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# Exploring social charging behavior between EV users in sharing charging points

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**Summary**
With the growing uptake of Electric Vehicles (EVs) world-wide the demand for charging infrastructure has increased as well. In a number of frontrunner countries mature public charging infrastructure have been developed over the last years. Research has revealed issues of limited effective use of Charging Points (CP) in terms of connection duration and lower charging duration, which negatively affects the business case of charging infrastructure as well as availability for EV drivers. Anecdotal evidence in the Netherlands suggests that EV drivers organize themselves and collaborate on charging, for instance in WhatsApp groups or dedicated (commercial) applications, to increase utilization of charging infrastructure by enabling other EV drivers to charge, a process that we label 'social charging'. In this paper we present the results of a survey amongst EV drivers to explore the extent to which social charging is taking place and under which conditions social charging is more likely to occur.

As such this paper aims to contribute to a more thorough understanding of social behavior of EV users, which in turn can contribute to a more effective and efficient utilization of the charging infrastructure.
*Keywords: social, sharing, behavior, charging, infrastructure*

## 1. Introduction

With the continuous uptake of Electric Vehicles (EVs) world-wide, as a result of the release of new Battery Electric Vehicles (BEV) the demand for charging infrastructure has increased as well [1], [2]. Expectations for future uptake point at an increase in demand as prices for BEV decrease while battery sizes increase [3], [4]. This has led to the extensive deployment of different modes of charging infrastructure; (i) DC at corridors and near highways [5], [6], (ii) (semi) private AC charging at home or office locations and (iii) public AC charging in cities where private parking is not available[7]

An increasing concern on the subject of public charging infrastructure is its utility from different perspectives of stakeholders [3], [8], [9]. In areas where the demand for charging infrastructure is larger than the supply of charging points the convenience of the EV system has been found to decrease perceived user convenience as the unsuccessful connection attempts due to occupancy increases [10], [11]. The unbalance between supply and demand in the system may also lead to vulnerability caused by perturbations such as unexpected occupancy of CPs from visitors or car sharing users[10], [12]. As a result of the increasing density, examples of complex emergent phenomena emerge due to interactions of different EV users and user types, related to this research, are competition for scarce and spontaneous cooperation between actors in the system[13].

Another option to optimize charging utilization is for neighboring EV drivers to collaborate on charging behavior to avoid congestion. For instance, an EV user arriving at 17:30 may remove its fully charged EV at 22:00 leaving room for another EV user to charge its vehicle overnight until the next morning. This type of cooperation may not only improve effective use, it also improves efficiency of charging points, as ratio between charging time and connection time increases as well. A side effect of neighbors sharing charging facilities is that it may improve social cohesion [14].

While the existence of WhatsApp groups or social charging apps are known to exist in (Dutch) practice [15], the current state of literature on this subject is limited to work that explores protocols for cooperation between EV users and EV user etiquette[14].To the best of our knowledge models on cooperative charging do not yet exist. To further research of potential forms of cooperation, the extent to which such social charging behavior exists between a network of EV owners in a neighborhood is investigated.

In this initial research we focus on factors that influence the willingness to perform social charging, treating charging points as a scare resource. This research is setup as follows. We first explore literature from which we may reveal factors that lead to patterns of cooperation. These factors are used to design a survey on social charging behavior. We then explore the preliminary results of the survey. Finally, we draw preliminary conclusions and look forward to future research.

# 2. Literature review

In this section we provide an overview of literature relevant for the subject of social charging behavior. Current literature provided limited insight in positive social interactions between EV users. A paper that closely relate to the topic of research is the cooperative charging protocol by Schurmann et al. [16]. The latter paper [16] designs setups and simulates cooperative charging at public charging stations. While this paper focuses on the protocol setup for communication and billing of incentivized cooperative charging, there are still several learnings from this paper. First, the research acknowledges that EV users require a threshold on the State of Charging (SOC) as prerequisite of an EV user to vacate its position at a charging spot.

Second, the paper suggests a decentralized protocol for communication between the requester and provider. In our research we acknowledge the existence of apps that provide this kind of communication[15], but also, we assume social actions without communication or even prior knowledge of the existence of requestors. Finally, simulation results on the effects of social charging suggest an increase of 120-250% of charging sessions and a decrease of failed connection attempts. A drawback of this research is that the assumptions on charging behavior are stereotypical [17] and that the willingness of EV users to cooperate is not driven by perceived nor stated preferences.

We conclude that to the best of our knowledge there is not yet a model that covers voluntary social behavior in charging infrastructure yet. We therefore combine knowledge from three types of literature to gain learnings for the setup of our survey. First, we explore learnings from charging behavior research to gain insights in the relation between arrival times of different users types and potential factors that affect willingness. Second, we look at behavior of drivers in competitive areas of parking to evaluate factors that may withhold drivers from switching parking spots. Third, we regard literature on modelling complex systems in relation to voluntary and spontaneous cooperation between elements. Based on the learnings of these fields we setup our survey.

## 2.1 Charging behavior

Charging behavior has been researched since the first uptake of electric vehicles. Early work explored the interaction between battery size and decision of EV users to [18]. Based on technological developments, DC fast charging behavior, known as corridor charging, has grown to a large extent[19], [20]. Due to the nature of our research we focus on AC charging as this is mostly related to parking behavior[21].

A large part of literature on charging behavior has focused on the relation between the arrival time, state of charging and the connection duration[22]–[25]. From this research we learn that there may be a relation between these factors and the willingness to act social to another EV user. Also, it has been shown that the battery size of the EV may affect the times between sessions and potentially the willingness to share charging points[4]. While the fast majority of charging behavior research focuses on modelling individual choices of EV users in relation to their convenience, some papers indicate the relation between charging behavior and potential negative effect for other users.

On the other side of the spectrum, research has been done into non-social charging behavior, as some users have shown to connect their EV longer than necessary and a fine to improve the charging station utilization has shown to be helpful in theory). While the opposite – a fee for social behavior like Schurmann proposed [16] – may be interesting for our research, it is not implemented in practice. We therefore did not include potential incentive schemes of social charging in our questionnaire but do ask about the reciprocity between users.

From the literature on charging behavior we see that modelling charging as an individual choice has been the primary focus of literature. Recently, due to simulation models, the interaction between EV users and the relation between individual choices and other EV users has been researched. Our research adds a new perspective on interactions.

## 2.2 Competition and cooperation for parking spots

Relevant research by Delot et al [26] proposes an algorithm and a protocol for sharing parking spot information between vehicles and between parking spots and between vehicles and parking spots. A central concept of this research is the likelihood of two drivers encounter given arrival and departure times. This may relate to potential overlap and encountering of different types of EV users (office charging versus residential overnight charging) [27]. Yet, the concept is based on complex math and not applicable for a questionnaire to EV users. Note, that unlike the EV situation, in the simulation model there is no exchange of functionally different parking spots, since both spots are functionally identical. On the contrary, a parking spot with an EV charger and without are not functionally similar and thus may lead to an unbalanced exchange.

From this stream of literature, we learnt that next to charging points, parking spots should also be considered as scarce recourses. We should therefore in our survey question on alternative parking spots as potential factor for willingness to act socially to another EV user.

## 2.3 Cooperation in Complex systems

Complex systems successfully describe phenomena in socio technical systems in which interactions actors in the systems are important. Recent research has indicated that behaviors within the EV charging infrastructure are similar to complex behavior, particularly in areas of mature AC public charging infrastructure [11], [28].

Simulation models have pointed at the spontaneous emergence of cooperative behavior in noisy systems where agents are success driven[13]. Results from this research show cluster formation of agents that are willing to help each other. Game theoretical research has shown that the closeness of players in multiplayer games affects their willingness to cooperate with other players [29], [30]. From this literature we learn that both reciprocal behavior and closeness or familiarity may be important factors in our survey.

## 3. Research question and methodology

Our research aims to provide insights for policy makers on social charging behavior. This work contributes to literature in the following ways. We provide a definition and explore the process of Social Charging Behavior (SCB). To the best of our knowledge a definition has not been posed in current charging behavior related research. We also provide insight in patterns of social charging behavior based on a questionnaire.
In this research we define social charging behavior as: *The voluntary action of an EV user to provide access to its current connected charging spot by removing its own vehicle either to a receiver that indicated the need for charging based upon communication or based on the expected usefulness of the freed spot for another not yet present EV user.*

Using this definition, we acknowledge that social charging may take two forms with the direct interaction between two EV users (Bilateral Social Charging Behavior, BSCB) or without prior knowledge of another EV users' needs (Unilateral Social Charging Behavior, USCB). Also, the need for a charging spot does not exclude the existence of alternatives nearby this specific charging spot. Our research question for this paper is: *What factors induce social charging behavior between EV users?*

In order to answer this question, we setup a survey based on the findings from our literature review. The results from the survey contributes to both the insight in social behavior of the EV-drivers and help to label the dataset of charging sessions, which allows to develop a data driven model for social charging behavior.

### 3.1 Survey design

The survey setup for this research combines our findings from the three types of literature explored. Next, to check on our conceptualization of social charging we added free fields that allows to reflect on social charging behavior for the EV users. Finally, in order to model social charging behavior based on charging data from public charging points we asked EV users to mention locations and times where they have performed social charging.

Based on the literature on charging behavior we first asked the respondents to provide insight in their charging modes (public AC, DC or semi-private), arrival times and connection duration. From these questions we may find a relation between peak demand for charging infrastructure and the willingness to perform cooperative behavior. From literature on charging behavior we also learnt that the state of charging, the number of relevant alternatives and the walking preparedness may be factors that influence the willingness to cooperate with others [11], [31].

Based on literature on parking in competitive areas we first asked questions that revealed the pressure on the charging? system. Next, as a check on this question we asked whether both sockets are occupied when BSCB occurs. If this is not the case, then there is at least one parking spot free. We hypnotize that the of BSCB starts with communication between the requestor and supplier. Like with literature on interactions between drivers in competitive parking areas, we are interested in the geographic span that the interaction between the users cover. For this we asked both the type of communication and the number of charging points which the interaction between the users covers.

From literature on complex systems we have learned that interactions between two actors are influenced by closeness, mutuality and alternative scenarios for both actors. We have therefore explicitly questioned respondents on both unilateral and bilateral social charging behavior. Next, we questioned EV users to indicate the rate of USCB and BSCB based on their portfolio of all sessions. Also, we are interested in the importance of reciprocity of social behavior, both for EV users that indicate to provide social behavior as well as those users that indicated not to provide such behavior. To get insight in the rate of which this behavior occurs we explicitly questioned EV users to indicate the percentage that they were able to charge due to social behavior. Lastly, we were interested in the closeness between both actors and the importance of prerequisites. We asked these questions in such way that during analysis we were able to correlate them.

Finally, we added several free fields for following purposes. First, we asked EV users to provide their definition of social charging behavior. This allows us to check the perception of EV users with our question.

Second, we asked EV users for locations of public charging points where they have provided social charging behavior. Based on these locations and the charging data from public charging infrastructure available for our research we are able to (i) check the validity of USCB / BSCB rates, (ii) label sessions as social for development of prediction models (iii) check on social charging points sharing networks of EV users in time and space.

## 3.2 Survey responses

We sent our questionnaire online and distributed it on diverse social media channels (primarily LinkedIn and Twitter), focused on Dutch network. The questionnaire was in Dutch and English. The questionnaire was open from 2020-02-24 to 2020-03-12. During this time 494 full responses were filed. An analysis of the respondents shows that 75% is from the Netherlands Participation was voluntary, anonymous and there was no form of incentive. Respondents could leave a reply in a dedicated field or send their feedback to a dedicated email address. Current work provides preliminary insights in all responses, future work will contain filtering on speeders and inconsistent data.

## 3.3 Sample characteristics

A total of $N = 502$ responses were gathered next to 5 responses which were invalid due to time restrictions. Out of the 502 responses 62.4% finished the questionnaire. We see that the vast majority of the 37.6% closed the survey due to a bug. This caused the respondent to see two questions on provision of specific social charging locations which were not applicable, that forced these respondents to close the questionnaire. Since the majority of questions were filled in and the remaining questions (that were not filled in) are used solely for future data analysis, we decided to count them as full respondents.

The spread of charging sessions by EV users over AC public, DC, private and semi-private charging in the sample correspond with the expectations, see Fig. 2(a). Private charging is most used by individual users and public AC second. Out of 385 users 51% indicated to use private charging as most used charging mode. And 21% indicates to charge mostly at public AC charging. A small group of 11 users indicated to prefer several CP's equally.

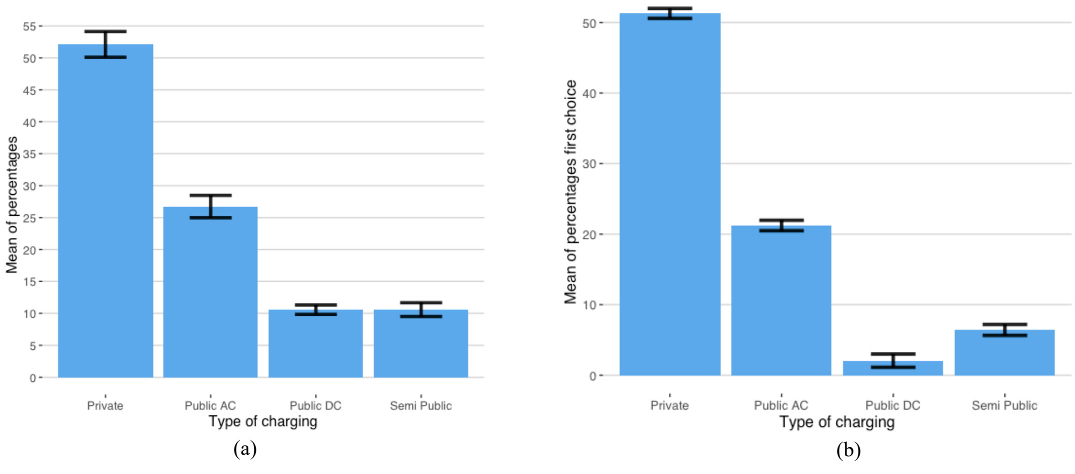


*Fig. 2 overview of charging modes over respondents: (a) mean values for modes over all respondents; (b) percentage of dominant charging mode per user over population*

The results show that connection time duration of the respondents are within similar ranges we find in earlier research [20]. We therefore conclude that the population of our respondents are sufficiently representative for the EV community in the Netherlands.

# 4. Results

## 4.1. EV users displaying social charging behavior

Out the 494 responses 282 or 57.7% indicated to remove their EV for another EV user while having communication with the other EV user (bilateral social charging behavior) and 171 or 34.6% indicated to experience other EV users to remove their EV for them. Using a ranked t-test we analyzed whether there is significant difference in the distribution of charging modes for users that display social charging behavior and do not, see Table 1. None of the results indicated a significant difference.

*Table 1 Results ranked t-test for mode of charging and yes-no social charging behavior*

| | **AC charging** | **Private charging** | **DC fast** | **Semi private** |
|---|---|---|---|---|
| **P-Value** | 0.593 | 0.560 | 0.153 | 0.714 |
| Cohen's d | 0.77 | 0.677 | 0.167 | 0.0433 |

A deeper analysis on Bilateral Social Charging Behavior (Fig. 2) shows that a distinction of EV users that infrequently displays BSCB (0-40% of sessions) and a group that regularly applies social charging (60-100% of sessions), with a peak at 20% of the sessions in which social charging is thought to be applied. In Fig. 3 the distribution of Uni-laterite Social Charging Behavior. It can be seen that this distribution deviates from BSCB. In the questionnaire we set the max percentage for USCB to 50%, which may have led to the large peak at 50% of sessions.

From Fig. 3 it may seem that there exists a specific group that act social as standard. Preliminary results of the free text fields of users with high USCB/BSCB percentages indeed shows that these users have the opinion that EV users should minimize their unnecessary connection times. This result is counter intuitive given that the research on charging station hogging[32].

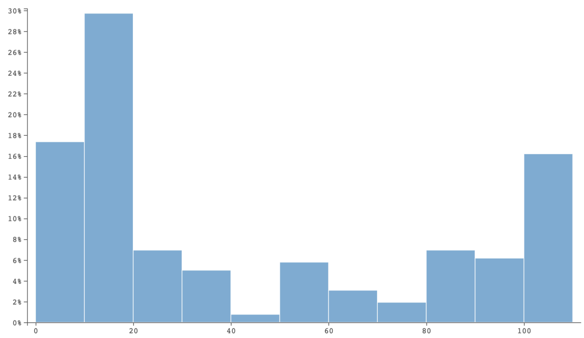

Fig. 2 Distribution of charging sessions shares with BSCB (axis is percentage)

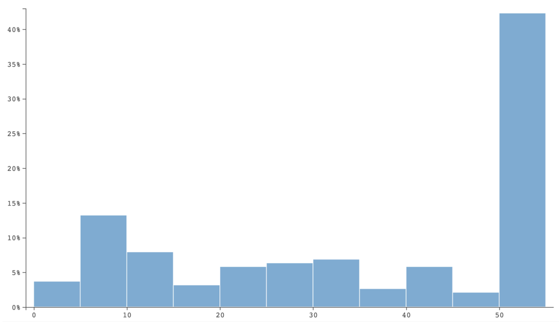

Fig. 3 Distribution of the percentage of charging sessions that EV users provide USCB (x-axis is percentage)

Regarding the difference between providing bilateral and unilateral social charging behavior (BSCB and USCB) we found that 350 respondents answered both questions. From Table 1 we see that 64% of EV users that display BSCD also disconnect and repark their EV without the explicit need of another EV user (USCB). As expected none of the respondents provides USCB without BSCB. A cluster analysis on the BSCB and USCB revealed that there is no evidence for separate user groups (sample size 187, Silhouette Score 0.398 on 3 clusters).

Table 2 bilateral versus unilateral social charging behavior

| | | EV users provides BSCB | | |
|---|---|---|---|---|
| | | Yes | No | **Total** |
| EV users provides USCB | Yes | 224 / 64.0% | 0/ 0% | **224** |
| | No | 25 / 7.1% | 101 / 28.9% | **126** |
| | **Total** | **249** | **101** | |

Table 3 Reciprocity of Social charging

| | | User removes car for other user | | |
|---|---|---|---|---|
| | | Yes | No | **Total** |
| Other user | Yes | 144/ 45.4% | 2/ 0.6% | **146** |
| | No | 72/ 22.7% | 99/ 31.2% | **171** |
| | **Total** | **216** | **101** | |

A closer look at the 317 respondents that answered both the questions on providing and receiving social charging behavior is found in Table 1. For this table it can be seen that there is a stronger positive reciprocity effect (45.4%) than negative (31.2%) reciprocity. Moreover, 33.3% (72 out of 216) of the EV users provide social charging behavior receiving social charging behavior. The correlation between the percentage of BSCB per user and percentage USCB per user revealed that while there is a medium positive correlation between both variables (P-value < 0.00001, Effect Size Pearson's r 0.353), the percentage of BSCB can limitedly predict the percentage USCB (R-squared 0.124).

Regarding the tendency of being annoyed by other EV users that occupy charging stations we see that there is a subtle but significant relation between BSCB and being annoyed by occupation (sample size 383, Effect size (Cramers V) 0.172, p-value 0.0233). There is also a subtle but significant relation between EV users that provide USCB and being annoyed (sample size 352, Effect size (Cramers V) 0.190, p-value 0.0125). Yet, there is no statistical significant relation between being annoyed and others receiving BSCB from other users (sample size 317, Effect size (Cramers V) 0.152, p-value 0.118). This indicates that EV users that experience being annoyed by occupied charging stations tend to provide social charging behavior to others. Yet, our research does not provide insight in causality between both.

An analysis on the prerequisites for providing BSCB and USCB in Table 3 shows that for the vast majority of EV users the battery size must at least be sufficient for the next trip. A deeper analysis of this result in relation to the type of vehicle (PHEV versus BEV) revealed that there is only a subtle but significant relation between the type of vehicle and whether the battery is fully charged (Cramers V 0.151, p-value 0.0464, sample size 216). This may indicate that BEV users may have slightly different prerequisites than PHEV users.

*Table 4 prerequisites for providing BSCB*

| | **No prerequisite** | **Battery must be sufficiently charged for next trip** | **Battery must be fully charged** | **Battery is not sufficiently charged for next trip but charging can be done later** |
|---|---|---|---|---|
| **Yes** | 13.4% | 87% | 45.8% | 43.5% |
| **No** | 86.6% | 13.0% | 54.2% | 56.5% |

Next to prerequisites on SOC, we also questioned EV users on (i) the importance of factors affecting their willingness (Fig. 3) and (ii) for whom they perform social charging behavior (Table 4). An interesting finding is that for all types of receiving users the "always"-category scores highest (green value in table). Next, we see that the "never"-category has in 3 out of 5 cases the lowest scoring. We see that the highest value in the table is "Other"-"Always". This may indicate that the question omits a type of user or that the question is unclear.

*Table 5 Overview degree of willingness to perform social behavior for different user groups*

| | Neighbours | Visitors of neighbours | Friends | Visitors | Other |
|---|---|---|---|---|---|
| **Always** | 36.7% | 33.2% | 47.3% | 40.8% | 51.4%t |
| **Often** | 17.9% | 16.3% | 17.7% | 16.7% | 8.6% |
| **Regularly** | 17.9% | 10.5% | 11.8% | 12.6% | 11.4% |
| **Sometimes** | 15.8% | 25.2% | 14.5% | 17.8% | 8.6% |
| **Never** | 11.7% | 15.8% | 8.6% | 12.1% | 20.0% |

The importance of factors affecting their willingness in (Fig. 3) reveal that three factors have been mentioned to be important: (i) battery level, (ii) not occupied alternative parking spot and (iii) reciprocal behavior of other EV users. Note that the type of distributions is significantly different. The battery level is most normal distributed with a low standard deviation and several outliers towards low importance. The alternative parking spot is highly left skewed with a large standard deviation. This suggests that for some contexts the alternative parking spot is not an issue as parking pressure may be low in certain locations, or that EV users swap parking spots. The reciprocity is normally distributed with a larger standard than battery size.

Based on these results we were able to correlate the receiving user type with the importance of factors that affect willingness, see Table 5. In this table the green values were found to have a significant relation. For several combinations of the degree of acquaintance versus the type of user this correlation is for obvious reasons. This result may also be seen as a confirmation of the validity of the data. Interestingly, the availability of an alternative parking spot shows significant relation with Visitors of neighbors and the neighbors themselves.

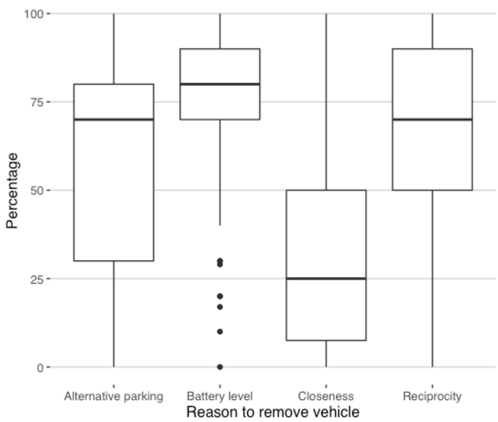

Fig. 3 Distribution of indicated importance of factors that lead to social charging behavior

*Table 7 Correlation between the prerequisites for providing social charging behavior and the receiving EV user type (numbers are P-value / Effect size Cohen's f)*

| | Availability alternative parking spot | The degree you are acquainted with the other person | The status of the battery | Reciprocity |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Visitors** | 0.155/ 0.202 | 0.0000753/ 0.425 | 0.752/ 0.158 | 0.771/ 0.102 |
| **Friends/ Acquaintances/ Family** | 0.152/ 0.194 | 0.000703/ 0.368 | 0.943/ 0.0707 | 0.834/ 0.0935 |
| **Visitors of neighbors/** | 0.00807/ 0.282 | < 0.00001/ 0.566 | 0.406/ 0.156 | 0.944/ 0.0639 |
| **Neighbors** | 0.0600/ 0.225 | < 0.00001/ 0.453 | 0.322/ 0.175 | 0.576/ 0.118 |
| **Other** | 0.162/ 0.329 | 0.184/ 0.383 | 0.975/ 0.0894 | 0.904/ 0.147 |

The effect of social charging behavior appears to be widely spread. A large group (25%) indicates to benefit from this behavior 1 out of 20 sessions. A group of 15% indicated to benefit 1 out of 10 sessions. Interestingly a subset of 9% of EV users indicate that 1 out of 2 sessions can proceed due to social charging behavior. This large subset leads to follow up questions on the interpretability of the question and the locality of scarcity for charging points. This may indicate that the effect of competition may be locally dispersed. Moreover, there appears to be no significant relation between the percentage of use at public charging points and the percentage of sessions that EV users can charge due to receiving BSCB (P-value 0.881, Pearson's r 0.0132, R-Squared 0.000175). A group of 17% indicate to not benefit from social charging behavior. This may also be an issue, as this question is asked after the question whether other "EV users act social to you". It is not possible to state whether our results are in line with simulation results of Shurmann [16].

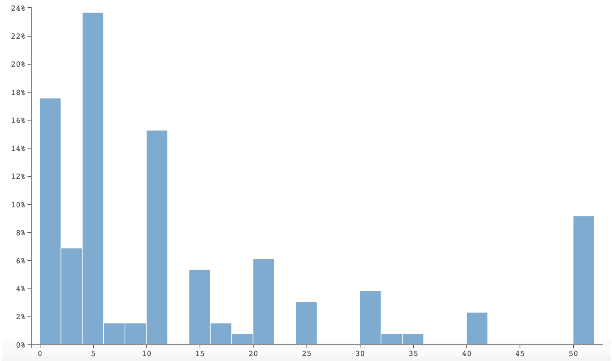

*Fig. 5 Percentage of sessions that EV users are able to charge due to receiving BSCB from other EV users*

### 4.2. EV users not providing social charging behavior to other users

Finally, we focus on EV users that indicated not to display any form of social charging behavior. First, we found that there is no significant relation between the vehicle type and the willingness to provide social charging behavior (P-value 0.292, Cramer's V 0.0543). We found no significant relation between not willing to display forms of social charging behavior and the distribution of sessions over the different modes of charging (public AC / DC / private AC). Regarding the reasons that EV users provide for not willing to charge their EV we found that the battery SOC is far most mentioned reason. Interestingly, reciprocity the least mentioned reason. We have not found statistically significant relations between the reasons mentioned ant the distribution of charging sessions over the different modes of charging (public AC / DC / private AC).

## 5. Conclusion

In this research we focused on social charging behavior as alternative optimization to smart charging. We developed a definition for social charging that separated Bilateral Social Charging Behavior (BSCB) form Unilateral Social Charging Behavior (USCB). The former contains explicit interaction with another user, the latter may be seen as behavior driven by a social norm to minimize unnecessary connection times.

We have shown that a large percentage (57%) of EV users is willing to cooperate with other EV users to share charging points and has at least once performed BSCB. Next, a subgroup 64% of users that indicate to act with bilateral social charging behavior users also act unilateral without the request for this behavior by any other EV user. From our analysis it appeared that EV users are willing to perform social actions regardless of closeness (e.g. friends, neighbors) in at least 30% of respondents. We found that the most important prerequisites for social charging behavior are (i) the state of charging (80%), (ii) reciprocity (65%) and (iii) availability of alternative parking spot (60%). Least important is the closeness to the other EV user, which is in line with the other findings.

The effect for EV users by receiving social charging behavior is present and widely dispersed. A large group (25%) indicates to benefit from this behavior 1 out of 20 sessions. A group of 15% indicate to benefit 1 out of 10 sessions. A subset of 9% of EV users indicate that 1 out of 2 sessions can proceed due to social charging behavior. For users that indicate not to provide social charging behavior, we see the state of the battery is the primary reason not to do so. This is in line with the mentioned importance of EV users that do sometimes display social charging behavior. From the rates of both the receiving as well as the providing number we conclude that social charging behavior may add to the business case of public charging infrastructure. A rough estimation based on our numbers is that 20-50 percent increase of charging point utilization may be possible. This number may increase if social charging behavior would be incentivized, given that our only takes into account voluntary behavior.

# 6. Discussion and future work

The results of our survey seem surprisingly positive, which leads to the question whether the population of respondents can be seen as a representative group of (current and/or future) EV users. A check on validity of rates of USCB and BSCB based on public charging data may be useful. Current research provides insight in general results. While clustering on several variables did not reveal statistically significant results, it may well be that after advanced feature engineering some statistically significant clusters of social charging EV users may be present in the data.

Current research focuses sec at the results of the questionnaire, while we may also focus on the demographic and environmental factors of charging. In additions the EV-drivers are questioned to share their locations at which they share charging points. Out of the respondents that indicated to display social charging behavior, 74 respondents have left relevant location information. This allows us to research environmental factors change over time as charging infrastructure matures. We may so do using a large real-world dataset of 8 million charging transactions in the large Dutch metropolitan areas (Amsterdam, Rotterdam, The Hague, Utrecht and the metropolitan region of Amsterdam) [33].

From this we can compare these EV user's behavior against other users present in neighborhood, average occupation rate, number of relevant alternatives and number of potential interactions with other EV users at CPs. From these factors we can develop a model that describes the probability of existence of social behavior in a neighborhood.

The implementation of such prediction model in an agent-based model allows us to simulate charging point key performance indicators of charging stations with social behavior with comparable charging stations where social behavior does not exist.

# 7. References


[1] R. van den Hoed *et al.*, *E-mobility: getting smarter with data*, 1st ed. Amsterdam: Amsterdam University of Applied Science, 2020.

[2] R. Wolbertus and R. Van den Hoed, "Electric Vehicle Fast Charging Needs in Cities and along Corridors," *World Electr. Veh. J.*, vol. 10, no. 2, p. 45, Jun. 2019.

[3] J. R. Helmus, J. C. Spoelstra, N. Refa, M. Lees, and R. van den Hoed, "Assessment of public charging infrastructure push and pull rollout strategies: The case of the Netherlands," *Energy Policy*, vol. 121, pp. 35–47, Oct. 2018.

[4] J. R. Helmus, I. Vermeulen, M. Lees, and R. Van Den Hoed, "Simulation of Future Electric Vehicle Charging behaviour - Effects of transition from PHEV to FEV -," no. 2, pp. 2–5, 2018.

[5] W. Ji, M. Nicholas, and G. Tal, "Electric Vehicle Fast Charger Planning for Metropolitan Planning Organizations," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2502, pp. 134–143, Oct. 2015.

[6] R. Wolbertus and R. Van Den Hoed, “Expanding charging infrastructure for large scale introduction of electric vehicles,” *EVS32 Symp.*, no. May, pp. 1–15, 2019.
[7] R. Van Den Hoed *et al.*, “Data analysis on the public charge infrastructure in the city of Amsterdam,” *2013 World Electr. Veh. Symp. Exhib. EVS 2014*, pp. 1–10, 2014.
[8] J. Helmus and R. van den Hoed, “Key Performance Indicators of Charging Infrastructure,” *EVS 2016 - 29th Int. Electr. Veh. Symp.*, pp. 1–9, 2016.
[9] R. Wolbertus and R. van den Hoed, “Benchmarking Charging Infrastructure Utilization,” pp. 1–15, 2016.
[10] M. Glombek, J. R, M. Lees, H. Van Den R, and R. Quax, “Vulnerability Of Charging Infrastructure , A Novel Approach For Improving Charging Station Deployment,” in *Proceedings of the 2018 Transportation Research Arena*, 2018.
[11] J. R. Helmus, R. Van Den Hoed, and M. H. Lees, “Exploring a Complex Systems Approach to Charging Infrastructure : implications for researchers and policy makers,” *EVS32 Symp.*, no. 1, pp. 1–17, 2019.
[12] V. C. Gorka, J. R. Helmus, and M. H. Lees, “EVS32 Symposium Simulation of Free-floating vehicle charging behaviour at public charging points,” in *EVS32*, 2019, pp. 1–10.
[13] D. Helbing and W. Yu, “The outbreak of cooperation among success-driven individuals under noisy conditions.,” *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, no. 10, pp. 3680–5, 2009.
[14] N. Caperello, K. S. Kurani, and J. TyreeHageman, “Do You Mind if I Plug-in My Car? How etiquette shapes PEV drivers’ vehicle charging behavior,” *Transp. Res. Part A Policy Pract.*, vol. 54, pp. 155–163, Aug. 2013.
[15] J. Geurts, “Home - Social Charging,” 2016. [Online]. Available: https://www.social-charging.com/. [Accessed: 30-Sep-2019].
[16] D. Schurmann, J. Timpner, and L. Wolf, “Cooperative Charging in Residential Areas,” *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 4, pp. 834–846, 2017.
[17] F. Ekman, A. Keränen, J. Karvo, and J. Ott, “Working day movement model,” *Proc. Int. Symp. Mob. Ad Hoc Netw. Comput.*, pp. 33–40, 2008.
[18] T. Franke and J. F. Krems, “Understanding charging behaviour of electric vehicle users,” *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 21, pp. 75–89, Nov. 2013.
[19] S. Hardman *et al.*, “A review of consumer preferences of and interactions with electric vehicle charging infrastructure,” *Transp. Res. Part D Transp. Environ.*, vol. 62, pp. 508–523, Jul. 2018.
[20] R. Wolbertus, M. Kroesen, R. van den Hoed, and C. Chorus, “Fully charged: An empirical study into the factors that influence connection times at EV-charging stations,” *Energy Policy*, vol. 123, pp. 1–7, Dec. 2018.
[21] R. Wolbertus, M. Kroesen, R. van den Hoed, and C. Chorus, “Fully charged: An empirical study into the factors that influence connection times at EV-charging stations,” *Energy Policy*, vol. 123, pp. 1–7, Dec. 2018.
[22] A. Almaghrebi, S. Shom, F. Al Juheshi, K. James, and M. Alahmad, “Analysis of user charging behavior at public charging stations,” IEEE, Jun. 2019.
[23] P. Morrissey, P. Weldon, and M. O’Mahony, “Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behaviour,” *Energy Policy*, vol. 89, pp. 257–270, Feb. 2016.
[24] R. Philipsen, T. Brell, W. Brost, T. Eickels, and M. Ziefle, “Running on empty – Users ’ charging behavior of electric vehicles versus traditional refueling,” *Transp. Res. Part F Psychol. Behav.*, vol. 59, pp. 475–492, 2018.
[25] X.-H. H. Sun, T. Yamamoto, and T. Morikawa, “Charge timing choice behavior of battery electric vehicle users,” *Transp. Res. Part D Transp. Environ.*, vol. 37, pp. 97–107, Jun. 2015.
[26] T. Delot, S. Ilarri, S. Lecomte, and N. Cenerario, “Sharing with caution: Managing parking spaces in vehicular networks,” *Mob. Inf. Syst.*, vol. 9, no. 1, pp. 69–98, 2013.
[27] J. Helmus and R. Van Den Hoed, “Unraveling User Type Characteristics : Towards a Taxonomy for Charging Infrastructure,” in *EVS28 International Electric Vehicle Symposium and Exhibition*, 2015, no. MAY 2015, pp. 1–16.
[28] M. Mureddu, A. Facchini, A. Scala, G. Caldarelli, and A. Damiano, “A Complex Network Approach for the Estimation of the Energy Demand of Electric Mobility,” *Sci. Rep.*, vol. 8, no. 1, p. 268, Dec. 2018.
[29] A. E. Depping and R. L. Mandryk, “Cooperation and interdependence: How multiplayer games increase social closeness,” *CHI Play 2017 - Proc. Annu. Symp. Comput. Interact. Play*, pp. 449–461, 2017.
[30] K. Vella, C. J. Koren, and D. Johnson, “The impact of agency and familiarity in cooperative multiplayer games,” *CHI Play 2017 - Proc. Annu. Symp. Comput. Interact. Play*, pp. 423–434, 2017.
[31] R. Wolbertus and B. Gerzon, “Improving Electric Vehicle Charging Station Efficiency through Pricing,” *J. Adv. Transp.*, vol. 2018, pp. 1–11, Sep. 2018.
[32] R. Wolbertus and R. Van Den Hoed, “Charging station hogging: A data-driven analysis,” in *EVS 2017 - 30th International Electric Vehicle Symposium and Exhibition*, 2017.
[33] University of applied sciences Amsterdam, “IDO-laad,” 2016. [Online]. Available: http://www.idolaad.nl/. [Accessed: 19-Apr-2017].

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