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Fully charged: An empirical study into the factors that influence connection times at EV-charging stations

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ABSTRACT

This study is the first to systematically and quantitatively explore the factors that determine, the length of charging sessions at public charging stations for electric vehicles in urban areas, with, particular emphasis placed on the combined parking- and charging-related determinants of connection, times. We use a unique and large data set – containing information concerning 2.6 million charging, sessions of 64,000 (i.e., 60% of) Dutch EV-users – in which both private users and taxi and car sharing, vehicles are included; thus representing a large variation in charging duration behaviour. Using, multinomial logistic regression techniques, we identify key factors explaining heterogeneity in charging, duration behaviour across charging stations. We show how these explanatory variables can be used to, predict EV-charging behaviour in urban areas and we derive preliminary implications for policy-makers, and planners who aim to optimize types and size of charging infrastructure.

1. Introduction

Electric Vehicles (EVs) show great promise to reduce locally harmful emissions such as NO_x SO_x and PM (Razeghi et al., 2016) and greenhouse gasses such as CO_2 (Rangaraju et al., 2015), triggering widespread positive attention among policy makers and researchers alike. However, three important barriers currently hamper widespread adoption, being high upfront purchase costs, limited driving range and a lack of public charging infrastructure (Coffman et al., 2016; Egbue and Long, 2015; Liao et al., 2015; Rezvani et al., 2015). Falling battery prices (Nykvist and Nilsson, 2015) and plans for new, more affordable long range EV models suggest that the barriers of price and range can be overcome.

However, private sector investments in the roll-out of a charging infrastructure have been lagging behind these vehicle developments due to the well-known chicken-and-egg problem (e.g. Struben and Sterman, 2008). To stimulate the adoption of EVs and overcome the chicken-and-egg problem, governments at various levels are keen to help with funding charging infrastructure. Yet, in developing such charging infrastructure, policy makers face the challenge of efficiently using tax payers' money. this challenge is exacerbated by rapid technological developments such as fast charging stations (up to 350 kW) and (static and dynamic) wireless charging which further complicate decision-making. This is because such developments increase the risk of investments into potentially soon-to-be-obsolete technology rendering them worthless. In addition, new behavioural patterns, such as changing charging frequencies depending on battery size, that differ from current refueling behaviour are not yet well understood, making it difficult to predict demand (and to optimize charging infrastructure). In the end, however, postponing the decision on how and when to roll-out which charging opportunities could increase the barrier for candidate EV drivers and thereby hamper the transition to a more sustainable transport system.

As alluded to above, efficient planning of charging infrastructure for electric vehicles (EVs) involves accurate modelling of charging demand. In predicting EV charging demand, understanding variations in the starting time and location of charging sessions is recognized to be of key importance; as such it comes as no surprise that several recent studies have been devoted to modelling demand variations (across space and time) in EV charging. While earlier work was based on the tradition of optimal planning (He et al., 2015; Nie and Ghamami, 2013), more recent studies have moved towards a more behaviourally oriented perspective (Morrissey et al., 2016; Neaimeh et al., 2017; Sun et al., 2016).

An important aspect of demand for charging stations is missing in these studies. By nature, electric vehicle charging stations are not accessible to other users when used. When planning to meet demand it is therefore necessary to know for how long the charging station will be occupied by a given user at a given time. Yet variations in the duration

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of charging sessions in the public domain are not well understood. What makes predicting the duration of these sessions particularly difficult, is that it results from an interplay between *refueling* and *parking* behaviour; also when fully charged, vehicle owners may wish to occupy the charging station for parking reasons (Faria et al., 2014; Gerzon, 2016; Wolbertus and van den Hoed, 2017), and this effect may be exacerbated by local policies which provide EV-owners with parking/charging locations for free (Wolbertus et al., 2018). New refueling behaviours also comes with establishing new social norms, which can vary in different circumstances (Caperello et al., 2013). Understanding the factors that drive these behaviours is important for efficient charging infrastructure planning as it allows policy makers to optimize planning itself or to create policy measures such as pricing strategies to steer behaviour into the desired direction.

This study is the first to systematically and empirically explore the factors that determine the length of charging sessions at public charging stations for EVs in urban areas. We use an unique and large data set – containing relevant information concerning 2.6 million charging sessions of 84,000 (i.e., 70% of) Dutch EV-users – in which both private users, taxi and car sharing vehicles are included; thus representing a large variation in charging duration behaviour. By estimating a statistical model, we identify key factors that explain heterogeneity in charging duration behaviour. We show how these explanatory variables can be used to predict EV-charging behaviour in urban areas and we derive preliminary planning and policy implications regarding the optimal design of charging infrastructure (-related policies).

2. Literature review

Most currently available charging infrastructure planning studies work under the assumption that EV charging at public charging station occurs when the battery level of the car can no longer meet the travel needs of the driver and that the charging there is only done to create enough range to complete the (next) trip, leading to connection times to charging stations that are equal to charging times (Brady and O'Mahony, 2016; Brooker and Qin, 2015; Dong et al., 2014). Such assumptions may hold for fast charging stations (Motoaki and Shirk, 2017; Neaimeh et al., 2017; Sun et al., 2016), however, for slower level 2 charging infrastructure in the city, charging duration is known to be a complex interplay between parking and refueling behaviour by a variety of drivers, such as taxis (Asamer et al., 2016; Tu et al., 2015; Zou et al., 2016) and car sharing vehicles (Van der Poel et al., 2017), each with different recharging demands. As different types of drivers make use of the same infrastructure, understanding the interplay between these factors is of key importance.

Some studies do recognize that EV drivers can recharge during longer dwelling times. These studies then tend to assume that vehicles will recharge each time they are parked for a longer time or they ignore the fact that charging stations are rival goods (Paffumi et al., 2015; Shahraki et al., 2015). In addition, these studies do not account for other intentions to charge (e.g. using a charging station mainly for the ease of parking), the effect of local parking policies such as free parking for EVs (Wolbertus et al., 2018) and particular pricing structures.

It has been recently recognized that pricing strategies form a possible solution to influence connection times. The effects of such strategies have been studied by Gerzon (2016) using a stated choice survey. He found that pricing by the hour caused a significant reduction in connection times. Motoaki and Shirk (2017) find that a fixed fee at fast charging stations increases the time connected to a charging station compared to the free charging situation, as users tend to want to get their money's worth. These results suggest that pricing strategies could possibly serve as a policy tool to influence charging behaviour.

Studies that make use of real life data from EVs or charging stations do mention variations in charging and connection times. These studies mainly point at the start of the sessions as the most important factor that determines the length of the charging session (Sadeghianpourhamami et al., 2018). Morrissey et al. (2016) consider charging session length; they compare fast and slow public chargers and find that, not surprisingly, charging times are shorter at fast charging stations. Robinson et al. (2013) took a closer look by identifying different types of charging behaviour based on activity type. They however only considered charging times –which barely differed across activities in their data– and not connection times. Kim et al. (2017) focused on factors that influence inter-charging event times; they identified two different user type groups, regular and random, and found significant differences between these groups.

In sum: while providing very valuable insights into charging behaviours, the current literature studies connection times to charging stations in a manner that does not reflect the full complexity and subtlety of real charging behaviour in a city context. The wide variety in charging durations is currently only acknowledged in descriptive studies but a systematic and quantitative analysis of the factors that drive the variation in durations is missing. This research contributes to the understanding of charging infrastructure planning by modelling (variation in) the time connected to charging stations based on a large dataset of charging sessions using public charging infrastructure. This dataset provides an unique insight into charging behaviours not only because of its sheer size but also because it encompasses the entire public charging infrastructure within four cities, allowing for an analysis of different (local) policies and EV-owner types which use and compete for the same charging stations.

3. Methodology

Data were collected from public charging stations in the four major Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht) between 2014 and 2016. The data were provided by the charging point operators in these areas. Note that charging stations in these areas were accessed by swiping a RFID-card and then connecting a charging cord to the vehicle. Data were collected concerning the starting point (clock time) of the charging session, its duration, the amount of kWh charged, and the location; a unique anonymous RFID code related all relevant sessions to the RFID-card. In total 2.692.446 Sessions were recorded in this period. Sessions with a length shorter than 5 min and longer than 300 h were excluded from the dataset. Additionally, sessions without any charge were not taken into account during the analysis as such data seemed unreliable. Many of these short sessions without any or little charge were considered to be most likely due to an error while connecting the car to the charging station, requiring the user to swipe the card multiple times. Also sessions with a charging speed over 50 kW were removed, as the charging stations in the dataset were not capable of offering these speeds. After this filtering process 2,531,841 (i.e., 94% of the original data points) sessions were left for the analysis.

Timing data were transformed to separate time-of-day and day-of-the-week variables. Information about charging station and user type was made available by the charging station operators. Charging station type categories were as follows: regular (2 outlets, 11 kW), charging hub (at least 4 outlets clustered together) or fast charging station (50 kW). A price variable was added to the model. Prices at all charging stations were at a kWh basis and fixed at a city level due to tendering processes in which the cities set fixed prices for a time period. The only exception being charging point provider "EVNet", which, at an earlier time, placed charging stations at more strategic locations in the cities. To prevent the price variables to represent the differences between cities, we also included a dummy variable for each of the cities. Here, the city of Utrecht served as the reference category. User type categories were as follows: regular, car sharing vehicle or taxi. For regular users two different sub-categories were extracted, being frequent and non-frequent, on the basis of the number of observed charging sessions (20 charging sessions turned out to provide a useful cut-off point). Data on the time of day were transformed as follows: from 5 a.m. to 9 a.m. was considered morning, from 10 a.m. until 3 p.m. afternoon, from 3 p.m.