Which factors influence the success of public charging stations of electric vehicles?

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Abstract

This paper aims to answer the question: "Which factors influence the success of public charging stations?". For the empirical analyses we used data provided by the public charging stations of the city The Hague. In the second half of 2015 more than 91.795 charge sessions were logged of more than 6.693 unique charge cards. By using this database we investigated four hypotheses, which were (partly) confirmed:
1. EVs with larger capacities of rechargeable batteries lead to higher kWh usage (per charging station);
2. Higher charging station density (per acre) leads to higher kWh usage (per charging station);
3. Higher address density (per acre) leads to lower kWh usage (per charging station);
4. Higher car density (per acre) leads to lower kWh usage (per charging station).

1 Introduction

The Hague is one of the frontrunners in E-mobility in Europe when it comes to the charge infrastructure density and electric vehicle (EV) adoption. However, it has limited insight in the relevant key performance indicators of the charge infrastructure as a means to support effective decision making. This paper aims to answer the question: "Which factors influence the success of public charging stations?" (see references [1] – [15]). In this paper the success of public charging stations is defined as the average daily charged electricity in kilowatt hours (see references [16] – [18]).

The research question of this paper is very relevant. At this moment (i.e., June 2016) the city of The Hague has 568 public charging stations (each with 2 sockets, and thus 1136 charging points). This number will grow up to 1500 charging stations in 2020 (3000 charging points). To realize this ambition The Hague needs insight into the mechanisms which determine the success of new *public* charging stations for electric vehicles. The placement of new *private* charging stations is outside the scope of this paper.

During the period 2012 – 2016 The Hague used the following hypotheses, among others, to place new public charging stations.

Hypothesis 1. EVs with larger capacities of rechargeable batteries lead to higher kWh usage (per charging station).
Probably an EV with a relatively large capacity of its rechargeable battery will charge relatively many kWh per charging session. In addition, an EV with a relatively large battery capacity will drive relatively long distances and will use relatively many kWh.

Hypothesis 2. Higher charging station density (per acre) leads to higher kWh usage (per charging station).
A psychological effect of a cluster of charging stations is expected: EV users are more willing to charge at a cluster of charging stations than at stand-alone charging stations.

Hypothesis 3. Higher address density (per acre) leads to lower kWh usage (per charging station).
A relatively high address density corresponds to a relatively low average salary per household. Because the EVs are relatively expensive, we expect that a relatively low average salary per household will cause a relatively small number of EVs and relatively little charging station usage.

Hypothesis 4. Higher car density (per acre) leads to lower kWh usage (per charging station).
In streets with relatively many cars, relatively many people will use their cars to drive to their work. EV drivers who drive to their work will probably charge their EV close to their work before they start working.

In this paper we will empirically check whether these four hypotheses resulted to successful public charging stations. If the four hypotheses will be confirmed, The Hague can continue to use them for placing new public charging stations. If one or more of these hypotheses will be contradicted, The Hague has to adjust his strategy regarding the placement of new public charging stations.

The outline of this paper is as follows. In the next section we discuss the data which we will use for the empirical analyses. Next, we present the results of this research. Finally, we deal with conclusions and implications.

2 Data

For the empirical analyses we used data provided by the public charging stations of the city The Hague (i.e. the CHIEF database of the University of Applied Sciences Amsterdam;

see references [9], [15], [18], and [19]). In the second half of 2015 more than 91.795 charge sessions were logged of more than 6.693 unique charge cards. Among others, for each charging session the following variables were registered: id-number of charging station, address of charging station, id-number of EV-user, starting time and end time of charging session, and kWh charged. By using the abovementioned information the capacities of the rechargeable EV-batteries were estimated (see reference[19]).

In addition, we used demographic data from the CBS (Central Bureau for Statistics) in the Netherlands. By using this dataset we can calculate for each of the 38 districts in The Hague, among others, the following information: address density per acre, car density per acre, and percentage residential function.

3 Results

By using the CHIEF database and the CBS dataset we checked the four hypotheses which were used for the placement of new public electric charging stations.

Hypothesis 1: EVs with larger capacities of rechargeable batteries lead to higher kWh usage (per charging station).

Figure 1 provides a confirmation of the first hypothesis. Every dot represents a charging station with frequency of use (x-axis) and energy transfer (y-axis). Blue dots correspond to charging stations where regular high capacity EVs (i.e. charged at least once more than 30 kWh) dominate (i.e. more than 50% of EVs), red dots charging stations where regular low capacity EVs (i.e. charged never more than 30 kWh) dominate (i.e. more than 50% of EVs).

The blue regression line is plotted above the red regression line. This means that the average kWh per week per charging station where regular high capacity EVs dominate is greater than the average kWh per week per charging station where regular low capacity EV's dominate. Grey stripes around the regression lines correspond to 95% confidence intervals of the regression lines. The grey stripes around the regression lines confirm statistically that high capacity EVs lead to high kWh usage per charging station (i.e. there is no overlap between the 95% confidence interval of the blue regression line and the 95% confidence interval of the red regression line).

Hypothesis 2: Higher charging station density (per acre) leads to higher kWh usage (per charging station);

The second hypothesis could not be confirmed for the complete group of 38 districts in The Hague. To show this, we run a regression analyses with for each district 'the average kWh per week per charging station' as dependent variable and the 'charging station density per acre' as independent variable. It turned out, that the regression coefficient corresponding to the slope of the regression line was not significantly different from 0 on a 0.05 level. So, we could not statistically confirm the second hypothesis for the complete group of districts.

Therefore, by using the variable 'percentage residual function of a district' of the CBS dataset, we divided the complete group of districts in The Hague into two subgroups: districts with more and districts with less than 33.3% a residual function. In Figure 2 we distinguished whether a district has more or less than 33.3% a residential function. Each dot corresponds to a district. The blue line fits to districts which have for more than 33.3% a residential function. The red line represents districts with less than 33.3% a residential function. For both subgroups of districts the second hypothesis is confirmed: the slopes of both regression lines differ significantly from 0 (on a 0,05 level). This means, 'charging station density per acre' and 'Average kWh per week per charging station ' are positively correlated.

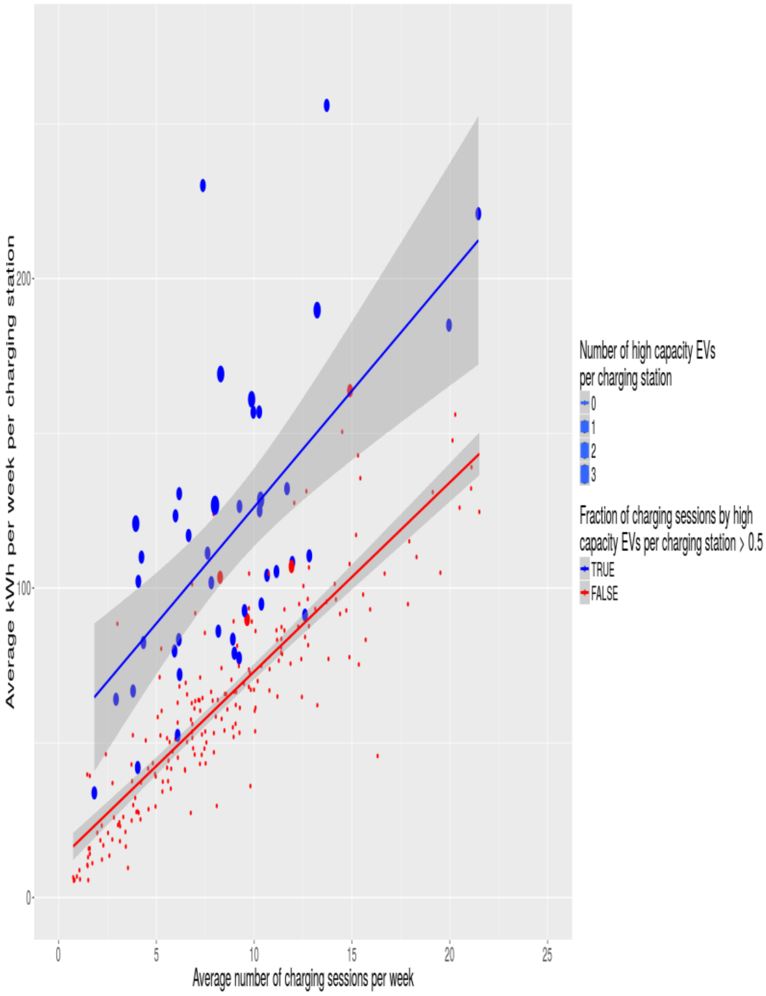

Figure 1: Average number of charging sessions per week vs. average kWh per week per charging station. (*dot: charging station*; blue line: charging stations with fraction of charging sessions by high capacity EV's larger than 50%; red line: charging stations with fraction of charging sessions by high capacity EV's smaller than 50%.)

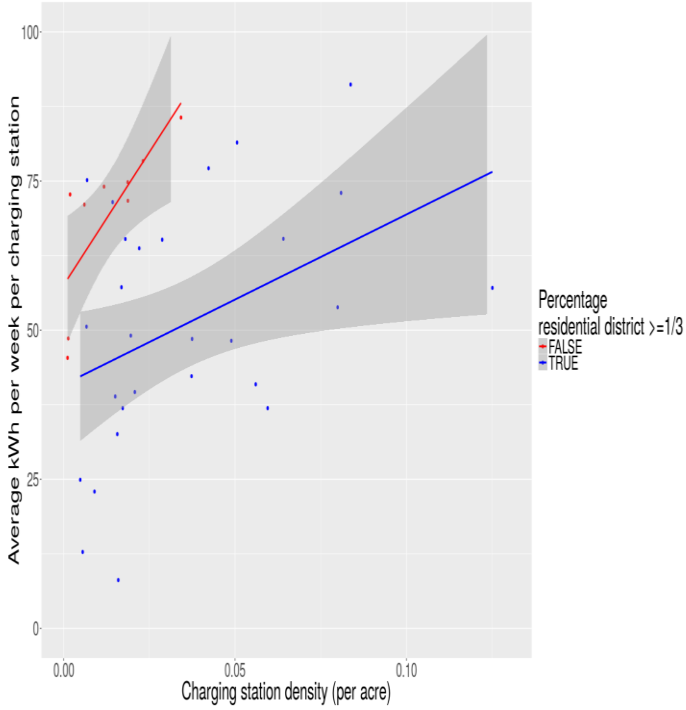

Figure 2: Charging station density (per acre) vs. average kWh per week per charging station (*dot: district*; red line: percentage residential function in district is smaller than 33.3%; blue line: percentage residential function in district is larger than 33.3%)

Hypothesis 3: Higher address density (per acre) leads to the lower kWh usage (per charging station).
In Figure 3 each dot corresponds to a district. Figure 3 shows that an increasing average number of addresses per acre corresponds to a deceasing number of charged kWh (per charging station). From the regression analyses results it follows that the slope of the regression line in Figure 3 differs statistically significant from 0 (on a 0.05 level). So, 'address density per acre' and 'average kWh per week per charging station' are negatively correlated, which confirms the third hypothesis.

Hypothesis 4: Higher car density (per acre) leads to lower kWh usage (per charging station)

The fourth hypothesis is also (weakly) confirmed by our analyses. In Figure 4 the dots represent the 38 districts in The Hague. We excluded districts with one and a half times more registered cars than inhabitants (i.e. 2 out of 38 districts) in Figure 4. We made this decision due to the fact that in industry districts relatively few people live and relatively many cars are registered (mainly, lease cars). The plotted blue line indicates: as the number of cars (per acre) grows the number of loaded kWh's per week per charging station will decrease. Our regression analyses show that the slope of the regression line in Figure 4 differs significantly from 0 (on a 0.05 level). As a consequence 'car density per acre' and 'average kWh per week per charging station' are negatively correlated. However, not that much dots in Figure 4 were predicted by the regression line (i.e. adjusted R-square equals 0.095). This implicates that the negative correlation is not strong.

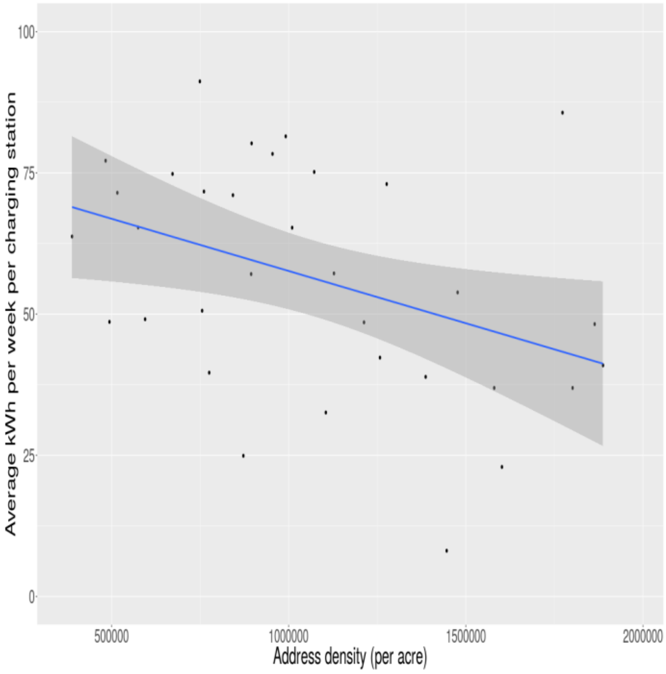

Figure 3: Address density per acre vs. average kWh per week per charging station (*dot: district*)

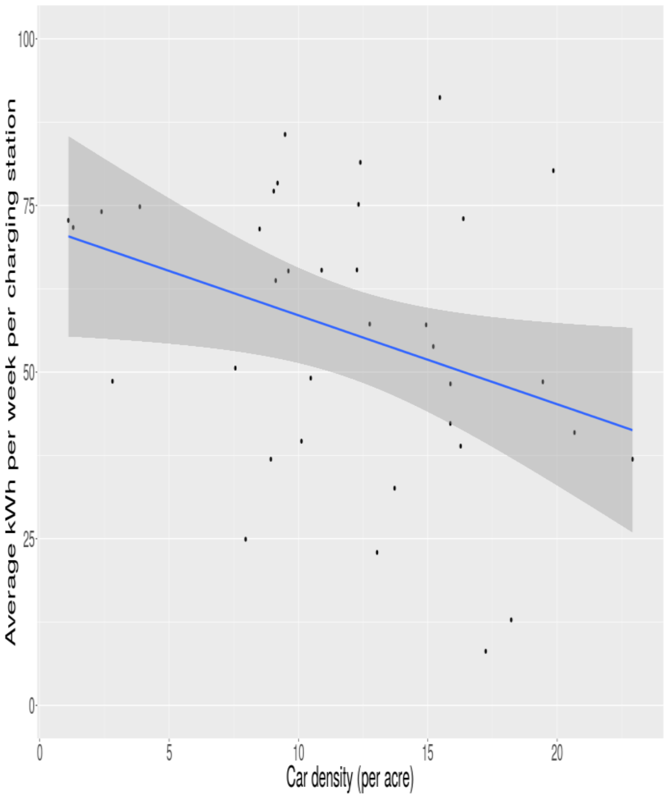

Figure 4: Car density per acre vs. average kWh per week per charging station (*dot: district*)

4 Conclusions and implications

Where hypothesis 1 seems like an open door it provides us with useful information when it comes to charge station usage. Larger batteries result in more kWh's charged. The ever growing size of battery packs in electric cars and the shift from plug-in hybrids to full electrics, the latter having larger batteries, will likely result in better used charge stations. In countries like the Netherlands where electric drivers pay per kWh charged this results in a better business case for charge station operators.

Hypothesis 2 supports the idea that electric drivers grow more rapidly than the amount of charge stations needed. Firstly this result hints towards the idea that cars don't charge at a particular charge station but use a network of charge stations. As electric cars don't use a charge station every day multiple users may be found. This can be tested through volatility tests of charge station usage. If this interpretation is true this would mean that the amount of cars using the charging network increases at a higher rate than the amount of charge stations. This would result in a more efficient usage of the current and future charging network.

The results of hypothesis 3 and hypothesis 4 appear to be contradicting. In many urban areas car ownership tends to increase when address density decreases and vice versa. However, both hypotheses may be interpreted separately without contradicting each other. In order to do so hypothesis 4 is discussed first. Car ownership tends to rise in areas where living is the main activity, contrary to working and recreation. This means that charge stations tend to be used at night when the drivers are at home where in areas with lower car ownership, charge stations are used more throughout the day.

Simultaneously, suburban areas where car ownership is high, often have their own driveway and therefore public charge station usage is automatically lower.

Hypothesis 3 shows that high urbanism isn't an essential element to public charge station usage. This is due to the fact that many areas where address density is high, income and car ownership tends to be lower. As electric cars are fairly costly at this moment income seems to be a key factor and therefore adaptation of electric cars lie lower. Please keep in mind that the difference within a municipality is studied and not the difference between municipalities. Otherwise this hypothesis would mean that the more rural an area, the higher a public charge station is used. This hypothesis, just as hypothesis 4 just shows that within a city different neighbourhood characteristics are at play that influence charge station usage.

In the field of electric vehicles charging is considered key to success. This research shows with hypothesis 3 and 4 one essential insight, which is that usage isn't homogeneous throughout a city. Charge station location is a determinant factor for charge station usage. Factors such as urban density and car density appear to be playing a key role in charge station usage. Other factors like average income, housing typology and value, functional diversity, personal preference and household size may provide an even better understanding into what factors determine proper charge station locations (see reference [15]).

Hypothesis number two shows that the density of the charging network affects the usage of it and that usage increases as the network increases with it. This hypothesis points at the idea that over time, when the network expands, usage will increase continuously and is therefore good news for charge station owners. In the beginning your network might not be used properly but as the uptake of electric vehicles takes place so does your usage of your charging network. Further research into individual usage and charge station usage volatility can provide better answers into the question on how this increase takes place.

Hypothesis number 1 shows that Dutch charge station owners' business case will increase over time and that governmental aid towards charging can be reduced over time and even become profitable in certain neighbourhoods.

All in all this research shows that charge station location plays a central role into the usage. Not only the location in neighbourhoods and cities but also in comparison to each other. Simultaneously the usage isn't static as electric car ownership and battery size keep changing. These four hypotheses provide a first insight into the dynamics of charge station usage and shows us a glimpse of the field of research that needs to be conducted in order to provide us with the necessary knowledge to build an efficient, effective and robust network of charge stations.

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