EVS29 Symposium
Montréal, Québec, Canada, June 19-22, 2016

Benchmarking Charging Infrastructure Utilization

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Short Abstract

Since 2012 the Dutch metropolitan area (The metropole region of Amsterdam, the city of Amsterdam, Rotterdam, the Hague, Utrecht) cooperate in finding the best way to stimulate electric mobility through the implementation of a public charging infrastructure. With more than 5600 charge points and 1.6 million charge sessions in the last two years this is one of the most extensively used public charging infrastructure available worldwide. In this paper a benchmark study is carried out to identify different charge patterns between these 5 leading areas with an extensive public charging infrastructure to establish whether and how charge behaviour (e.g. charged volume, capacity utilization, unique users) differs between cities. Based on the results first explanations for possible differences in charge patterns between cities will be provided. The study aims to contribute to a better understanding of the utilization of public charging infrastructure in a metropolitan area existing of four city centres and the Amsterdam metropolitan area and to provide input for policy makers to prepare a public charging infrastructure ready for the projected growth of electric mobility in the next five years.

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1 Introduction

Since a couple of years the Dutch metropolitan area (The metropole region of Amsterdam, the city of Amsterdam, Rotterdam, the Hague, and Utrecht) cooperate in finding the best way to stimulate electric mobility. Distinct differences exist between the roll out strategy of the municipalities both in terms of volume, location selection and incentive systems. By the end of 2015 a comprehensive and innovative grid has been created of more than 5600 charge points in the city areas. In the last two years more than 1.6 million charge sessions were recorded. This is one of the most extensive urban coverages of public charging infrastructure worldwide. In the coming years the municipalities will invest in the further development of charging infrastructure to grow from 5600 to more than 8.500 charge points in 2018.

Important questions for municipalities relate to where new charge points should be placed (location selection), when to place them (timing) and what type of charging infrastructure is to be placed (charge station with 2 sockets, charge hubs with 4+ poles, fast charging infrastructure). The 5 cities cooperate with the Amsterdam University of Applied Sciences (AUAS) in the four year research project “Intelligent data-driven optimization of charging infrastructure” (IDO-Laad) to develop forecasting and simulation models for charge behaviour and dashboards to explain particular well- or ill-performing charge stations. All charge records of the cities and their regions are brought together in one data warehouse at the Amsterdam University of Applied Sciences. Based on this unique set of more than 1.6 million charge records, the AUAS carries out data analyses, fore-casts, simulations, policy evaluations and cost-benefit analyses in order to help actors involved in the chain to roll out smart strategies for the charging infrastructure.

Objective of this paper is to present research findings regarding differences in charge behaviour and charge patterns between the five – in terms of available public charging infrastructure - leading cities in the Netherlands: Amsterdam, Rotterdam, the Hague, Utrecht and the Metropole region of Amsterdam (MRA). The five cities have slightly different local regulations, incentive structures and spatial structures but operate in a similar national regulatory context. Analysing and comparing charge patterns between the cities provides opportunities to distinguish differences and evaluate the effect of local incentive structures, regulations and spatial structures on the use of public charging infrastructure. This paper will present the results of extensive analysis of differences in charge behaviour and use of the public charging infrastructure, defines possible influencing factors to describe these differences, and will anticipate on possible measures to create a future-proof public charging infrastructure in urban areas.

2 Related works

With a growing number of EV's on the road and a growing number of (public) charge points the number of studies investigating charge behaviour and charge infrastructure utilization is growing. Early research has focussed on theoretical models of how an optimal charge infrastructure should be designed [1][2][3]. These theoretical models vary from an entirely mathematical approach [4], to using traffic data [5]. Starting point of these studies was either to have an efficient infrastructure usage or to accommodate the EV driver.

Alongside the development of these models real world trails were executed to monitor driving and charging behaviour. Studies have focussed on the effects of range anxiety [6][7] but also on how charge infrastructure effects driving behaviour [8].

In the last years the number of EV's and charging points has increased significantly [9] and prospects are that they continue to grow at a fast rate in the coming years. This means that more research on actual driving and charging patterns has become available.

Several studies have analysed the driving and charging behaviour from EV's in either trails or real world situations. To our knowledge studies have been performed in Germany [6], The United states [8], Australia [10][11], England [12], Canada [13], Ireland [14] and the Netherlands [15][16][17]. Many of these studies look at the EV driver or the impact of EV charging on the grid yet charge infrastructure utilization as a study has been scarce. Studies focussing on this topic are more elaborately discussed below.

2.1 Charge infrastructure utilization

The following section evaluates the studies that have focussed charge infrastructure utilization as such. Each of the studies is discussed more in-depth.

United States

The Idaho National Laboratory [8] has performed one of the larger studies on charge infrastructure utilization and charge behaviour. The research evaluated home, workplace, public and public fast charge stations. Home and workplace charging were the dominant mode (96% of charge events) both for FEV as PHEV.

Public charge infrastructure usage was low (1.4 events per week) but was also very location dependent, some of the public charge stations had between 7-11 charge sessions a day. Public fast charging was used more intensively (7.2 charges a week). The researchers found weak correlations between the location (e.g. shopping malls) and infrastructure usage but saw that these factors were often location specific and differed between cities.

Charging behaviour was influenced by the price of electricity as most drivers started their home charging either at midnight or at 1 when prices of electricity were lower than during the daytime. Fast charge utilization also showed a significant drop when fast chargers were no longer free to use.

The report did compare the roll-out strategies of several cities of public charge infrastructure but the utilization of these charge points was not evaluated.

The Netherlands

In the Netherlands a study [17] was performed on 1.913 public charge points which were installed by using two different roll-out strategies: Demand-driven or strategic. Usage of these charge points was compared showing little differences in general trends such as number of sessions or kWh charged.

However demand driven charge points recorded an average higher amount of energy charged per session, more longer sessions and few shorter sessions, a lower amount of unique users and showed a different use profile throughout the day. Strategically placed charge points had more sessions that started in the morning. Demand-driven charge points showed an utilization comparable to home charging.

A second study [15] on the charge infrastructure in Amsterdam shows that charge point utilization can differ between the neighbourhoods. Local conditions can thus be important for charge point utilization. The type of users such as electric car sharing schemes also create a different dynamic of charge infrastructure utilization. These cars are only used for short rides and thus only require little energy to recharge but are often connected to a charge point.

The study further shows that most charge points are underutilized but that utilization grows as more EV's become available. The utilization of charge points however is much lower when only the charge time is considered. Only 12% to 18% of time connected is actually used for charging. This leads to overall utilization of only 4% to 5%.

Ireland

The study in Ireland [14] analysed the utilization of over 700 home, public and fast charge points over the course of 3 years. The study investigated the relation between the location and type of the charge station and it's utilization.

Standard and fast charging installations are compared by using the surroundings they are placed in, either a car park or a petrol station. In a car park charge sessions and consumption are significantly longer and higher for standard charge equipment compared to petrol stations. For fast charge equipment this reversed, the average consumption is higher at petrol stations.

The utilization of charge points during the day also differed as standard charge points were used mostly in the morning while fast charge stations were mainly used in the evening and night corresponding to commute behaviour. Standard equipment at car parks were used when the car was not used, while fast charging and charge equipment at petrol stations was used to 'top-up' the battery's energy level to complete the trip.

2.2 Conclusions

With a growing number of EV's on the road and charge stations available the number of studies to evaluate the utilization of this infrastructure is increasing. More often real-world data is used expanding the knowledge on the behavioural differences between EV and ICE drivers.

The few studies using the infrastructure as a subject of study have been using descriptive statistics as a means to compare the utilization often at an individual level or at the characteristics of these charge points such as the location (petrol station vs car park) or the roll-out strategy (demand driven vs strategic placement).

Such studies however do not consider the interactivity between several charge stations. This is most likely because the charge point density is low and charge points can be considered as the sole option to recharge in the surroundings. However with a growing number of EV's and increasing numbers of charge stations a more dense network is developing in many cities.

Therefore there is a need to evaluate the infrastructure utilization at a higher abstraction level. As cities are often actively involved in developing a charge infrastructure analysing the usage at this level is considered relevant and not yet available. The city as an unit of analysis also allows municipalities to compare and evaluate their roll-out strategies or to identify patterns at a larger scale. This analysis allows cities to compare the utilization at city level but also at comparable neighbourhoods, e.g. using household density, income levels.

This review of literature has shown that although the analysis of charge infrastructure utilization has taken off in the recent years, the unit of analysis has mostly been the single charge point or its characteristics. This papers provides using the city as a unit of analysis a new insight into charge infrastructure utilization which is becoming more valuable as the charge point density is increasing.

3 Methodology

Data has been collected since March 2012 on charge sessions of publicly accessible charge points with in the cities. Charge points can all be accessed by swiping a RFID card after which the user connects the charge cord to the socket. The session ends when the charge cord is disconnected. The charge points belong to a number of different providers but can all be accessed with the same RFID card due to an implemented communication protocol. Users receive a monthly bill from their RFID providers and are charged per kWh and depending on the charge point and RFID provider are also charged with a per session fee. Charge points are level 2 AC chargers capable of both 1 and 3-phase charging. The power supplied differs between the charging point.

The following type of data is collected from the charge sessions:

Variable	Example	Description
RFID	60DF4D78	RFID Code of charging card
Charge point operator	Essent	Owner of the charge point
Location_skey	456	Unique location key per charge station
City	Amsterdam	City in which charge point is placed
Address	Prinsengracht 767	Address charge point is placed
Postal Code	1057EW	ZIP Code in which charge point is placed
Start Connection Date Time	24-04-2015 13:56:00	Start date and time of charge session
End Connection Date Time	24-04-2015 17:14:00	End date and time of charge session
Connection Time	2:18:00	Time the car is connected
Charging Time	1:45:00	Time the car is charging
Volume	6.73	Amount charged [kWh]
Chargesession ID	4568970	Unique charge session

Table 1 Data variables, examples and descriptions from CHIEF database

Since the start of the project, March 2012 until the end of 2015 1.9 million charge sessions were recorded. Charge sessions with no kWh charged or shorter than 5 minutes are not likely and irrelevant for the analysis and therefore considered as erroneous data. To our understanding there or no EVs on the market with a battery package of over 100 kWh and therefore these charge sessions are left out of the dataset. Charge sessions longer than 28 days are outliers in the dataset and therefore considered not relevant. Most analysis focus on the period in 2014 and 2015. After applying these filters 1.6 million sessions are left in the dataset, 84% of all sessions.

3.1 Charge Time

In an earlier study on data solely from the city of Amsterdam [15] not only the time connected but also the time actually charging is studied. As users only pay for kWh charged and not per hour connected users have no incentive to move their EV once fully charged. EV users also use public charge point as a substitute for a home chargers as on-street parking is the only available option in many of the inner-city areas.

To evaluate the utilization of charge points the time charging is a relevant performance indicator. Such data is however not directly available in the dataset and therefore needs to be derived. The following method has been applied to derive the actual charge time:

As the power supplied to charge point can differ and EV’s on the market have two types of charging possibilities (1 and 3 phase) a matrix of charge speeds need to be considered.

The subset of charge stations is defined as $X_z = (1,2 \dots \dots, x)$

The charge speed I is therefore a function both the RFID and charge stations characteristics:

$$I = f(N_n, X_{ampere})$$

The charge speed of a certain RFID at a certain charge station is dependent on the characteristics of the RFID as the charge station. The set of possible charge speeds is limited to the set as defined in table 2.

Charge station	1-Phase (230V)	3-Phase (400V)
13A	3.0kW	9.0kW
16A	3.7kW	11.0kW
20A	4.6kW	13.8kW
32A	7.4kW	22.0kW
63A	NA	43.5kW

Table 2 List of possible charge speeds

As both the technical specifications from the charge station as the RFID are unknowns in the database they have to be derived from the dataset. For each RFID (considered as unique user) the maximum charge speed is defined as follows:

We use the set:

$$N = (1,2 \dots \dots, n)$$

Were n denotes each unique RFID

The set of RFIDs is divided by its technical capabilities being either a 1-phase or three phase charger:

$$N = \begin{cases} N_{230V} \\ N_{400V} \end{cases}$$

For each of the unique RFID's the subset of charge sessions is defined as:

$$K_n = (1,2, \dots \dots, k)$$

For each charge session *k* the charge speed *I* is evaluated:

$$I_k = \frac{Volume_k}{Connection\ time_k}$$

The maximum charge speed for each RFID is calculated:

$$\underset{n \in N}{\mathrm{Imax}} = \max_{k \in K} \left(\frac{Volume_k}{Connection\ time_k} \right)$$

Each charge station is categorised by the amount of Ampere it is supplying using the maximum charge speed Imax as a measure.

$$X_{ampere}(Imax) = \begin{cases} 13, & Imax_x < 9.0 \\ 16, & 9.0 \ \geq \ Imax_x < 11.0 \\ 20, & 11.0 \geq \ Imax_x < \ 13.8 \\ 32, & 13.8 \geq \ Imax_x < \ 22.0 \\ 63, & Imax_x \geq 22.0 \end{cases}$$

As can be seen from table 1, in case of 1-phase charging charge speeds never reach more than 7.4 kW. Therefore:

$$N_n = N_{400V}\,, \qquad Imax_{\ n} > 7.4kW$$

As 3-phase chargers can have longer connection times than charging times it is possible that the Max charge speed <7.4 kW. To avoid these errors both the charge stations and charge sessions are defined by their maximum charge speed.

For the subset N != N_{400V} each charge session *k* is categorised in the following way, in which $I_{Ampere\ x-\ 230V}$ is the maximum speed for a 1-phase charger given a certain Ampere and $I_{Ampere\ x+1-230V}$ is the maximum speed for a 1-phase charger given a certain Ampere that is one category higher.

$$k_{cat}(I) = \begin{cases} A, & I < I_{X_{ampere}-\ 230V} \\ B, & I_{X_{ampere}-\ 1\ phase} > I < I_{X_{ampere}+1\ cat-230V} \\ C, & I > \ I_{X_{ampere}+1\ cat-230V} \end{cases}$$

For each charge station the charge sessions are evaluated and the following rules are applied where either the same category of Ampere is maintained or is shifted upwards into the next category.

$$X_{ampere} = \begin{cases} X_{ampere}(Imax), & \mathrm{A} > 0 \ \ \mathrm{B} = 0 \ \ \mathrm{C} = 0 \\ X_{ampere}(Imax), & \mathrm{A} = 0 \ \ \mathrm{B} = 0 \ \ \mathrm{C} > 0 \\ X_{ampere}(Imax), & \mathrm{A} > 0 \ \ \mathrm{B} = 0 \ \ \mathrm{C} > 0 \\ X_{ampere}(Imax)_{+1\ Cat}, & \mathrm{A} = 0 \ \ \mathrm{B} > 0 \ \ \mathrm{C} = 0 \\ X_{ampere}(Imax)_{+1\ Cat}, & \mathrm{B} > \mathrm{A} \\ X_{ampere}(Imax)_{+1\ Cat}, & \mathrm{B} > \mathrm{C} \ \mathrm{C}! = 0 \\ X_{ampere}(Imax)_{+1\ Cat}, & \mathrm{A} = \mathrm{B} \\ X_{ampere}(Imax)_{+1\ Cat}, & \mathrm{B} > 20 * \dfrac{\mathrm{A}}{100} \\ X_{ampere}(Imax), & else \end{cases}$$

For the RFIDs:

$$N_n = N_{400V}\,, \qquad C > 0$$

The charge speed of all charge sessions are evaluated once again using the new input using the following rule:

$$I_k = \begin{cases} I(N_n, X_{ampere}), & I(N_n, X_{ampere}) > \ I_k \\ I_k, & I(N_n, X_{ampere}) < \ I_k \end{cases}$$

As last step the charge time T is calculated using: $T_k = \dfrac{Volume_k}{I_k}$

3.2 Key Performance Indicator selection

To select the relevant Key Performance indicators (KPI’s) to compare the cities performance we turn to Helmus & Van den Hoed [21] . Helmus & Van den Hoed have identified the relevant KPI’s for municipalities after an analysis of the needs of the stakeholders within the municipalities. The relevant KPI’s are identified at different levels of the infrastructure. Although most are applied at the city level but some KPI’s are measured at the parking zone level or the charge point level. The KPI’s at these level are translated to KPI’s at the city level and their relevance is explained in more detail.

With the current dataset it is possible to compare all the KPI’s among the 5 areas with the exception of effectiveness of the investment. Although there are general numbers about the costs of installing public charge infrastructure these costs are too location specific for a comparison at city level.

3.3 Basic information

During this research 5 different urban areas are compared. Table 2 displays some of the basic information about these urban areas to give context to these figures.

City	Inhabitants	Area (km^2)	Inhabitants /km^2
Amsterdam	834.000	219	3808
MRA	1.203.000	2.580	466
Rotterdam	629.000	319	1972
The Hague	519.000	98	5296
Utrecht	339.000	99	3424

Table 2 Basic information on analysed cities

4. Results

The results section follows the structure of Helmus & Van den Hoed (2016). It uses the four main categories of KPI’s that are identified. In each section the KPI’s are compared for the 5 areas to signal important differences. Using the data significant differences are identified and explained by using the local circumstances.

4.1 Sustainability goals

The main goal of municipalities to invest in charge infrastructure is to increase the air quality in the city. The number of kilometres driven on electricity instead of fossil fuels contribute this goals. This is most easily measured by the numbers kWh charged. Figure 1 shows the monthly amount of kWh charged in each city. All cities show a significant growth over the years. The growth is however not consistent especially in the city of Amsterdam. These troughs in the graph are during the summer months and can most likely be contributed to the summer holidays when commuters are not using the charge infrastructure.

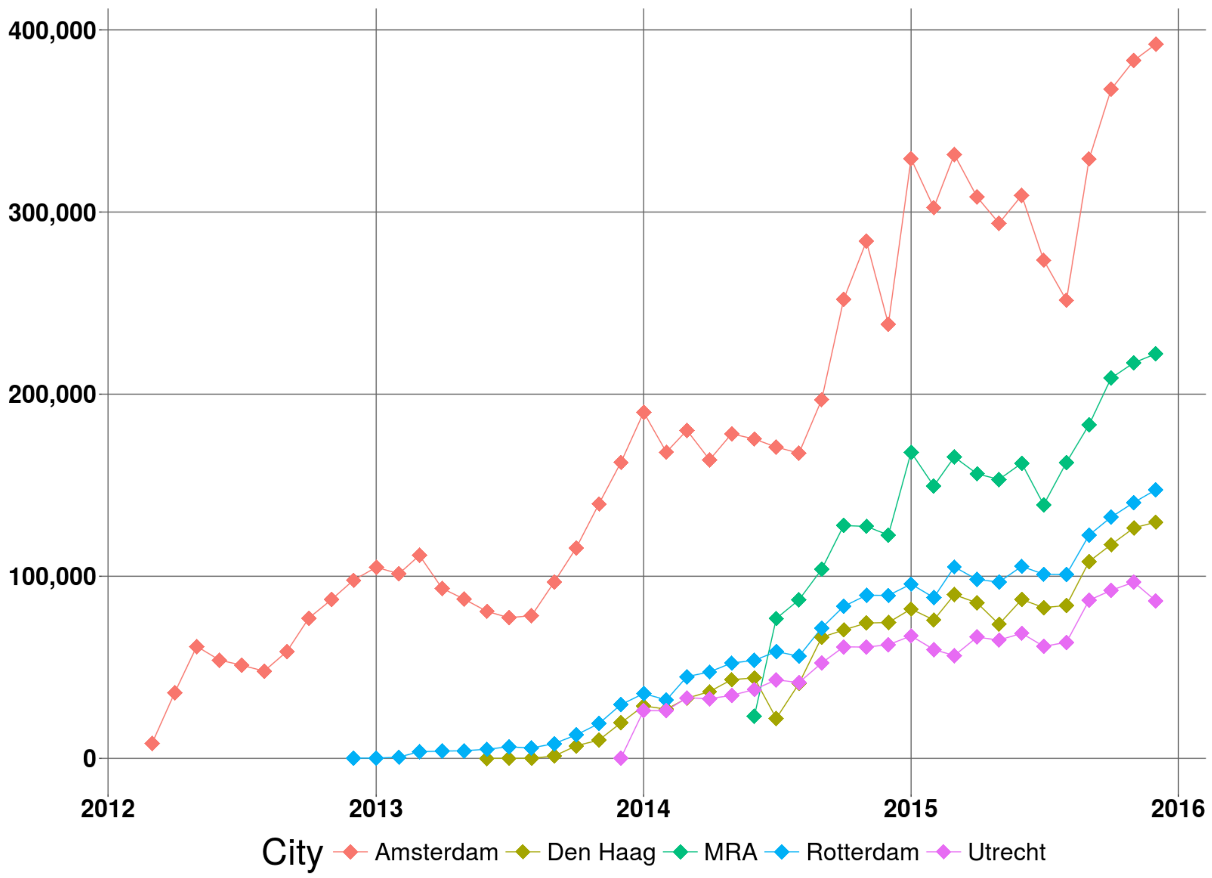

Figure 1 Amount of kWh charged per city per month

The early start of the city of Amsterdam in developing a charge infrastructure has given them a head start in comparison to the other cities. The head start gained in comparison other cities which actively rolled-out a charge infrastructure has remained in place. The cities are now developing at a similar pace with the exception of Amsterdam and MRA which have widened the gap in amount of kWh charged compared to other cities over the years. This gap has widened in the last months of 2015 when a large number of EVs were sold in the Netherlands [].

4.2 Managing public concerns

An effective roll-out strategy not only ensures the interests of EV drivers but also takes into account the concerns of other stakeholders such as charge point operators, grid operators and ICE drivers. The most common complaint heard from these stakeholders is that charge points occupancy rates are either too high or too low.

Occupation differs between charge stations and in time, as well during the day as in weekly, monthly and annual patterns. Large differences observed in the early phase of deployment of the infrastructure can be explained by a limited amount of charge stations which makes the data vulnerable to large changes. However also for the well-developed infrastructures these fluctuations keep appearing. Annual patterns such as summer holidays can be detected in each city but on a month-to-month basis occupancy ratios differ with sometimes more than 10%.

Yet over a longer period of time charge station occupancy is rather stable for most charge stations, with occasional shifts when a charge station is ‘discovered’ by new users. However between charge stations and cities structural differences occur. Figure 2 illustrates the range of occupancy rates observed at the charge stations within these cities over the course of one year.

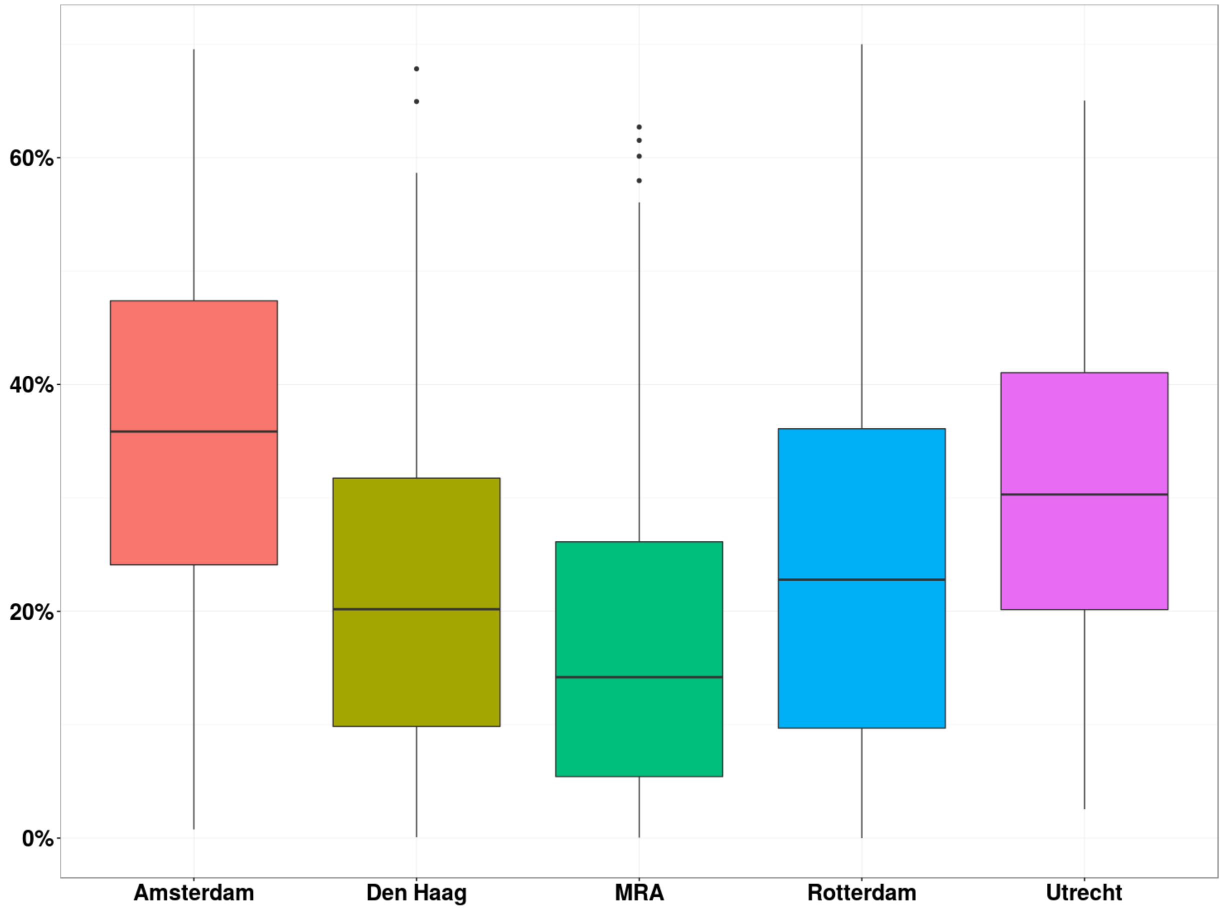

Figure 2 Boxplot of charge station occupancy over the year 2015

Noticeable is that there is wide range observable in each city from charge stations with nearly 0% occupancy to those with over 70%. This range is observed in each of the cities although the quantiles are similar in size each of the cities. Average occupancy rates of 35% such as in the city of Amsterdam and Utrecht are high compared to studies performed on public charge infrastructure in different countries and also the three other cities observed in this dataset. One of the explanatory variables for this higher occupancy rate is that many of the charge points are used as a replacement for home charging as users within these cities are often constrained to on-street parking possibilities. Plugging-in overnight contributes a great extent to the number of hours connected. Comparison with other regions needs to happen on a basis in which parking conditions are similar [18]. The cities infrastructure planners need to be aware of typical usage of points or may seek possibilities to combine 'pillow' and 'work' chargers [16].

Occupancy rates can highly differ from one charge point or neighbourhood to another but also differ during the day. Figure 3 shows the average connection profile throughout the day for each city. The cities of Amsterdam and Utrecht show a similar pattern in which occupancy ratios during the night around 43% but significantly differ during day time. The city of Utrecht can therefore be said to facilitate more 'pillow' then 'work' chargers or visitors. The cities of Rotterdam, Den Haag and MRA follow are similar pattern to Amsterdam but have a lower offset to begin with.

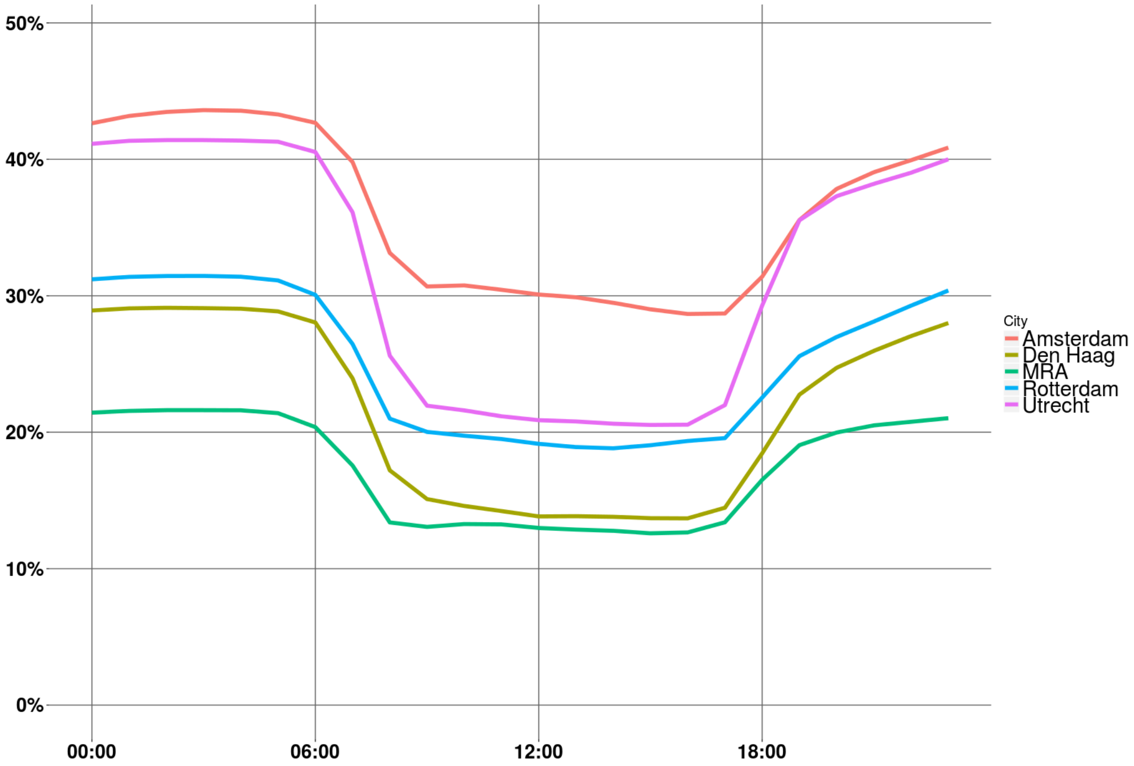

Figure 3: hourly connected profile per city.

From this we can deduct than the city of Utrecht has more residents with EVs and less in-coming commuters or visitors compared to the other cities. From a managing perspective this can cause considerable problems as EV drivers might encounter more occupied stations during night time hours and ICE drivers might observe that parking space during the day is not used by EVs in areas with heavy parking pressure. Balancing day-and-night demand is a challenge for municipalities.

Managing public concerns can be a challenging tasks for municipalities as they have to incorporate the interests of many different actors. The occupancy ratio is good KPI to measure the performance. The analysis shows however that this task cannot simply be done by analysing the mean occupancy rate in the city as there are large differences between charge stations. Occupancy rates differ from 0-75% and are shown to varyduring the day. During day time, occupation levels are low which opens opportunities for other EVs to charge. Managing the difference between day and night time is an opportunity as well a challenge for municipalities as the number of EVs continues to grow but investments in public charge stations remain high.

4.3 Facilitating Electric Mobility

To assess the extent in which a city facilitates electric mobility the KPI’s to evaluate the cities infrastructure are the number of charge points installed, the number of unique users, the number of charge sessions of how many charge sessions each charge point facilitates on a monthly basis

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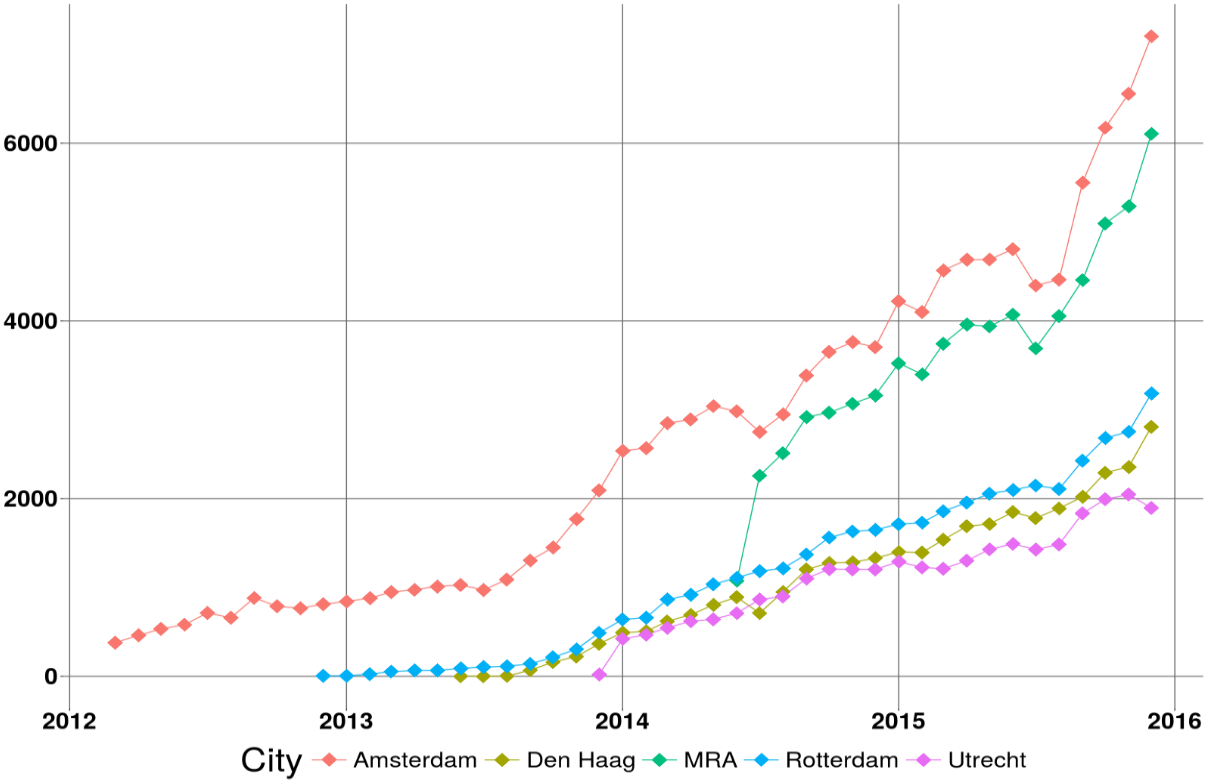

Figure 4 Number of unique RFID per city per month

Figure 4 shows the amount of unique users each city has. Clear front runners are the city of Amsterdam and the MRA. Growth in the number of unique users accelerates with sales in EVs but especially the city of Amsterdam and the MRA show a large increase in the number of users in the end of 2015. Possibly the head start this region has had from 2012 onwards has increased exposure for others in the region. This increased the chance that drivers within the same area also purchased which would be in line with diffusion theory and earlier findings of the 'neighbour effect' in EV purchase behaviour [19].

Compared the cities in size measured in habitants the city of Amsterdam and Utrecht clearly show more unique users than The Hague and especially Rotterdam. The number of charge stations as shown in figure 5 has a clear relationship with the number of unique users except for the city of Utrecht. Utrecht facilitates a larger amount of unique users compared to the networks size. As shown earlier in figure 2 and 3 this results in a higher pressure on the infrastructure especially for night-time chargers.

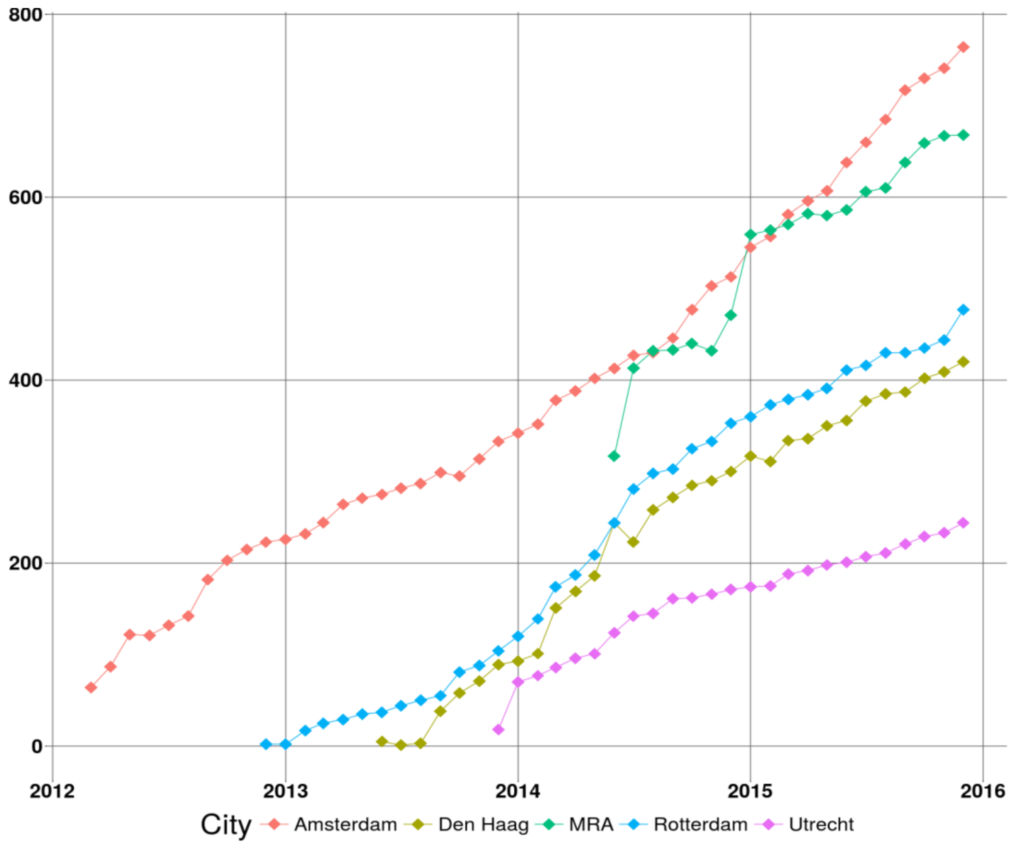

Figure 6 number of active charge stations per city

Table 3 shows the number of unique users and charge point per city in December of 2015. The city of Utrecht and the Metropole region and the city of Amsterdam have high a number of unique users per charge station. This could indicate very effective usage but also a pressure on the network as more users have share a charge point.

City	**Unique users** **December 2015**	**Charge station** **December 2015**	**Unique users/ charge station** **December 2015**	**Average unique users/ charge station/month** **2015**
Amsterdam	7204	764	9.43	7,81
Rotterdam	3184	477	6,67	5,37
The Hague	2809	420	6,69	5,13
Utrecht	1895	244	7,76	7,48
MRA	6105	668	9,13	7,00

The approach of the city of Amsterdam towards EV's generates an unique situation in which besides 'regular' users also electric car sharing companies and taxis make use of the cities infrastructure. Car sharing companies can make use of charging infrastructure without additional parking costs resulting in a high charge point volatility compared to 'regular' users. Car sharing and taxi's in the city make up 1.8% of the users and 7.2% of all charge sessions. These users increase usage of the infrastructure in various ways, e.g in 2015 the average number of unique users per charge stations was 7.15 without car sharing and taxi's compared to the 7,81 with these users.

Not only the amount of unique users or charge stations is a relevant KPI but also the amount of charge sessions. The number of unique users could indicate a large number of visitors but low structural usage.

Figure 7 shows the average number of charge sessions per month per charge stations for each city. The results show just as with the occupancy rate that there are large differences between the charge stations. The range compared to the quantile size is relatively large. The distribution of the charge stations is skewed towards the lower bound. Amsterdam facilitates on average more charge sessions per charge compared to other cities. Utrecht shows a slightly elevated number however this does not correlate with the relatively high number of unique users per charge station in Utrecht. This could indicate a higher number of visitors compared to Rotterdam and Den Haag. This is however in contrast with the daily pattern in occupancy, which shows a higher number of ‘pillow’ chargers, which are often more regular users.

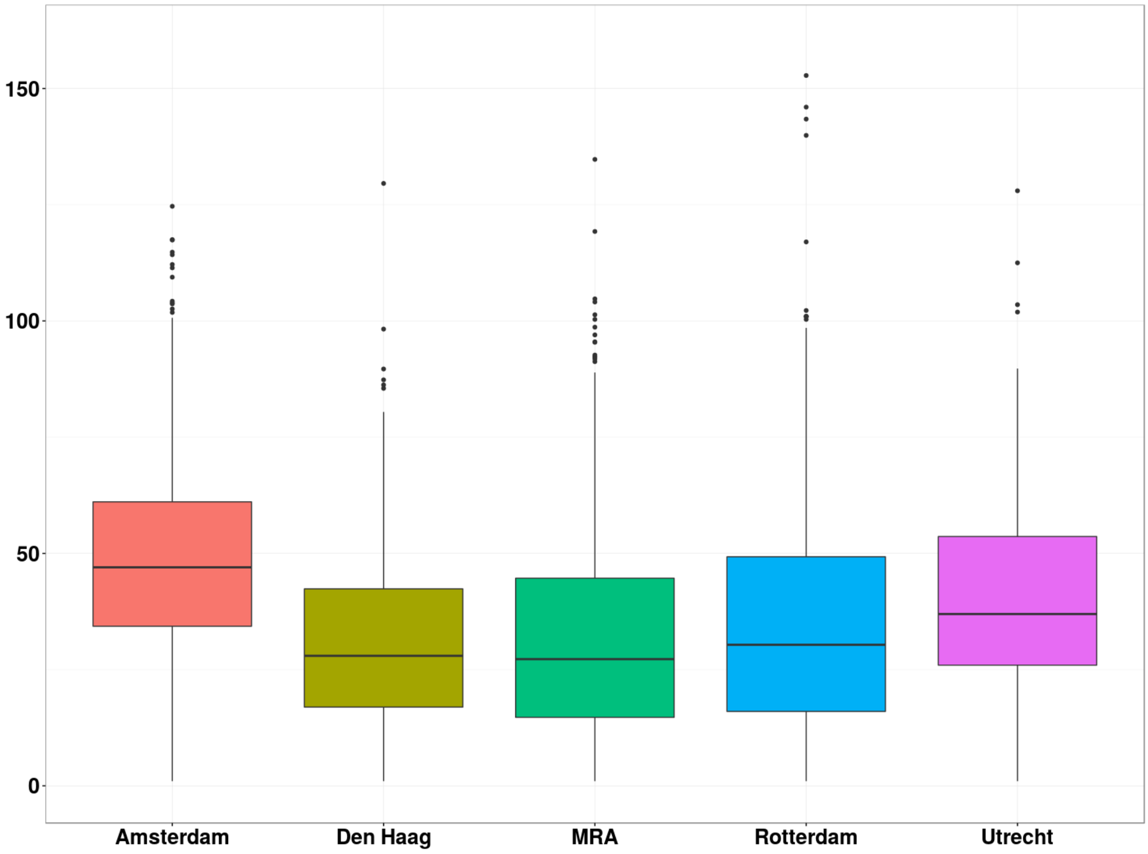

Figure 7 average number of charge sessions per charge station per month for each city

The Metropole region of Amsterdam shows a low number of charge sessions per charge station especially compared to the number of unique users per charge station. This could indicate the presence of more strategically placed charge stations which do not serve as a substitute for home place charging. Such behaviour could be in line with the geographical characteristics in this areas which is less densely populated as the region is composed by a number of different municipalities.

The KPI’s for facilitating electric mobility show some clear differences in infrastructure usage between the cities. The city of Rotterdam and Den Haag behave in a similar fashion with an average amount of charge stations, unique users, charge sessions per charge station but a lower number of unique users per charge station. Amsterdam and the MRA have a large amount of charge stations facilitating a larger number of unique users. However the MRA does not have a lot of charge sessions per charge stations, indicating more occasional than structural usage of the charge infrastructure. The city of Utrecht has created a scarcity in the number of charge stations but does facilitate an equal number of users compared to Den Haag and Rotterdam. This means a larger number of unique users per charge station, but this does not lead to a significant higher number of charge stations. Alongside with the daily occupancy profile this could mean that there is a shortage of charge stations at night time at which users have to share a charge station.

4.4 Facilitating business case

Municipalities in the Netherlands are currently funding the deployment of public charge stations within their own city. This is expensive as the current charge stations are not yet profitable. Municipalities seek ways to improve the business case of charge stations making it able to leave such investments to commercial parties.

Currently the business case around charge stations in the Netherlands is based upon the number of kWh charged. Within the analysed cities, the municipalities have agreed that users are only charged for the amount of kWh charged or are also billed a per session fee on top of the amount charged. To analyse the business case it is therefore necessary to see how many kWh are charged per charge station. Figure 9 shows the range of kWh charged per charge station in each of the cities.

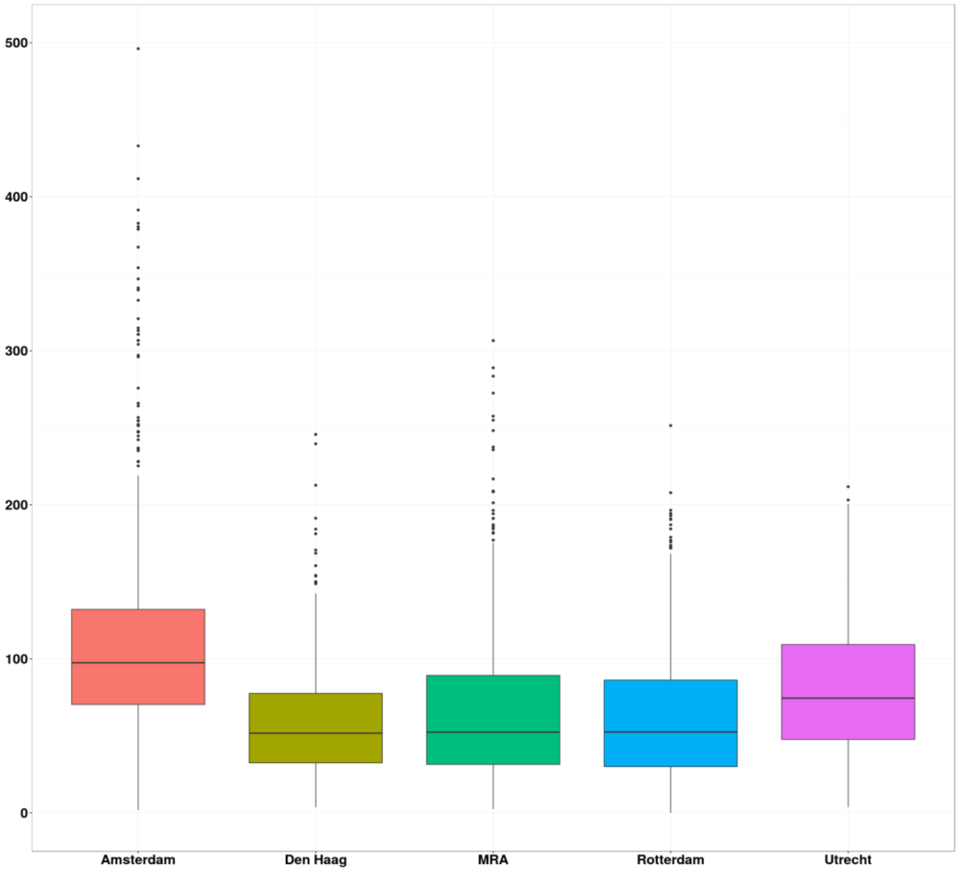

Figure 8 Amount of kWh charged per week per charge station

The range in the number of kWh charged per charge station per week is large compared to other KPI's that have been considered. Especially in Amsterdam some of the charge stations outperform others by a large margin. Such behaviour can be induced by a larger number of charge session but also by more EVs with a larger battery capacity. The differences between the cities shows a similar pattern with the number of charge sessions. As seen in table 4 there are however differences between the average amount of kWh charged per charge session. A part of the higher value can be explained by taxi companies operating EVs with a large battery capacity which are not present in other cities. However the average still remains higher compared to the other cities.

City	**kWh/session**
Amsterdam	**9,83**
Amsterdam w/o taxi	**9,00**
Den Haag	**8,09**
MRA	**8,66**
Rotterdam	**7,62**
Utrecht	**8,19**

Table 4 Amount of kWh per session per city

To assess the business case it is useful to compare these figures to what is necessary for a profitable charge station, solely based upon sales of kWh. According to Madina et al. [20] a charge station in the Netherlands needs 3.16 charges a day of 10 kWh (above the average observed) to be profitable. On a weekly basis this means over 220 kWh charged. Only a few of the charge stations average a use of over 200 kWh charged. The majority of the charge stations provide only 100 kWh or less.

As charge point operators increase the profitability by selling more kWh it is interesting for them to see how many hours users are actually charging and not only connected. With the exception of the MRA all cities show on average sessions that use below 20% of the time connected for actual charging. The average time an EV is charging at a charge station is equal across the cities, however the time connected at the MRA (7.5 hours) is much lower than in the other cities (10 hours).

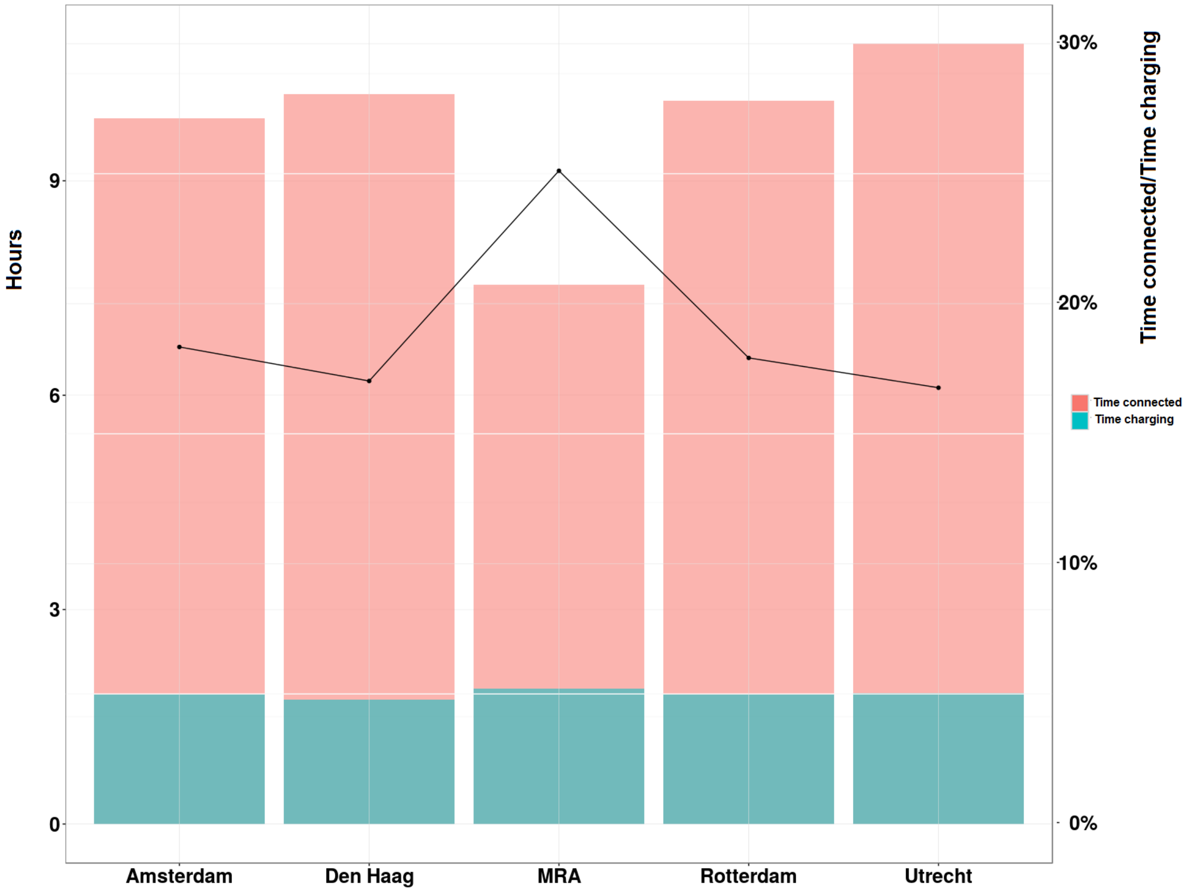

Figure 9 Hours connected (pink) and hours charging (blue) and the efficiency of the charge session

Charge sessions in the MRA are shorter on average compared to other cities. This is likely due to the fact that night time occupancy is low and the ratio between daytime and night time occupancy is high. The city of Utrecht shows that a large ratio between night and day time charging increases the average time connected. However the time charging is not influenced by these figures resulting in a low efficiency in usage. Figure 9 shows that the charge infrastructure has a lot of room for improvement in the case of effective usage. This means that municipalities instead of focussing on expanding the network could focus their efforts on reducing the idle time of charge stations. Although a large portion of this idle time is concentrated during the night, and is thus less relevant, a significant portion of daytime connection time is not used for charging. Municipalities can develop policies to reduce the time connected but not charging which reduces the need to place additional and costly charging stations.

The KPIs on facilitating the business case for charge point operators show that a positive case for the majority of charge points solely based on electricity sales is not yet possible. The average number of kWh charged per week is half of what is defined by Madina et al. [20] for a positive business case. Comparing the different cities we see that there are differences between the cities on the amount of kWh charged per session. This KPI is influenced by the number of long range BEVs in the city which can be deduced from the lower amount of kWh per sessions when taxis are not included in the dataset.

The business case could be greatly improved if the idle time, the time connected but not charging, is reduced. On average below 20% of the time connected is used for charging. This can partly be explained by that the charge stations partly serve as a substitute for ‘home’ and ‘workplace’ charging in which the car is parked for a longer time, however results also show that there are very lengthy sessions which prohibit other users from charging. The MRA showed a strikingly different pattern indicating more strategically placed charge points. These results show that municipalities should not only focus on expanding their network but also on policies that could increase the effective usage.

5. Discussion

This paper has showed that by identifying relevant KPIs at the city level charge infrastructure policies of different cities can be compared. Although some cities show similar behaviour such as the cities of Rotterdam and Den Haag, others have shown that policies on the roll-out and usage of charge infrastructure effect the way the charge points are used. Rolling out a relatively sparse number of charge points such as in the city of Utrecht results in a high number of unique users per charge point and relatively more charge sessions and kWh charged. As a consequence a large pressure on the charge system which could possibly lead to complaints of EV drivers about finding an available charge point.

Other roll-out strategies such focussing on more strategically placed charge points as in the metropole region of Amsterdam result in more effective usage of the charge points when comparing the time actually charging to the time connected. Also a high number of unique users make use of these charge points indicating that they serve more occasional charging. However on the whole the charge infrastructure is not used very often resulting in an unattractive business case for charge point operators.

Besides the roll-out strategies the analysis also showed that focussing on other policies such as allowing electric car sharing schemes and encouraging electric taxi’s results in different usage of the charge infrastructure. Taxi’s with large battery packs results in more kWh charged and more kWh per charge session. Although car sharing only make up a small portion of the users that do result in a large number of charge sessions. From the point of facilitating electric mobility within the city this policy measure can both have up- and downsides. The upside is large number of emission free kilometres within the city and a relatively high occupancy rate. This could however also be prohibiting for other users if they find their charge point occupied by a such a car.

This study has focussed on identifying and comparing the KPIs at the city level on the roll-out policies for charge infrastructure. This study has only taken into account these specific strategies and has further not looked into the differences between these cities. Further research could look into the effects of other relevant factors such as income, population density etc.

Secondly this research has focussed on KPIs on the city level. As showed earlier by Helmus & van den Hoed there are also within cities differences on the district level. From a the perspective on the municipal policy maker these differences could be more interesting to see if there is larger local need instead of monitoring the entire infrastructure usage. Yet these research has shown that even at the city level the policy implications can already be see.

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