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When do you charge your electric vehicle? A stated adaptation approach

Joram H.M. Langbroek[a,b,*], Joel P. Franklin[a], Yusak O. Susilo[a]

[a] Department of Transport Science, School of Architecture and Built Environment, KTH Royal Institute of Technology, Teknikringen 72, 10044 Stockholm, Sweden

[b] Transportation Research Institute, School for Transportation Sciences, Hasselt University, Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium

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ABSTRACT

A large scale deployment of electric vehicles (EVs) is likely to contribute to a more sustainable transport system. However, charging EVs will increase the load on the electricity network. The maximum load may be minimized by coordinating the timing of charging activities, in order to spread electricity demand more equally over the course of a day. In this study, based on a stated-choice experiment, the effects of two different temporal price differentiation strategies on stated charging time are investigated, including socio-demographic, behavioural and socio-psychological variables.

In a situation without charging time coordination, a peak in charging events is likely to occur during the early evening. Temporal price differentiation has a significant influence on charging time and in particular the level of price differentiation matters. The likelihood to change charging time differs and different alternative time slots are chosen when comparing high to low levels of price differentiation. People that have more knowledge about EVs have a higher chance to change their charging time, whereas people that have the tendency to plan their trips long time beforehand are less likely to adjust their charging time in the scenarios with temporal price differentiation.

1. Introduction

Large scale deployment of electric vehicles (EVs) is often named as a strategy that can help make the transport system more sustainable. The main benefits of EV-use are the absence of local emissions, leading to an improvement in air quality, reduced greenhouse gas contributions, and higher energy efficiency compared to internal combustion engine vehicles (ICEVs) (Faria et al., 2012).

However, electric vehicles must be charged and their energy use is considerable. For example, an electric vehicle consuming 20 kWh per 100 km and with a mileage of 15,000 km per year consumes 3000 kWh per year, which is comparable to the total household non-heating electricity consumption in Sweden (E.ON, 2016) or Belgium (Knapen et al., 2012).

Importantly, electricity demand may not be equally distributed over the course of a day. If all electric vehicles were charged during current peak hours of electricity consumption, these peaks of electricity demand would be even higher. Therefore, to minimize peak loads, electric vehicles should ideally be charged during off-peak hours. Temporal electricity price differentiation might be an option to steer charging behaviour towards off-peak hours (e.g. Shao et al., 2010).

The aim of this paper is to explore behavioural adaptations as a result of electricity temporal price differentiation among a population of current and prospective EV owners in Greater Stockholm, Sweden. To which degree do drivers deviate from their preferred charging time in the case of scenarios with temporal price differentiation, and is the likelihood to change behaviour equal among people with different socio-economic and behavioural characteristics?

The hypotheses for this paper are the following:

1. The from a car user's point of view most preferred starting time for electric vehicle charging in a situation without temporal price differentiation is in the start of the evening, so that charging can continue overnight.
2. Greater price differentiation of electric vehicle charging leads to a greater probability of changing charging patterns.
3. Travel pattern characteristics such as evening trips and the use of alternative transport modes have an influence on the preferred charging time.
4. Socio-economic characteristics such as gender, age and income have an influence on the preferred charging time.

* Corresponding author at: Department of Transport Science, School of Architecture and Built Environment, KTH Royal Institute of Technology, Teknikringen 72, 10044 Stockholm, Sweden.

E-mail addresses: joram.langbroek@abe.kth.se, joram.langbroek@uhasselt.be (J.H.M. Langbroek), joel.franklin@abe.kth.se (J.P. Franklin), yusak.susilo@abe.kth.se (Y.O. Susilo).

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The rest of this paper is structured as follows: In Section 2, a background of electricity supply and demand is given, followed by subsection about electricity demand peak hours, potential policy measures counteracting these peak hours and a subsection about empirical studies regarding charging behaviour. In Section 3, the methodology is described. In Section 4, the results are presented, followed by a discussion and conclusions in Section 5 and Section 6.

2. Background

2.1. Electricity supply and demand

Because of the volatile nature of electricity, supply should in most cases match demand. Different energy sources have a dissimilar potential to flexibly adjusting supply in order to meet demand variation. For example, nuclear power plants provide a fairly stable supply base but it is not possible to adjust the generation capacity within a short time. On the other hand, gas turbines have a smaller start-up time and the capacity can be adjusted more flexibly. Renewable energy sources such as wind or solar energy also provide a more variable energy capacity, but these sources are on the other hand more unpredictable. In general, wind energy peaks during night hours, whereas solar energy reaches its peak during day time (Nunes et al., 2015).

Considering the demand side, household electricity demand is highest when most household members are at home but not sleeping. In general, electricity demand is lowest during night time when industry productivity is lower, there is much less transport and household electricity demand is at a much lower level as well.

The supply and demand profiles of a specific area define peak hours: those hours during the day where demand peaks and supply needs to be adjusted in order to meet the electricity demand.

In Sweden, total electricity use in 2015 accounted for 126.8 TWh, out of which 33.8 TWh (26%) concerned household electricity consumption. Most electricity is generated by hydropower plants (47%) and nuclear power plants (34%), while only 8% of the electricity is produced by thermal power plants that use oil, natural gas and coal. The remaining 11% are produced by wind turbines (Statistiska Centralbyrån, 2016). Household electricity use is not spread equally throughout the day. There are peaks around morning rush hour and afternoon rush hour (see Fig. 1; based on Swedish Energy Market Inspectorate (2016)).

2.2. Consequences of electricity peak hours

Electricity peak hours result in capacity issues of power plants and especially local electricity distribution systems, which may force electricity companies to invest in more infrastructure. Moreover, there may be environmental costs related to the imbalance between electricity demand and electricity supply. It has been found that energy use during peak hours generally has higher carbon content. This is due to the fact that in many countries, the energy sources that can be used to flexibly increase electricity generation are more carbon intensive (such as gas turbines) than the energy sources that form the stable base of electricity supply (hydropower or nuclear power). Foley et al. (2013) showed that total electricity demand (from all sectors) in Ireland peaks in early evening and that a high number of electric vehicle charging events in early evening would increase the pressure on the electricity market during peak hours, resulting in higher emissions of CO2, NOx and SOx per kWh.

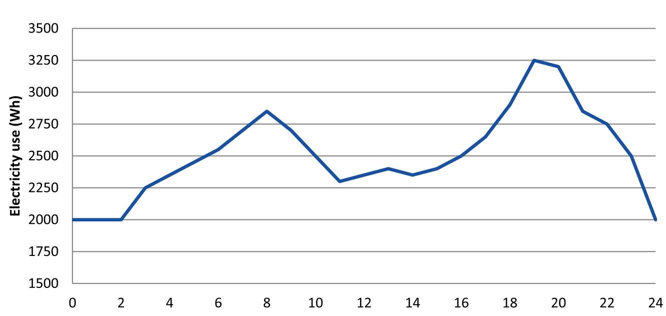

Fig. 1. Median household electricity use in Sweden per person over the course of a day.

2.3. Peak-shaving

It has been acknowledged that peak-shaving, meaning to spread out electricity demand more equally over the day, would be beneficial (e.g. Robinson et al., 2013; Morrissey et al., 2016; Knapen et al., 2012). In the case of a large scale deployment of electric vehicles, the issue of the timing of charging events will play an important role in how green EV-use will be. Based on a study in California, it has been shown that a large number of PHEVs charging off-peak instead of during peak hours would result in a decrease of greenhouse gas emissions for EV charging by 7–12 per cent (Sohnen et al., 2015). According to an English case study (Robinson et al., 2013), the carbon content of electricity to recharge the EVs could have been reduced by 11–22 per cent in case all participating EV-users would charge their EV in non-peak hours rather than during peak hours. Also Rangaraju et al. (2015) concluded that the most environmentally friendly time to charge EVs in Belgium is between midnight and 8 a.m., because of the fact that the electricity will mainly be generated by nuclear and wind power. Besides environmental reasons, there is also a large economic benefit of not increasing the load on the system (e.g. Azadfar et al., 2015). However, not in all situations off-peak charging is beneficial for decreasing the carbon content of electricity generation. Li et al. (2016) have shown by a study in China that night time charging there would lead to higher carbon content due to the fact that during night time, a relatively larger proportion of the electricity in that system is generated by coal powered plants.

2.4. Temporal price differentiation

Temporal price differentiation can be used as a tool to stimulate people to charge their electric vehicle during specific hours of the day in order to decrease the peak load on the electricity system. By applying lower prices during non-peak hours and higher prices during peak hours, a more equal distribution of electricity use of the day is expected. The degree to which prices should be adjusted in real time, directly reacting to the load on the electricity system, is up to discussion. For example, Lyon et al. (2012) found that a simple price differentiation system is likely to have a larger net present value than a real-time adjustable energy grid. Also Schmidt et al. (2014) came to the conclusion that simple charging control systems (but not real-time control systems) are efficient for peak-shaving and saving costs. Fell et al. (2014) investigated the perceived control of electricity users confronted with fixed price differentiation, real-time price adjustments and direct load control and found that consumers have the highest perceived control level in the case of fixed price differentiation. A fixed price differentiation system has the advantage over real-time adjustable prices that it gives a higher sense of control and predictability: a certain charging time is connected to a certain price, which makes it possible to anticipate based on this price. The lowest sense of control was associated with direct load control, where the use of electricity can be remotely controlled by the electricity company, making it impossible to use certain devices during peak hours of electricity use.

In some countries, time-of-use pricing (TOU) has now become common practice for residential electricity use. A study in New Zealand (Thorsnes et al., 2012) showed that peak electricity use did not change as a result of a TOU pricing scheme. However, off-peak electricity use depended on the prices of electricity in off-peak hours. Electric vehicle