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Public charging infrastructure use in the Netherlands: A rollout-strategy assessment

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Abstract

Over recent years numbers of public charging points in the Netherlands have known a strong growth in order to facilitate charging for electric vehicles of which the sales continue to increase as well. These charging points were either installed following a request by electrical drivers with the need for charging infrastructure in the vicinity of their home, the demand-driven rollout, or by local and regional governments with the need to facilitate electric vehicle charging near public facilities and strategic locations, the strategic rollout. With a new roll-out wave coming up in the Netherlands, understanding how these charging infrastructure characteristics influence the use of the infrastructure is essential. This paper provides a detailed analysis of the use of these 'demand-driven' and 'strategic' public charging points and the implications of these rollout-strategies by analysing charging transaction data from 788.336 transactions on 1.913 public charging points between January 2012 and February 2015. Results show that demand-driven charging points show higher energy transfers and longer connection durations, and that strategic charging points generally have a higher number of unique users and have a large share of rarely used charging points. With regard to charging profiles, most demand-driven charging points, and well-used strategic charging points show high peak loads during working days and especially demand-driven charging points show a high share of nighttime chargers. These results provide insights in the use of public EV charging points which could contribute in the development of new rollout-strategies.

Keywords: EV (electric vehicle), charging, infrastructure, policy

1 Introduction

Over recent years numbers of electric vehicles (EVs) in the Netherlands have shown a strong growth, from 1.100 in January 2012 [1] to 60.000 in August 2015 [2], and sales continue to grow [3]. With a total number of 8 million cars in the Netherlands in January 2015 [4], and governmental policy aimed at 1 million EVs in the Netherlands in 2025 [2], the growth potential of EVs in the Netherlands is high. For facilitating charging possibilities for these vehicles, numbers of public EV charging points in the Netherlands have grown simultaneously from 1.250 in January 2012 [1] to 7.065 in August 2015 [2], and are also expected to continue to grow [5]. Not only will the demand for public EV charging infrastructure increase with the growth in EV's, governmental policy is also aimed at a continued large scale rollout of public charging infrastructure with initiatives in 2015 such as the Green Deal for public charging infrastructure and the creation of the National Knowledge Platform Charging infrastructure aimed at reducing the costs of the charging points [5].

The public EV charging point rollout by the national government was started in 2009 and was aimed at overcoming the chicken-egg problem between EV sales and EV charging infrastructure. The national governmental policy until 2013 has been that local and regional governments could apply for a charging point at stichting E-laad, the current EVnetNL, which would manage the application, selection and installation procedure for a charging point, and the national government would subsidize these procedures [6]. Two rollout-strategies were used. In the first strategy, the applications were based upon a request by an electrical driver for a charging point near to home, a so called 'demand-driven' charging point. In the second strategy, the applications were based upon a decision by a local or regional government to place a charging point near public facilities (e.g. governmental buildings, shopping malls) or on strategic locations where (occasional) use was expected (e.g. sporting grounds and leisure locations), a so called 'strategic' charging point.
A demand-driven rollout suggests that the resulting charging points have at least one dedicated user and have a higher probability to be located in a residential area. A strategic rollout suggests that the resulting charging points are used by a wider variety of users, that the use of certain charging points could be related to the opening times of nearby facilities, and that they might be located in low-populated areas with a low demand for charging.

With the upcoming expansion of the public charging infrastructure in the Netherlands using the demand-driven and strategic rollout-strategies, it is relevant to research how the rollout-strategy with which a charging point is established, influences the use characteristics of this charging point. Research on public charging infrastructure rollout-strategies has been performed [7] [8] [9] [10], however they tend to focus on only the early phase of rollout (first 100-500 charging points), and use a limited database in both charging transaction quantity and time-scale. This research uses a database of unequalled size in charging transactions, charging points and time-scale in order to analyse the use patterns of charging points of both rollout-strategies. This paper will therefore focus on the question: *How does the rollout-strategy of public EVnetNL charging points in the Netherlands influence the use of these charging points?*

2 Methods

First, the public charging points in the Netherlands were placed in historical context in order to understand the development of use characteristics over time. Thereafter, the use of these charging points are discussed in the context of the rollout of the public EV charging infrastructure in the Netherlands. Below, the different characteristics are discussed on the basis of which the data are analysed and results are elaborated.

2.1 Charging point characteristics

For describing the rollout of charging points in the Netherlands over time, three charging point characteristics were used. The first characteristic was the *rollout-strategy*. This rollout-strategy for a charging point could either be the demand-driven rollout or the strategic rollout. The second characteristic was the *installation date*, which refers to the day on which the charging point was connected to the grid and from which it could be used by EV drivers. The third characteristic is the *charging point location*, and refers to the exact location where the charging point is installed. By use of this characteristic, the spatial distribution of the charging points and the use of different rollout-strategies could be described.

2.2 Charging point use characteristics

The use of the charging points was analysed by using *charging point use characteristics* [11] [12] [13]. These characteristics are shown in table 1.

Table 1: Charging point dataset content

Charging point use characteristic	**Definition**
Charging transaction quantity	Number of charging transactions
Energy transfer	Amount of energy transferred
Connection duration	Date and time of start and stop of connection
Users	Userbase diversity, identified by amount unique charging pass ID's
Connection profiles	Profiles of connection times
Charging profiles	Profiles of charging loads

The *charging transaction quantity* is the amount of different transactions in a certain time period that have taken place on a charging point. This characteristic refers to the intensity of use of a charging point, and is an indicator of the development of EV in the Netherlands when monitored over time for all charging points. The *energy transfer* refers to the amount of energy transferred during the transaction, and is therefore both an indicator for the intensity of use of the charging point and an indicator for the development of EV charging demand when analysed over time. The *connection duration* refers to the duration in which a vehicle is connected to the charging point, and therefore an indicator of how long the charging point was occupied during the transaction. The characteristic of *users* refers to the number of unique users that use a charging point in a certain period. This is an indicator for the diversity in users by which a charging point is used. *Connection profiles* [13] [14] refer to the profiles of the start-times and stop-times of transaction connections over the hours of the day. These profiles are an indicator for the actual EV charging demand over time during the day and night, as these start and stop-actions require user involvement to plug-in or plug-out the EV. These transactions then lead to the characteristic of *charging profiles*, which refer to the profile of energy transfer over time during the day. The starts of these energy transfers should be close to the start of the connection, however the end of the energy transfer may come earlier than the end of the connection. Therefore, these profiles form a separate characteristic.

2.3 Data

The data used for this paper are provided by EVnetNL, and consists of two datasets. The first dataset consists of data regarding details on 1.913 EVnetNL charging points. This dataset was extracted from the EVnetNL installation management system, in which details on charging point applications, the installation, the maintenance and related financials are stored and monitored. Table 2 shows the information in this dataset. The second dataset consists of data regarding details on 788.336 charging transactions performed on these charging points between January 2012 and February 2015. Table 3 shows the information in this dataset.

Table 2: Charging point dataset content

Data	**Definition**
Charging point code	ID code for charging point
Charging point address	Street, number, postal code, municipality
Rollout-strategy	Applied for by EV driver (demand-driven), or by government (Strategic)
Charging point model	Manufacturer and model
Connectors	Number of connectors on charging point
EAN grid connection code	Identification code for grid connection
Connection installation date	Date of fist time charging availability

Table 3: Charging transaction dataset content

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

After filtering a small share of invalid transactions (incomplete data, negative energy transfers, connection durations below 15 seconds) in line with previous EV data analysis research [11], these datasets provide data on 788.336 transactions on 1.913 different charging points by use of 30.782 unique charging passes. Of these charging points, the application types of 75 points were unknown, 1.111 were strategic, and 727 were demand-driven.

A comparison of the amount of users that have used charging points will be made based on the charging passes that have been used for identification on the charging point, as no details are registered on the identity of the user itself. Despite the possibility of one person using more charging passes and vice versa, more unique passes being used is seen as an indicator for more unique users at a charging point.

Moreover, the database does not include data on the duration of the actual charging during a charging transaction. Therefore, for analysing the charging profiles of charging points, these charging profiles are constructed per transaction in the database using the average charging load provided during all transactions on a certain charging point, the starting point in time of the connection and the total energy that is transferred in a charging transaction. These profiles are the input that is used for constructing the average charging profile on charging points.

3 Results

Due to the fact that developments in charging point use, such as the number of transactions or amount of energy charged, are dependent on the development in the charging point rollout and related charging point characteristics, this development will first be described in historic perspective, followed by the rollout of charging points with regard to geographical spacing.

3.1 Charging point rollout over time

The numbers of public EVnetNL charging points installed in the Netherlands between January 2012 and January 2015 are shown in figure 1.

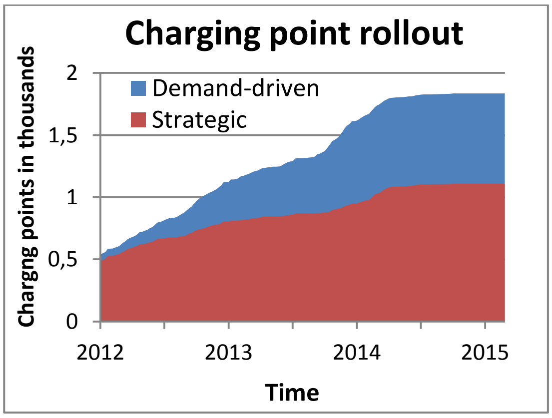

Figure 1: Public charging point rollout in the Netherlands between 2012 and 2015

Due to the fact that the public charging point rollout started in 2009 [15], and the first EVs came on the Dutch market in 2012, most charging points up until 2012 were strategic, and very little demand-driven applications were received before that. On January 1st 2012, 480 strategic charging points were installed against 54 demand-driven charging points. Due to budgetary reasons the Dutch national government stopped the application process for subsidised public charging points in January 2013, and all requests were temporarily put on hold [16]. In the meantime, only charging points that were accepted already in 2012 were installed in the start of 2013, which results in the smaller increase in charging points in this period. From June 2013 the charging points from the applications that were put on hold were resumed, and the installation of these charging points was finished in October 2014 [17]. From this point onwards until the start of 2015, no charging points were installed which were subsidised by the government. In the period between 2012 and 2015, the charging points from two different rollout-strategies grew with comparable numbers: 631 strategic and 673 demand-driven charging points were installed.

3.2 Geographical charging point rollout

When looking at a map of all EVnetNL charging points in the Netherlands on January 1st 2015, and differentiated by rollout-strategy (figure 2), several aspects stand out.

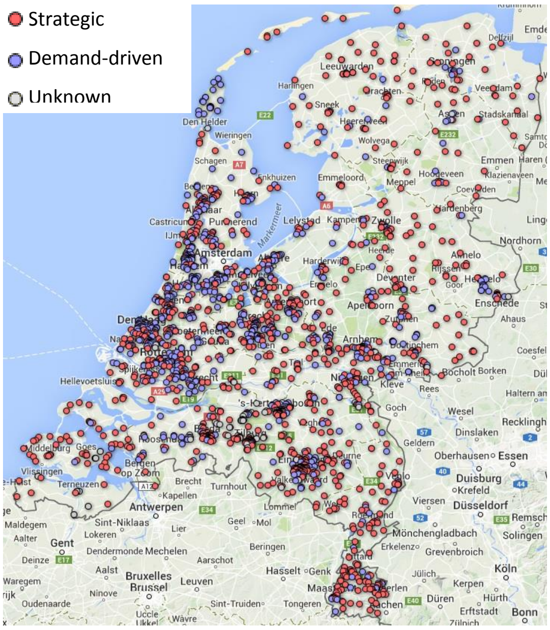

Figure 2: Public charging point locations in the Netherlands on January 1st 2015

Figure 2 shows that the charging points are located all throughout the Netherlands. However, the map also shows that most charging points in general and especially demand-driven charging points are located in the high populated area of the 'Randstad' (the triangle between Amsterdam, Rotterdam and Utrecht), and in larger cities in more rural areas such as Eindhoven, Tilburg and Arnhem. This is to be expected, as a higher population density brings a higher probability for the use of EV's, (and thus a higher demand for charging points), and people in higher-density areas might be dependent on public EV charging as they do not own ground on which to install a private charging point. One aspect that also stands out in the map is that even in very low populated areas such as the south of the province of Zeeland, the province of Drenthe and the Wadden islands, several primarily strategic charging points are located.

These aspects from the rollout over time and the rollout in geographical spacing could have implications for the use of these charging points, as the charging points from the two different rollout-strategies primarily show different characteristics which regard to development over time, and location in comparison with population density.

3.3 Charging point use

The results from the analysis of the use of charging points from different rollout-strategies are structured in this chapter using the before mentioned charging point use characteristics.

3.3.1 Charging transaction quantity

In figure 3 a graph is shown with the numbers of transactions per week for all charging points within a rollout-strategy, in the period 2012 to February 2015.

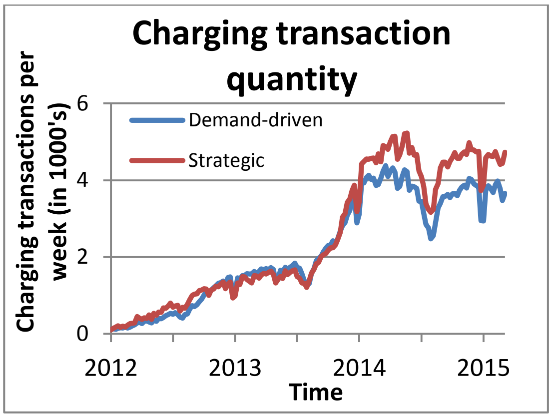

Figure 3: Number of charging transactions per week for the two rollout-strategies, 2012 – Feb 2015

Figure 3 shows comparable numbers and growth in transaction quantity for the both rollout-strategies, despite the large differences in numbers of charging points within these categories in the period between 2012 and 2014 (see figure 1). This shows that the use of charging points in this period was very low, and the higher number of strategic charging points did indeed precede the actual demand. The figure also shows that the number of transactions grew fast in the end of 2013, when EV sales exploded in the Netherlands due to a then expected decrease in fiscal benefits for EV ownership starting 2014 [18]. From this point onwards, strategic charging points show more transactions despite the comparable amount of active charging points in the categories. The large temporary decreases that are seen halfway through 2012, 2013 and 2014 represent the summer holidays in which the amount of transactions temporarily decreases by around 24%. The decreases in transactions during holidays are greater on strategic charging points than on demand-driven charging points.

3.3.2 Energy transfers

In order to compare the energy transfers (in kWh) for the different rollout-strategy charging points, figure 4 shows the amount of energy transferred per week by all charging points in the two different rollout-strategies, period 2012 to February 2015.

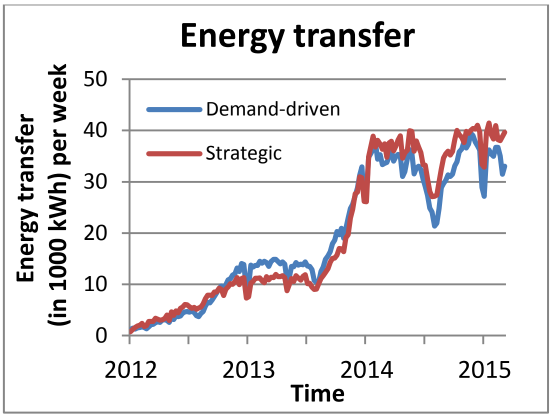

Figure 4: Energy transfer (kWh) per week for the two rollout-strategies, 2012 – Feb 2015

The development over time is almost the same for the two categories in the period 2012 – 2014. However, despite having the same amount of transactions in this period, demand-driven charging points show a higher total energy transfer in the first half of 2013. Moreover, the difference seen in transactions during 2014 is almost gone the energy transfer graph. These differences suggest that average energy transfers for demand-driven charging points are higher. Therefore, the average energy transfer per transaction per week for each of the two rollout-strategies is shown in figure 5.

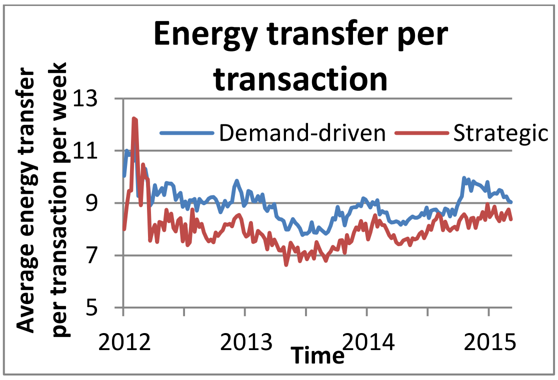

Figure 5: Average energy transfer (kWh) per transaction per week for the two rollout-strategies, 2012 – Feb 2015

Figure 5 indeed shows that the average energy transfer per transaction is structurally higher then strategic charging points, with an average difference in this period of 0,94 kWh. This difference is also visible in figure 6, in which all transactions in this period are organised based on energy transfer size.

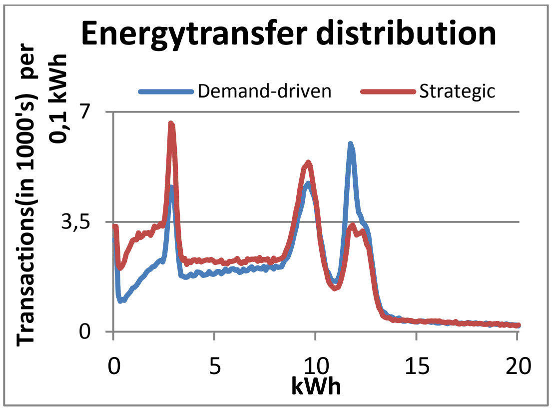

Figure 6: Distribution of charging transactions in thousands per energy transfer amount (kWh)

The distribution shows several differences between the rollout-strategies with regard to energy transfers. Smaller transactions occur more often on strategic charging points, and larger transactions, especially between 11-13 kWh, occur more often on demand-driven charging points. Charging transactions larger than 20 kWh account for only 4% of all transactions on demand-driven, and 4,2% of all transactions on strategic charging points.

3.3.3 Connection durations

When considering average connection duration per transaction over time, shown in figure 7, a comparable difference becomes apparent.

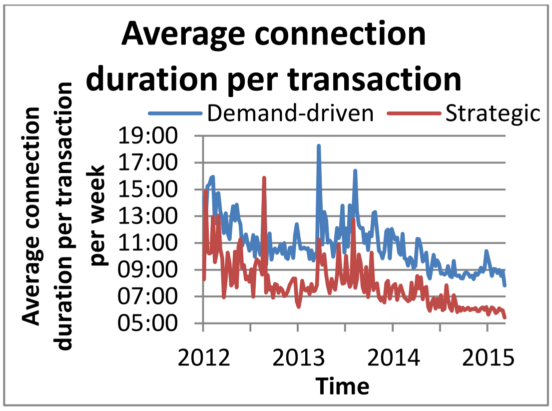

Figure 7: Average connection duration per transaction per week for two rollout-strategies, 2012 – Feb 2015

The average connection duration per transaction show a structural difference as well. This could be expected, as larger energy transfers require longer charging durations. On average, a difference of 3 hours connection duration is seen in this period. Moreover, strong positive outliers are seen during holidays, which are caused by connections lasting for more than a day, probably due to the EV not being used and still being connected. Also, a difference is seen between a decline in average connection duration towards the end of 2014 during an incline average energy transfer during this period. This could be caused by the strong increase in PHEV registrations (51% in 2014) [2] with battery capacities between 12 and 20 kWh [19] (above the average energy transfer in this period), and which would typically require a charging duration below the measured average connection duration. In the distribution of connection durations (figure 8) the same development is visible.

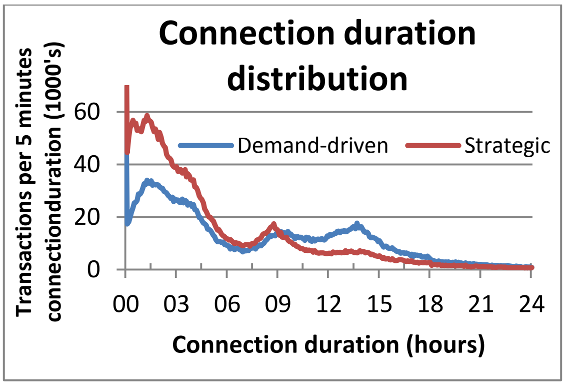

Figure 8: Distribution of charging transactions in thousands per 5 minutes connection duration

Longer connections occur more often on demand-driven charging points and shorter connections more often on strategic charging points. Also, a large number of transactions are faulty, and last shorter than 5 minutes: for demand-driven charging points these faulty transactions are 1,8% of all transactions, whilst for strategic charging points this amounts to 2,6%.

3.3.4 User

With regard to users of the two charging points categories, a comparison has been made with regard to the amount of unique charging passes that have been used on charging points. In order to compare the number of unique users over time between the two charging point categories, a correction has been made for the difference in amount of charging points over time. Therefore, figure 9 shows a comparison of the average amount of charging passes per week per charging point over time. Figure 9 shows a comparable increase in unique charging passes as the amount of transactions per week in figure 3.

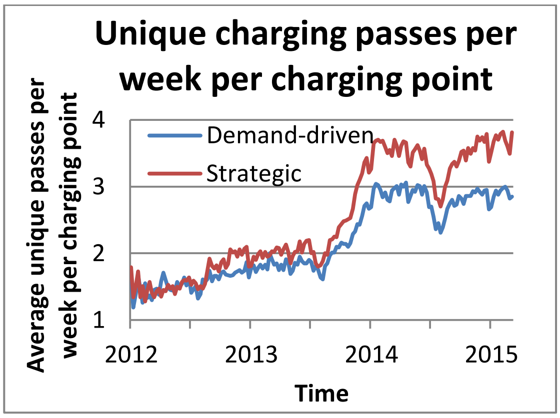

Figure 9: Average amount of unique charging passes per week per charging point, 2012 – Feb 2015

However, after the strong increase in transactions near the end of 2014, the difference between unique passes at strategic and demand-driven charging points increases. During 2014, strategic charging points showed on average 21% more unique charging passes per charging point in comparison with demand-driven charging points.

3.3.5 Connection profiles

The use activity at the charging points with regard to the time of day is shown using the time at which connections are started and ended. Connection profiles of start (figure 10) and stop times (figure 11) on working-days are shown below. These figures have been corrected for the difference in amount of charging points per category.

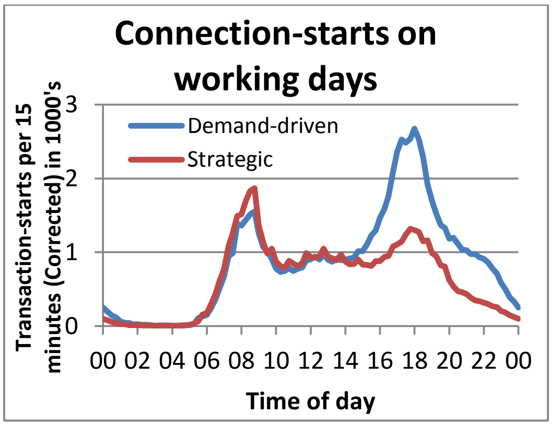

Figure 10: Connection starts profile on working days, 2012 – Feb 2015, corrected charging point quantity

The connection-starts on working days show comparable activity in the morning, and 96% more transaction-starts on demand-driven charging points between 5 pm and 7 pm.

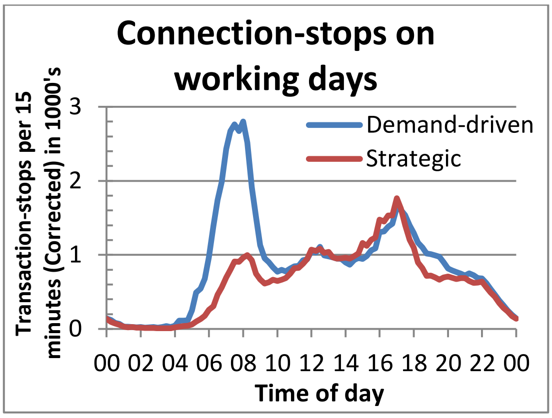

Figure 11: Connection stops profile on working days, 2012 – Feb 2015, corrected for amount of charging points

Figure 11, the connection stop profiles on working days, shows the opposite of figure 10: the evening shows comparable activity, however connections are ended way more in the morning (between 7 AM and 11 PM) on demand-driven charging points.

These connection profiles show several results. First, clear simultaneous activity is visible with start-peaks in the morning and in the evening, for both categories. Second, the start-peak on demand-driven charging points is twice as high compared to strategic charging points. Thirdly, the high start-peak in the evening and the stop-peak in the morning show a large share of 'nighttime chargers' on demand-driven charging points. And fourth, the relatively high start-peak in the morning on strategic points show a large share of daytime chargers on strategic charging points. When weekend connection profiles are analyzed, results show that activity is evenly spread (a normal distribution), throughout the day (between 7 AM and 12 PM) on both charging point categories.

3.3.6 Charging profiles

The connection profiles, profiles of user-activity, result in activity with regard to electricity in the grid resulting from the user interaction moments. In figure 12 the working day charging profiles with average values per charging point (considering all charging points within the category) are shown for both charging point categories.

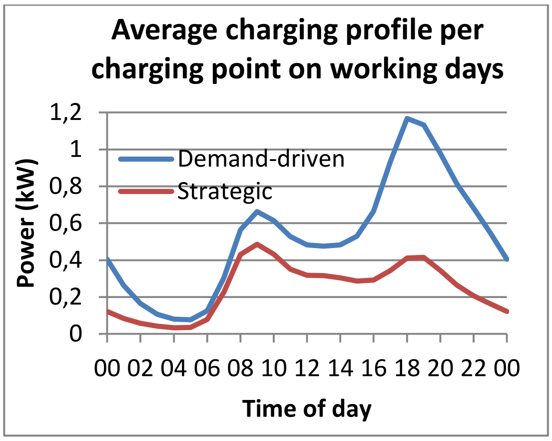

Figure 12: Average charging profile per charging point on working days, 2012 – Feb 2015

Figure 12 shows a large difference in power load during the evening hours between the two categories. This is a result of the high number of night-time chargers on demand-driven charging points. The overall power is low for charging points that offer a maximal charging load of 11 kW [20]. This is due to the influence of charging points that are used less frequent, which results in a decrease in the averages of the charging profile. Therefore, figure 13 shows the average charging profiles per charging point, for the top 100 charging points per category with regard to the amount of charging transactions.

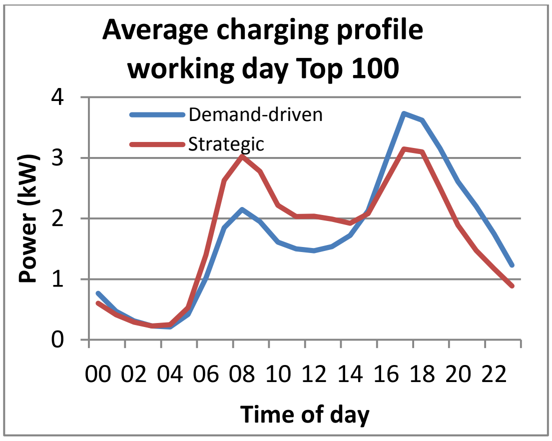

Figure 13: Average charging profile per top 100 charging point on working days, 2012 – Feb 2015

The top 100 charging profiles show that for the best used charging points, the average charging profiles do not differ a lot between the two categories. The morning peak is higher for strategic charging points, and the evening-peak is higher for demand-driven points. In the weekends, charging profiles show a normal distribution throughout the day between 7 AM and 12 PM, for both the general charging profiles as for the top 100 charging profiles.

4 Conclusion

This paper is focussed on the research question: *How does the rollout-strategy of public EVnetNL charging points in the Netherlands influence the use of these charging points?* This was done by analysing charging point characteristics and charging point *use* characteristics of demand-driven and strategic charging points. This was based on data from 788.336 charging transactions on 1.913 public EVnetNL charging points in the Netherlands.

With regard to the charging point characteristics, results show that before the first EV's came to the market in the Netherlands early in 2012, already 480 strategic charging points were installed throughout the Netherlands, against 54 demand-driven charging points. Between 2012 and February 2015, 631 new strategic and 673 new demand-driven charging points were installed. Regarding the geographical distribution, results show that especially demand-driven charging points are located in the high population density area of the 'Randstad', and that in low populated areas several primarily strategic charging points are located. Not only will a denser populated area induce a higher probability of the use of EV's, also will inhabitants more often rely on public charging points as they do not own ground on which to install a private charging point.

With regard to the charging point *use* characteristics, results show several differences and similarities between the two charging point categories. The charging transaction analysis shows that despite the large difference in charging points within each category between 2012 and 2014, the amount of charging transactions and the energy transferred is comparable during this period. After the EV sales growth in the end of 2014, all strategic charging points combined show more transactions. However during 2014, the difference in transactions does not lead to a difference in energy transfer. This is caused by the fact that demand-driven charging points show a structural higher average energy transfer per transaction in comparison with strategic charging points, with an average difference of 0,94 kWh. The energy transfer analysis shows that larger transactions, especially in the 11-13 kWh range, occur more often on demand-driven charging points. This is the result of the longer connection durations that are seen at demand-driven charging points. On average, connections on demand-driven charging points last 3 hours longer than on strategic charging points. Moreover, strategic charging points show more faulty transactions.

With regard to users, results show that in 2014, strategic charging points on average showed 21% more unique charging passes per charging point in comparison with demand-driven charging points. Connection profile analysis shows that large-scale simultaneous connection-starts primarily happen on working days. On these working days, the two charging point categories show comparable activity in connection starts in the morning (7 AM – 10 AM), however also show that between 5 PM and 7 PM, twice as much connections are started on demand-driven charging points in comparison with the strategic charging points. These transactions are mainly started by ‘night-time chargers’, as a considerable peak of connection-stops is seen in the morning on working days on demand-driven charging points. During weekends, connections are started and stopped distributed in a normal distribution throughout the day between 7 AM and 11 PM. These results are also visible when considering the charging profiles for all charging points combined. A strong charging load peak is seen on demand-driven charging points on working days between 4 PM and 23 PM. However, when these charging profiles are shown for the best 100 charging points per category, the difference is almost gone. In this graph, charging load peaks are seen for both charging points in both the morning and in the evening.

5 Discussion

The results from this research contribute to understanding what the influence of the rollout-strategies is on the use of the charging points.

These results add to scientific insights by showing the actual charging point use data which has so far not been publicised. Moreover, the implications from these results could serve as an inspiration and starting point for further research into charging point use and rollout-strategies.

The results from this research could also be used in developing and improving the rollout-strategies with regard to large scale EV charging infrastructure. The ongoing growth in EV’s in the Netherlands, combined with the ongoing increase of battery capacities and charging speeds bring a strong increase in power demand for charging these vehicles. This could result in local power overload in the electricity infrastructure [21] [22]. Understanding the implications for rollout-strategies for the use of charging points, and eventually the resulting risks for local power overload could allow policymakers to pro-actively avoiding these risks by using a balanced rollout-strategy. Moreover, for effective use of smart-charging technology capable of balancing these load peaks whilst avoiding the high costs of grid reinforcement, it is essential that the charging behaviour of users allows the system room, or flexibility capacity, to influence the charging transaction (such as the starting time or the charging speed) [22] [23]. It is therefore relevant to understand which charging point characteristics influence the use of these charging points, and what the results of these influences are.

In order to improve the insights on the influence of rollout-strategies, future research could emphasize several aspects. First, data could be involved on the ‘utility ratio’: the difference between connection duration and charging duration. Moreover, the duration of the actual charging process could be included in analysis which would add to the reliability of the charging profiles and related insights. Also, future research could involve the use of private charging points in order to retrieve a better view on the energy use of all EV charging activities in the Netherlands.

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