Travel Behaviour and Society 13 (2018) 144–154

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

How would you change your travel patterns if you used an electric vehicle? A stated adaptation approach

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ARTICLE INFO

Keywords:
Electric vehicle
Travel behaviour
Stated adaptation
Sustainable mobility
Rebound effect

ABSTRACT

The real environmental benefits of a transition towards EVs highly depend on the future EV-users' activity-travel patterns adapted to their new vehicle's capacity. Despite its importance, the impact of this adaptation is largely unknown. In this study, a stated adaptation experiment has been conducted to investigate changes of travel patterns as a result of range limitations or the opposite, abundant range. The basis for this experiment is a one-day travel diary among active drivers in Greater Stockholm. The main findings of this study are the following: (1) Drivers facing range limitations are more likely to make use of alternative means of transport (mainly public transport) if the travel time difference between car and public transport is low and if not many transfers are needed for the public transport trip. (2) In case of (perceived) range limitations, shopping trips and trips visiting friends or relatives are more likely to be cancelled than working trips. (3) The main trip purpose of additional trips in case of sufficient EV range is shopping. (4) A non-negligible number of public transport trips are likely to be replaced by EV. Shortly, the effects of the transition towards electric vehicle use on personal mobility seem to depend on the availability of accessible substitutes. Besides that, a rebound effect has been observed in this study.

1. Introduction

A transition from internal combustion engine vehicles (ICEVs) to electric vehicles (EVs) can contribute to a more sustainable mobility, for example by eliminating local tailpipe emissions and by improving vehicles' overall energy efficiency (Åhman, 2001). However, the travel patterns of future electric vehicle users cannot be assumed to be unaltered by the change of vehicle type, and these travel patterns can affect the degree in which EVs can contribute to sustainable mobility.

In studies predicting the future use of electric vehicles, it is often assumed that people will generally maintain their prior travel habits after replacing a conventional car with an EV (e.g. Kim and Rahimi, 2014). However, this ceteris paribus assumption might not hold. On the one hand, the beneficial effects of electric vehicle use can be amplified if total car travelling decreases because of the transition towards EV-use. On the other hand, a rebound effect would occur if car travelling increases because of the adoption of electric vehicles. A rebound effect in this context can be defined as a side effect due to behavioural responses that diminishes the beneficial effect of a certain (technological) change, such as in this case electric vehicle adoption (e.g. Berkhout et al., 2000). Electric vehicle adoption as such increases energy efficiency per kilometre compared to driving an ICEV, but if the amount of kilometres driven increases, part of the total energy efficiency gain would get lost. Besides that, additional car travelling might contribute to traffic congestion (e.g. Humphreys, 2010) and traffic accidents (e.g. Hakkert and Braimaister, 2002).

A switch from an ICEV to an EV may alter travel patterns in several ways. Range limitations may change travel patterns of people adopting an electric vehicle. Electric vehicles have a finite battery capacity, even though this battery capacity has increased over the years with vehicles currently on the market having a range of up to 500 km. After depleting the battery, the EV must be charged, which comes with a certain time cost. This time cost depends on the charging speed as well as the coverage and capacity of public and private charging infrastructure. Some trips can therefore be easier to make by ICEV than by EV. Much has been written about long-distance trips for which the electric vehicle cannot easily be used (e.g. Pearre et al, 2011; Franke and Krems, 2013). Even range anxiety (e.g. Salah and Kama, 2017), implying that people do not dare to use the total available range of their EV because they are afraid of sudden battery depletion, might limit the usability of EVs for

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https://doi.org/10.1016/j.tbs.2018.08.001
Received 6 April 2018; Received in revised form 1 August 2018; Accepted 6 August 2018
2214-367X/

certain trips or trip chains.

Unlike studies covering range limitation issues, relatively little is known about behavioural adaptations resulting in increased car use. However, increased car use is not unlikely, since the operational costs of electric vehicles are lower than those of conventional ICEVs. Hagman et al. (2016) compared the total cost of ownership (TCO) of EVs and ICEVs in Sweden and concluded that the electricity costs for EVs in particular were significantly lower than the fuel costs for ICEVs. Assuming three years of ownership and a mileage of 15,000 km per year, the fuel costs for using an EV (BMW i3) would be €633, whereas the fuel costs for using an ICEV in the same class (Volvo V40d) would be €4132 over that ownership period. These lower marginal costs (costs per additional kilometre driven) might contribute to increased car use, which would constitute a rebound effect. In countries like Germany, it has been shown that full electric vehicles are currently not economically feasible for most consumers (Bubeck et al., 2016). A potential reason for this is the significantly higher electricity cost. A probabilistic TCO analysis, also for the German case, has shown that there is a large influence of vehicle class in combination with yearly driving distance (Wu et al., 2015). Palmer et al. (2018) concluded that battery electric vehicles and conventional vehicles have reached cost parity in the United Kingdom and California and Texas in the United States, due to the fact that there are subsidy schemes in place.

More insight into the travel patterns of future electric vehicle users is important in order to better anticipate to potential undesired side effects of large-scale electric vehicle adoption, and to choose policies that have a more realistic chance of achieving emissions-reduction goals. Because of the fact that the number of current electric vehicle users is relatively low and these EV-users have specific socio-economic and socio-cognitive characteristics (overrepresentation of male, highly educated people with medium or high incomes and scoring high on environmental awareness as well as being interested in new technology) that are distinct from the average car driver (Vassileva and Campillo, 2017), a stated adaptation approach has been used in this study. The aims of this study are to *explore the concept of behavioural strategies in relation to electric vehicle use* and to *investigate the risk for alterations leading to increased car use due to electric vehicle adoption*. In addition, the context of these behavioural changes in terms of user characteristics, trip characteristics and stimulus characteristics will be explored. The stated adaptation experiment has been conducted among active car drivers (driving at least once a week) in Greater Stockholm, Sweden in 2014 and 2015.

The number of EVs in Greater Stockholm is still comparatively low, with 1.2% of new person vehicles in 2017 being battery electric vehicles. The market share of plug-in hybrid electric vehicles is with 6.8% significantly larger (Elbilsstatistik, 2018). In Sweden, people buying vehicles with low carbon emissions were entitled to a subsidy of 40,000 SEK (approximately 4000 euro) during the time of data collection (Transportstyrelsen, 2018). Besides the presence of some free charging stations, there are not many other policies in place to incentivize electric vehicle adoption in Greater Stockholm. For example, due to current Swedish law, no free parking is provided allocated specifically for electric vehicles. In some cases, free charging is provided but the general hourly parking fee still has still to be paid. Greater Stockholm has been selected as a study area because there are a relatively large number of "choice travellers" or travellers that in principle could make use of different transport modes, which is interesting as modal shift is one of the aspects of travel behaviour being looked at. A study in rural areas might lead to a different result and will be needed for making country-wide predictions in the future. However, the area covering Greater Stockholm is comparatively large and comprises a mixture of urban, suburban and rural areas.

The rest of the paper is structured as follows: In the next Section, the concepts sustainable mobility and behavioural alterations as an effect of electric vehicle adoption are discussed. In Section 3, the Methodology of this stated adaptation experiment is described, followed by the Results in Section 4. Section 5 consists of a discussion of the results and the Conclusions are given in Section 6.

2. Sustainable mobility and behavioural alterations

The concept of sustainable mobility consists of two parts, "sustainable" and "mobility". A sustainable Development is often defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Sustainable Development can be considered of having three dimensions: an economic, an ecologic and a social (equity) dimension (Campbell, 1996; Litman and Burwell, 2006) that all have to be considered. The second part of the concept of sustainable mobility, "mobility", deals with the ability to go from A to B, often described using generalized travel costs (National Research Council, 2002). Without a good mobility level, one cannot speak of sustainable mobility because the needs of the traveller are not met. As travel demand is often considered as a derived demand, a good mobility level enables engaging the activities that one wishes. This paper discusses the potential effects of large-scale EV-use on sustainable mobility.

The transition from an ICEV towards an EV implies a significant behavioural change. Battery Electric Vehicles (BEVs) have to be charged rather than pumped with liquid fuel and Plug-in Hybrid Electric Vehicles (PHEVs) should be charged regularly to make most use of their beneficial characteristics. These charging events take significantly more time than refuelling a conventional car, and access to charging infrastructure may be limited. The public acceptability of electric vehicles largely depends on whether the EV is able to meet the mobility needs of average car users without burdensome changes to their travel patterns (De Gennaro et al., 2014). Therefore, several studies have investigated travel patterns of car users and to which degree they fit within the range limitations of electric vehicles (e.g. Pearre et al., 2011 Tamor et al., 2013; Khan and Kockelman, 2012). Jakobsson et al. (2016) concluded that the EV would fit better as a second car. Because of the different use patterns of second cars in the household, less behavioural adaptations are needed and multiple car households have the flexibility to assign the "right car for the right trip". In an early study by Kurani et al. (1994), households were presented with challenging ranges and in these cases, car swapping was one of the most frequently chosen options.

It is unclear which behavioural strategies are selected, if any, in order to cope when the range does not suffice for making the planned trips by EV, either incidentally or regularly. Also the perception or fear of (almost) not having enough range (range anxiety) can induce the same behavioural strategies. A systematic approach to explore rebound effects related to the lower marginal costs of driving EVs is also currently lacking. In this paper, these issues will be addressed. In the following subsections, the behavioural strategies to cope with range limitations or related to increased car travelling are identified, followed by a discussion about the hypotheses of this study related to the selection of a certain behavioural strategy.

2.1. Alterations and EVs

In this study, travel behaviour is represented in such a way that it is easy to differentiate between a few specific strategies for altering travel patterns, hereafter called alterations. Car drivers can use these strategies to cope with the range limitations of electric vehicles. Firstly, they can adjust their driving behaviour and route choice. Driving slower or using secondary or tertiary roads rather than arterial or motorway routes can increase the available range (e.g. Bingham et al., 2012). Secondly, drivers can select another transport mode for a trip if the available range does not allow all trips to be made by EV. Thirdly, they can change the timing of making trips. Re-scheduling trips might enable charging the electric vehicle at home for a longer time prior to