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Managing parking pressure concerns related to charging stations for electric vehicles: Data analysis on the case of daytime charging in The Hague

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Abstract

With the rise of the number of electric vehicles, the installment of public charging infrastructure is becoming more prominent. In urban areas in which EV users rely on on-street parking facilities, the demand for public charging stations is high. Cities take on the role of implementing public charging infrastructure and are looking for efficient roll-out strategies. Municipalities generally reserve the parking spots next to charging stations to ensure their availability. Underutilization of these charging stations leads to increased parking pressure, especially during peak hours. The city of The Hague has therefore implemented daytime reservation of parking spots next to charging stations. These parking spots are exclusively available between 10:00 and 19:00 for electric vehicles and are accessible for other vehicles beyond these times. This paper uses a large dataset with information on nearly 40.000 charging sessions to analyze the implementation of the abovementioned scheme. An unique natural experiment was created in which charging stations within areas of similar parking pressure did or did not have this scheme implemented. Results show that implemented *daytime charging 10-19* can restrict EV owners in using the charging station at times when they need it. An extension of *daytime charging* to 10:00-22:00 proves to reduce the hurdle for EV drivers as only 3% of charging sessions take place beyond this time. The policy still has the potential to relieve parking pressure. The paper contributes to the knowledge of innovative measures to stimulate the optimized rollout and usage of charging infrastructure.

Keywords: Electric vehicles, charging infrastructure, charging behavior, policy, parking

1 Introduction

The dominant solution to overcome the barriers of limited range and long recharging times for electric vehicles [1][2] is the ability to charge your car while parking. Especially home and workplace charging have shown to be prominent modes of charging [3][4] because idle times are long. These charging modes have the additional benefit that they can be installed at relatively low costs per station compared to other alternative fuel vehicle infrastructure such as natural gas and hydrogen [5][6] and can be located where needed by the user. Although charging stations can only serve few users at a time, these characteristics allow for a more bottom-up and gradual approach for building the necessary infrastructure with the ability to serve the specific user needs of early adopters. Yet a paradox seems to be present, in cities where electric driving has most potential due to limited driving distances and direct air quality improvement, a lot of users have to rely on on-street parking facilities and therefore cannot install their own charging infrastructure. Market parties or public authorities are required to install public charging infrastructure to meet the demands of future EV users.

Municipalities often take on a central role to increase the number of electric vehicles on the road by removing the barriers of limited range and long recharging times through installing the necessary, publicly available charging infrastructure. As the number of electric vehicles on the road is growing [7] so is the demand for public charging infrastructure. Municipalities are looking for efficient roll-out strategies to serve the needs of EV users. Guidelines for designing the parking layout exist [8] but their effect on charging behaviour has not yet been investigated. Guidelines include the recommendation to exclusively reserve the parking spot for electric vehicles that are charging. This prevents non-EV drivers from occupying the scarce number of charging stations that are currently available.

Reserving parking spaces exclusively for electric vehicles can create annoyance among non-EV drivers when these parking spots remain underutilised. As the number of electric vehicles remains limited, occupancy of charging stations [9] [10] is usually lower than the parking pressure [11] in dense urban areas. Municipalities, such as the city of The Hague, The Netherlands, are receiving complaints about increased parking pressure due to charging stations.

To address these problems the city of The Hague decided in 2013 to reduce restrictions on the availability of parking spots next to charging stations. In 2013, daytime parking (10:00-19:00) was applied to charging stations in areas with the highest parking pressure, these parking spots were exclusively available for EV during indicated times. After 19:00 other vehicles were allowed to use these parking spots as well. Due to an incident the *daytime charging policy* was never applied to 20 designated parking spots, creating a natural experiment in which charging behaviour can be observed under different conditions while assignment to the these groups was random. This provides an unique opportunity to investigate the effect of this policy on charging behaviour. This paper uses data from the charging sessions (+/- 40.000) of the city of The Hague to analyse the differences in the utilization between charging stations in high parking pressure areas in which daytime charging was or was not applied. The key research question in this paper is to what extent such daytime charging policies restrict EV users in using the charging station, which times are appropriate to suffice the needs EV owners while managing parking pressure concerns. More generally the paper contributes on the question how the *daytime charging policy* fits in the options municipalities have for rolling out a charging infrastructure while satisfying the interests of different stakeholders in the process.

2 Methodology

This section explains how daytime charging was implemented, the criteria on which charging stations were chosen and the specifics of this policy. Using this information the charging stations are divided into two groups which can be compared. Thereafter the data used to analyse differences across the charging stations is introduced and statistical methods are discussed.

2.1 Daytime charging

Daytime charging implies that the parking spot next to a charging stations is exclusively reserved for electric vehicles for the indicated part of the

Figure 1 Road sign to indicate daytime charging (10:00-19:00)

day. A sign, of which an example can be found in *Figure 1*, is put up to indicate the designated times. Beyond these hours both electric as gasoline driven cars are allowed to use the parking spot.

The municipality of The Hague implemented *daytime charging 10-19* in January 2013 at charging stations in areas in which over 90% of parking spots were occupied during peak hours. In total 79 charging stations were selected but due to an unknown error with the municipal services 20 charging stations did not receive a daytime charging sign, thereby creating an experimental group (n=59) and a comparable control group (n=20) with *full day charging*. Daytime charging was set between the periods 10:00 and 19:00. Charging stations in areas with parking pressure below 90% (n=311) remained exclusively available for EVs.

By September 2015 the municipality expanded the time for exclusive EV charging to 10:00-22:00. They also put up the road signs at the 20 charging stations that first did not have this sign installed, putting the charging stations in comparable conditions again. *Table 1* shows an overview of the different groups and their conditions.

Table 1 Group assignment of charging station based daytime charging condition

Group	Number of charging stations	January 2013 – August 2015 Daytime EV charging 10:00 – 19:00	September 2015 – June 2016 Daytime EV charging (10:00-22:00)
1	59	Yes	Yes
2	20	No	Yes

2.2 Data

The research makes use of a dataset on charging station use of the City of The Hague in the Netherlands. This dataset is provided by the IDOLaad project which has been used in studies before [9][12][13] and contains over 300.000 charging sessions in the city of The Hague during the period of January 2014 and June 2016. Nearly 40.000 sessions took place during this time at one of the charging stations in high parking pressure areas. *Table 2* presents the available data for each session. Although daytime charging was already implemented in 2013, reliable data is only available from 2014 onwards. The data contains relevant information about the location and timing of the charging session and provides an anonymous code to identify the user. After filtering for sessions above 100 kWh and sessions shorter than 1 minute (0,8%), 20.856 data lines for the period January 2014 – August 2015 and 18.858 sessions for the period September 2015- June 2016 remained.

Table 2 Charging transaction dataset

Charging transaction number	Definition
Charging point code	ID code for charging point
Charge pass code (RFID-code)	ID code for charging pass
Start-date and time of connection	Date and time of start connection
Stop-date and time of connection	Date and time of stop connection
Connection duration	Duration of connection
Energy-transfer (kWh)	Energy transferred

The data is aggregated on charging station and hourly level to calculate the occupancy ratio of each charging station and the relative number of charging sessions per hour. Each charging station has two sockets, which implies that when only one of the sockets is used the occupancy ratio is 50%. Average occupancy ratio per hour is calculated from the date the charging station is first used until the set end-date of the dataset, either 23:59 31st August 2015 or 23:59 30th June 2016. For the average occupation ratio only the weekdays are taken into account as weekend charging can show very different behaviour and parking related problems are usually different. Each charging station is assigned to one of the groups as defined in *Table 1*. Data for the group assignment was supplied by the municipality of The Hague.

2.3 Analysis

Statistical analysis to compare the occupancy ratios at an hourly interval is done by an independent t-test. To compare the distributions of the number of charging sessions over the day Mann-Whitney-U tests are done on the cumulative percentage of charging sessions at each hour.

3 Results

3.1 Daytime charging 10:00-19:00

Figure 2 shows the average occupancy ratio over the day during the period January 2014 – August 2015 for the different categories of charging stations. Average occupancy by EVs is relatively low, 15% during the daytime and 25% during the night time but also show differences between the groups.

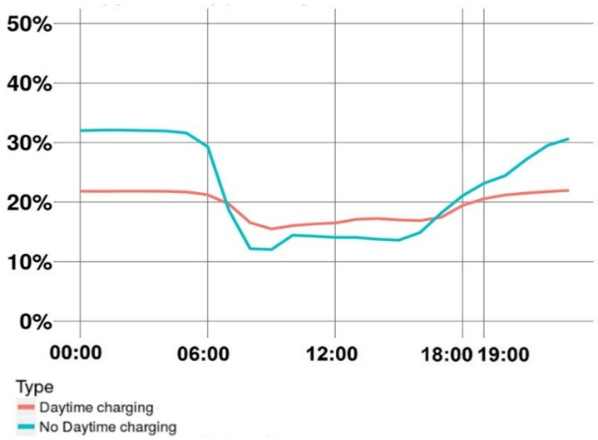

Figure 2 Charging station occupancy throughout the day for daytime and no daytime charging for 2014- August 2015

The results in *Table 3* show that differences in occupancy between charging stations with *full day* and *daytime charging 10-19* are significant after 20:00. The difference in occupancy continues to grow throughout the evening and reach a maximum of 10.2% difference at midnight. Between 12:00 and 20:00 occupancy ratios are not significantly different between the different groups. Charging stations that have *daytime charging 10-19* implemented have a higher occupancy during the day, although the differences are not significantly different. The data suggests that having full day access to charging points will lead to higher occupancy at nighttime and that the daytime charging scheme seems to hamper occupancy to rise after 7pm, the time at which non-EV drivers are allowed to occupy the parking spot as well.

Table 3 Charging station occupancy per time of day for different groups and results of t-test for 2014- August 2015

Time of Day	Group 1 High parking pressure - Daytime charging (%)	Group 2 High parking pressure - No Daytime charging (%)	p-value
0:00	21.8	32.0	0.00
3:00	21.8	32.0	0.00
6:00	21.2	29.3	0.00
9:00	15.4	12.0	0.02
12:00	16.5	14.0	0.25
15:00	17.0	13.6	0.09
18:00	19.4	21.1	0.41
19:00	20.6	23.2	0.23
20:00	21.2	24.4	0.16
21:00	21.5	27.2	0.02
22:00	21.8	29.5	0.00
23:00	21.9	30.6	0.00

The growth in occupancy after 19:00 until 0:00 is 1.2% for the group with *daytime charging 10-19* implemented and 8.6% for the group with *full day charging*.

3.2 Daytime charging 10:00-22:00

After September 2015 daytime charging for group 1 was extended from 10:00-19:00 to 10:00-22:00 because the number of EVs within the city was growing rapidly. Group 2, previously with *full day charging*, had road signs installed which indicate daytime charging 10:00-22:00 in September 2015. The two groups were from then on in comparable conditions. In *Figure 3* this group is still noted as *No Daytime Charging*.

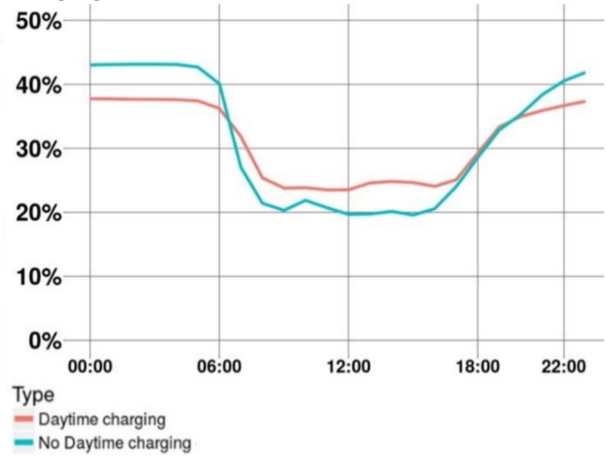

Figure 3 Charging station occupancy throughout the day for three different groups after September 2015

Occupancy ratios for both groups have risen compared to the situation before September 2015. The main reason for the surge in occupancy is the sharp increase in EV sales by the end of 2015 due to the announced ending of fiscal advantages for plug-in hybrid vehicles [14]. Night time occupancy has risen on average 15% for each of the groups while morning and early afternoon charging on average had increased 7%. Although the shapes of the profiles seen similar as before September 2015 the results in *Table 4* show that at no point throughout the day the differences are statistically significant. This implies that there are no significant differences between charging station use between the groups now they are in the similar *daytime charging 10-22 policy* condition. This is in line with the findings from before September 2015, suggesting that the found effect could be attributed to daytime charging policy.

Table 4 Charging station occupancy per time of day for different groups and results of t-test for August 2015 - June 2016

Time of Day	Group 1 High parking pressure - Daytime charging (%)	Group 2 High parking pressure - No Daytime charging (%)	p-value
0:00	37.7	43.0	0.13
3:00	37.6	43.1	0.11
6:00	36.2	40.1	0.27
9:00	23.8	20.3	0.19
12:00	23.5	19.7	0.19
15:00	24.8	19.6	0.07
18:00	29.2	28.5	0.81
19:00	33.3	32.9	0.87
20:00	34.9	35.3	0.90
21:00	35.9	38.4	0.41
22:00	36.6	40.5	0.23
23:00	37.4	41.8	0.18

3.3 Differences over time

3.3.1 Full day charging – Daytime charging 10-22

To analyse differences over time of the group with *full day charging* before September 2015 and *daytime charging 10-22* after September 2015, profiles over the day are compared. To remove any magnitude effects from the data, the cumulative percentage of the starting times of the charging sessions per hour is used. *Figure 4* shows the before and after situation for this group of charging sessions.

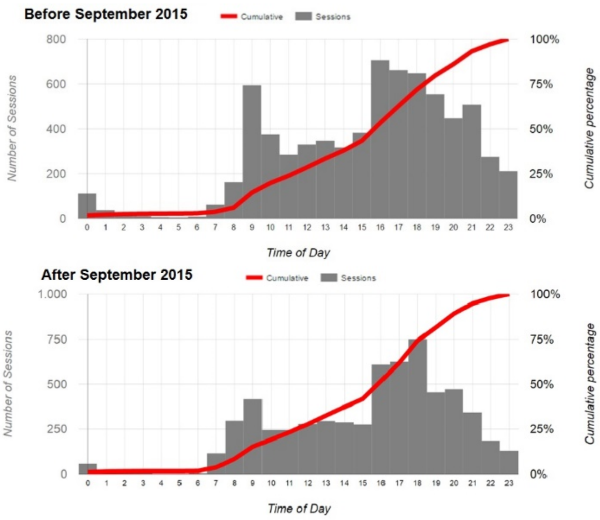

Figure 4 Cumulative distribution of charging sessions over the day for charging station with full day charging before September 2015 and daytime charging 10-22 after September 2015

The profile before September 2015 shows a small peak in the morning, average consumption throughout the day and an evening peak starting at 16:00 lasting until 22:00. Hardly any differences can be observed for the distribution of charging sessions throughout the day after September 2015 with the exception of a lower morning peak. To test if the cumulative profiles show statistically measurable differences we use the Mann-Whitney-U test. The Mann-Whitney-U test (p=0.53) confirms the visual findings showing no significant differences between the two profiles indicating that charging behaviour at these stations is similar before and after implementing *daytime charging 10-22*, showing that this policy did not affect charging behaviour at these stations.

3.3.2 Daytime charging 10-19 – Daytime charging 10-22

The profiles of charging station with daytime charging from 10:00-19:00 before September 2015 and 10:00-22:00 are different to the ones without daytime charging.

They show no peak in the morning and the number of charging sessions decreases rapidly after 19:00, unlike charging stations with *full day charging* which still show significant number of sessions until 22:00. Mann-Whitney U test (p=0.85) also showed no differences over time although the daytime charging policy was expanded from 10:00-19:00 to 10:00-22:00, indicating that EV owners did not shift their sessions to a later time of the day. Users at these charging stations did not take profit from the possibility to able to start charging at a later time with more certainty no non-EV had taken their place.

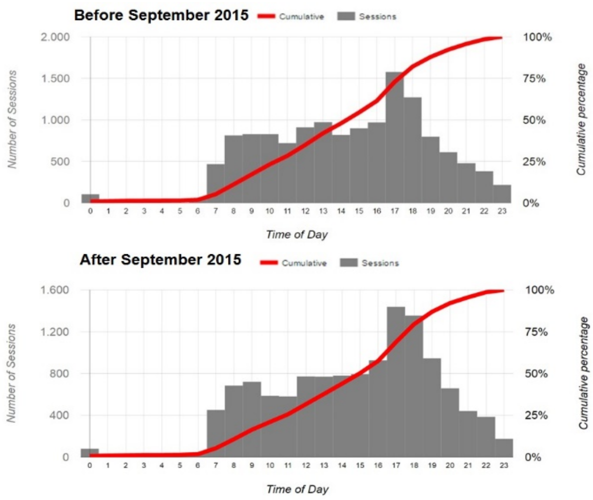

Figure 5 Cumulative distribution of charging sessions over the day for charging station with daytime charging 10-19 before September 2015 and daytime charging 10-22 after September 2015

4 Conclusion

It can be concluded that the *daytime-charging 10-19 scheme* did influence charging behaviour. Charging stations with this scheme had only a few new charging sessions started after 19:00, the time that also gasoline cars were allowed to park on these spots. They were occupied significantly less by EVs than charging stations in areas with similar parking pressure after 19:00, which was the result of differences in the number of new charging sessions during these evening hours while occupancy rates in the late afternoon were comparable. These results could indicate that indeed these parking spots were taken by gasoline drivers which prohibited EV drivers from using the charging stations, although this could only be measured indirectly. As a consequence occupancy rates at charging points without the *daytime charging 10-19* scheme increased higher from 19 onwards (in comparison to the charging points with the policy implemented), had higher occupancy during the night and the early morning.

Charging stations with *daytime charging 10-19* in high parking pressure areas however also showed higher occupancy rates in the late morning and the early afternoon, although not statistically different from charging stations with *fullday charging*. Such patterns could indicate a different demand at these charging stations which is more comparable to “office chargers” [15]. The results could also indicate that users shifted their pattern to more daytime charging because they feared charging stations to be occupied during the evening hours by gasoline driven cars. Such a conclusion can however not be tested as only incomplete data exists on the time before implementing the daytime charging policy.

Once *daytime charging 10-22* was implemented at both the groups the statistical differences between both groups had disappeared showing that *daytime charging 10-22* did not prohibit users in their charging behaviour. In slight contrast to this the results also showed that demand profiles did not significantly differ after daytime charging times were extended from 19:00 to 22:00. EV drivers did not use the opportunity to start their charging sessions later in the evening because of this extension. This could be due to a different demand at these charging stations or because users had already adapted their daily patterns to the earlier policy on which the policy had no effect. Users at charging stations that previously had *fullday charging* also did not shift their behaviour to earlier times due to the implementation of *daytime charging 10-22*. This was mainly caused by the fact that the peak in demand was before 22:00, only 3 % of the sessions take place between 22:00 and 00:00. The policy did not require them to change their behaviour.

This paper has analysed the effect of daytime charging 10:00-19:00 and 10:00-22:00 using a large dataset in the municipality of The Hague, a policy that could overcome the before mentioned conflict. The results suggest that *daytime charging 10-19* prohibits EV users from using the charging infrastructure during the evening. However, daytime charging from 10:00-22:00 seems to provide a solution that does not affect EV users to a large extent but can tap into the needs of neighbours wanting to use unoccupied parking spaces.

5 Discussion

This paper has discussed a possibility for municipal policy makers for implementing public charging infrastructure in high parking pressure areas. Cities are likely to be a frontrunner in electric mobility as dense urban areas are a natural habitat for the electric vehicle because of short driving distances and zero tailpipe emissions. Providing the right infrastructure is however hard as more often than in rural areas inhabitants rely on on-street parking facilities and therefore also on public charging. This could create potential conflicts with non-EV drivers when parking spots remain underutilised in high parking pressure areas.

The discussed policy is especially applicable during a transition phase when the number of electric vehicles on the road is rather small. As can be seen in the analysis overtime, charging station occupancy increases if the number of electric vehicles rises. As electric vehicles reach a large enough market share occupancy of charging stations will also rise and parking spots next to charging stations shall be considered as more regular.

Although the policy can potentially relieve parking pressure during a transition phase without a big impact on charging behaviour, it can make driving electric more complex. Recharging your EV requires different behavioural patterns compared to refuelling your gasoline car. With a limited amount of charging stations available EV users would want certainty when it comes to their availability. Policy makers have to find a trade-off between wanting to promote zero-emission transport within their city and reducing the impact on non-users. This discussion could fall within the greater realm of potential benefits for EV users such as free parking, use of HOV lanes etc.

The research has added scientifically to the understanding of charging behaviour by users in a data-driven manner, a body literature that is fairly small but growing [16][17][18]. From a societal and practical standpoint municipal stakeholders can use this research to expand their toolbox to efficiently roll-out charging infrastructure which already exists out a large variety in roll-out strategies [13] [19] [20] and more hands-on tools [8] [21] to design the parking layout.

Future research should incorporate different factors to be able to investigate the differences in occupancy profiles at the charging stations. More evidence could be gathered in other cities, and using different hours of the day to see which time fits the users behaviour the best. Sightings at charging stations would have to prove that the parking spots are also used by gasoline cars beyond these hours. Additional research could look at more factors that influence charging behaviour in all its aspects, this includes other municipal policies such as free parking but also the pricing of charging, especially in respect to 'smart charging' policies. Data driven research with a focus on real world charging behaviour could provide these new insights.

6 Literature

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