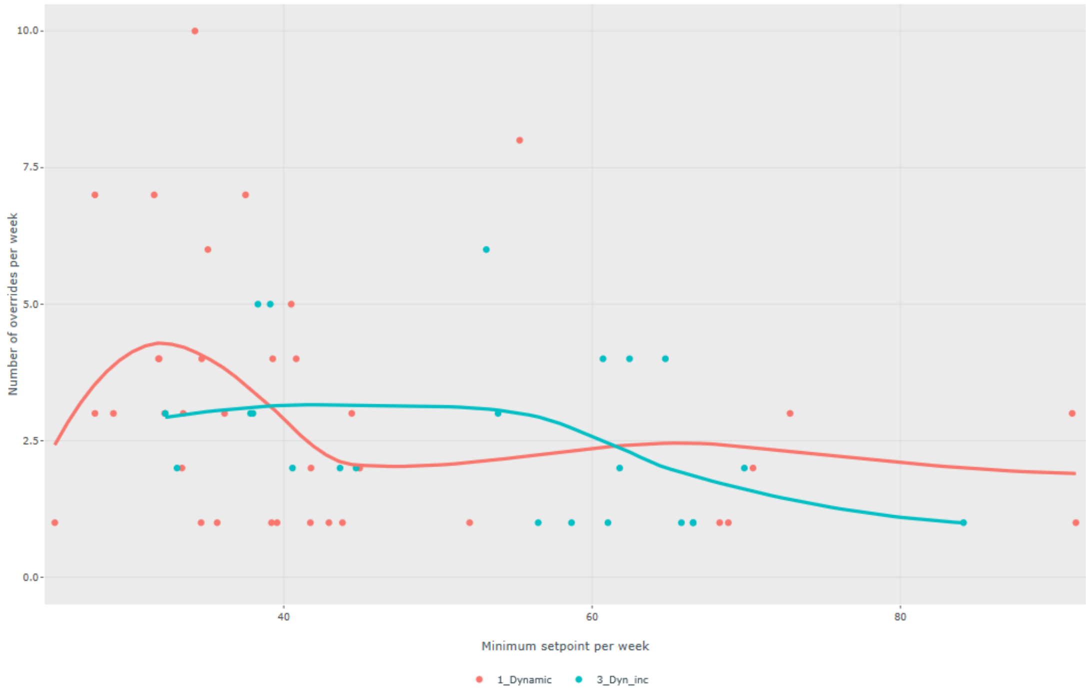


Figure 4: Correlation between the number of overrides and setpoint for the dynamic signal groups

This means that the use of the override function is triggered by aspects other than the strictness of the constraint. In other words: changing the constraint does not result in other levels of (in)convenience related to charging the EV to the point where participants would use the overrule funtion. The results of the behavioral research shed more light on this.

When participants (N=89) were asked if they were aware of the override function, 87% answered that they were familiar with this function. For 18%, it was unclear how the override function should be used. In the second survey, 63% (56 respondents) said they did not use the override function during the pilot period. 16% (14 respondents) used the override function because of curiosity or to test its function. Occasionally, the override function was used either to check the correct settings, as a mistake, because there were problems with charging or because of other technical problems.

Notably, almost half of those interviewed indicated that the override option was essential for their participation in the project. One interviewee said, "I would not have joined this pilot if I did not have the choice to override charge management." In addition, half of the interviewees thought the override option was a good and useful option, lowering the threshold for participation and making it less stressful. A minority of the respondents thought the button was a good addition, but not necessary.

Although the presence of the override button was perceived as essential, few pilot participants experienced inconvenience by controlled charging, as the majority of respondents started charging their vehicle after peak hours.

4.4 Participants on financial incentives

Though we can see some minor differences between the groups with and without financial incentive, there are no direct differences that can logically be traced back to the financial incentive. Therefore, it can be concluded that the financial incentive had no observable influence on the behavior of the participants and thus the network load. This will now be further explained.

In the two surveys eight statements were presented about a financial incentive in relation to charge management, such as, “A financial incentive makes it more attractive for me to make my electric vehicle available for charge management” and “I do not need to receive a financial incentive for my contribution to a stable electricity network.” To measure whether the participants’ attitude would change, these questions were posed both before and after charge management was applied. The average score of 5.4 on a scale from 1 (negative attitude) to 7 (positive attitude) shows a predominantly positive attitude towards the financial incentive. The difference in this score between the first and second survey is negligible.

Of the 48 respondents who received a financial incentive and completed the second survey, 23% (11 respondents) indicated they had taken the financial incentive into account when considering whether to use the override function or not. Eight of these respondents indicated that they did not use the override function during the pilot.

Respondents were also asked what they thought of the level of financial incentive (N=48). 27% indicated that the level of financial incentive was too low, while 69% indicated that they thought the level of financial incentive was good. 4% thought the level was too high.

When the respondents from the experimental groups with a financial incentive were asked how they prefer to receive this financial incentive, most chose the option of receiving a monthly amount, based on the offered flexibility (chosen by 24 respondents). Estimates of the amount that respondents wanted to receive ranged from €4.50 to €100 per month. Respondents found an average remuneration of €26 to be appropriate. The second most chosen option for financial compensation was a discount on network operator costs (18x). On average, respondents found an amount of €12 suitable for this discount. Some also selected the options for a fixed amount per month (13x) and a discount on the Maxem (HEMS) subscription (12x). Donations (4x) and gift cards (3x) were chosen the least. Four respondents explicitly stated that they do not need a financial incentive.

Notably, 10 out of 20 interviewees mentioned they do not expect a financial incentive if charge management is applied to all users.

4.5 Willingness to continue charge management in the future

There is strong willingness among the participants to continue with charge management: 84% (75 respondents) stated that they want to (continue to) use it in the future, and 81% (72 respondents) would recommend using charge management to other EV-drivers.

Finally, respondents were given the following information in the survey: “By charging your EV at home, your total energy demand increases. To meet this demand, your grid connection may have to be reinforced. This could lead to extra costs. A variable capacity connection where energy consumption is spread more during the day can save costs.” Subsequently, questions were asked on willingness to switch to a variable capacity connection. The willingness to switch to a variable capacity connection is highest when it is offered at a lower cost: 81% (72 respondents) indicate that they are willing to use a variable capacity connection. Fewer participants (55%/49 respondents) were willing to switch to a variable capacity connection at current cost. The willingness to switch to a variable capacity connection at higher costs is the lowest: only 15% (13 respondents) indicate that they are willing to do this.

5 Conclusion and discussion

Based on the data-research it can be concluded that using (dynamic) charge management can substantially reduce the peak load of a low-voltage grid. This pilot study achieved a reduction up to 40%. Despite this degree of constraint, it can also be concluded that charge management via a HEMS has a minimal effect on the attitude and experience of participants. There is hardly any difference between the attitude towards charge management before and after charge management was executed. Participants in general have a predominantly positive attitude towards charge management. Results show that participants are willing to continue using charge management.

In addition, there is no significant difference in attitude between the static and dynamic signal research groups. Nevertheless, slightly over half of the participants noticed when charge management was active. This means that charge management cannot be applied unnoticed. Given that EVs have a connection time of between eight and twelve hours on average, they provide a large potential for flexibility. Applying charge management (preferably with a dynamic profile) can significantly reduce the grid impact of charging EVs.

The possibility of using the override function plays an important role in the attitude of households towards charge management and their experience. Although actual data shows that participants have not used the override function frequently, most participants describe having the override function as important – some even describing it as “essential”. Most participants used the override button out of curiosity or to test its function. It was only rarely used for practical reasons such as problems or because participants needed the EV to charge as quickly as possible.

Finally, we can conclude that the existence of a financial incentive did not seem to influence participants’ attitude and experience towards charge management in this pilot. Data shows that participants who were rewarded with a financial incentive do not have deviant charging behavior. However, we did not investigate what the effect would be if the financial compensation would have been higher or whether this result has to do with the specific characteristics of this research group. This requires further research. Participants did indicate that they find financial incentives attractive and hold a positive attitude towards them.

When interpreting these conclusions, it is important to take the following notes into consideration. This research concerns the charging of EVs at home charge points. Approximately, two-thirds of the respondents indicate that their EV is connected to their home charge point for an average of eight to twelve hours a day. This offers leeway for shifting the charge times and power load without further consequences. Next to that, a large portion of the participants usually start their charging session outside peak hours when no charge management is applied. 80% of the participants indicate they have a day-and-night energy tariff at home, which possibly explains this timing of charging. Subsequently, these participants are likely to experience minimal impact from charge management. It is important to note that the research group of this pilot has a specific profile and is not necessarily representative of future EV-drivers. For example, we suspect that this group of users has a high willingness and interest in innovation, technology and sustainability, which contributes to their positive attitude towards charge management. Whether or not future EV-drivers (early majority) will have the same attitude needs to be investigated further. More than three-quarters of the participants drive a Tesla (Model S and Model X). This is an EV with a large range (over 400 kilometers). The large range could imply that drivers are less likely to experience problems due to charge point management. Finally, the participants in this research seem to be affluent. This might indicate that participants are not sensitive to the relatively small financial incentives used in this research.

In future research, it is recommended to study the override function in more depth, in order to gain insight into why people value it. A recommendation is to include direct user-interaction to shed light on why the override function is used. The surveys identified some of the reasons (e.g. to test the system) but only afterwards. It is also suggested to conduct more research on the provision of information, as some participants indicated that they would have appreciated more information on topics including the charge profile of their vehicle with active charge management. A second suggestion for future research is to study different customer propositions to determine whether people are willing to allow more charge management for an (extra) financial benefit in return. Finalliy, the groups of participants were relatively small, with an average of 34 households per group. As a result, not all differences could be explained, because they were sometimes caused by a single outlier. For future research, it is recommended to consider a larger pilot group and, if possible, a more diverse group and different household compositions.

Acknowledgments

This research is part of the *Flexible Charging behind the Meter project*, a joint initiative of Maxem, Enpuls, Enexis Netbeheer, and ElaadNL.

References

[1] J. Druitt, W-G. Früh. *Simulation of demand management and grid balancing with electric vehicles.* Journal of Power Sources, 216(2012), 104-116

[2] B.K. Sovacool, L. Noel, J. Axsen, W. Kempton. *The negelected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review,* Environmental Research Letters, 13(2018), 1-18

[3] J. Axsen, J. Bailey. *Anticipating PEV buyers' acceptance of utility controlled charging*, Transportation Research Part A, 82(2015), 29-46

[4] G.R. Parsons, M.K. Hidrue, W. Kempton, M.P. Gardner. *Willingess to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms.* Energy Economics, 42(2014), 313-324

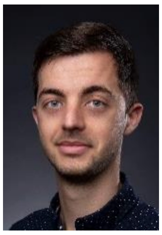
[5] A. Hoekstra, N. Refa. *Characteristics of Dutch EV drivers.* EVS30 Symposium, (2017)

[6] ElaadNL, *Onderzoek wijst uit: EV-rijders zien voordelen slim laden,* URL accessed on 19-03-2020; https://www.elaad.nl/news/onderzoek-wijst-uit-ev-rijders-zien-voordelen-slim-laden/.

Authors

Lotte Gardien is working as behavioral researcher at the innovation centre in the field of Smart Charging, ElaadNL. She is currently working on the adoption of Smart Charging by Dutch EV-drivers. She received her MSc. degree in Cultural Anthropology from Utrecht University in 2011.

Nazir Refa received his Master of Science degree in 2015 from Utrecht University, Netherlands. Currently, he is working as a data scientist at ElaadNL. His primarily research interests are in the field of EV grid impact, and smart charging studies. Within ElaadNL he is responsible for monitoring, and analysis of various smart charging pilots in collaboration with the Dutch grid operators, and research institutes. He has co-developed several bottom-up models for EV diffusion, and deployment of EV charging infrastructure.



Milan Tamis is lecturer and researcher at the Amsterdam University of Applied Sciences and part of the Urban Technology research program. His research interests include consumer preferences, attitudes and behavior regarding smart energy systems and e-mobility.