The Impact of Charging Needs on Battery Electric Vehicle Drivers' Route Choice Behaviour: a stated preference survey in the Netherlands

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ABSTRACT

Electric travelling appears to dominate the transport sector in the near future due to the needed transition from fuel-dependent vehicles towards Electric Vehicles (EV). Given this trend, investigation of the EV drivers travel behaviour is of importance to stakeholders including planners and policymakers. This research explores the Battery Electric Vehicle (BEV) drivers route choice and charging preferences through a Stated Preference (SP) survey. Collecting data from 505 EV drivers in the Netherlands, we report the results of estimating a Mixed Logit (ML) model. Respondents were requested to choose a route among six alternatives which are freeways, arterial ways, and local streets with and without fast charging. Our findings suggest that the classic route attributes, vehicle-related variables and charging characteristics can significantly influence the BEV drivers route choice and charging behaviour. When the state-of-charge (SOC) at the origin is high and a slow charger at the destination is available, routes without fast charging are likely to be preferred. Moreover, local streets can be preferred if SOC at the destination is expected to be zero (less consumption along the way) while arterial ways might be selected when a driver must recharge his/her car during the trip via fast charging.

Keywords: Electric travelling, Electric vehicles, route choice, charging behaviour, discrete choice modelling

1. INTRODUCTION

The transport sector is recognised as one of the primary drivers of energy consumption and Greenhouse Gas (GHG) emission with 23% of the total GHG emissions in Europe in 2015 (*1*) and also the only sector which demonstrates an increase in GHG emission (*2*, *3*). Electrification of vehicles is a major measure to increase energy efficiency as well as resource security and also decarbonisation of transport leading to climate protection and less pollution.

In recent years, the EV market share has significantly grown. Plug-in Hybrid EV (PHEV) and Battery Electric Vehicle (BEV) have dominated the EV market share (*4*). Policymakers incentivised users to purchase PHEVs at early stages of electric travelling in some countries such as the Netherlands, then the strategy shifted towards phasing out the sale of PHEVs and promoting BEVs share given the higher battery capacity and lower emission by a change in fiscal incentives in order to accomplish zero-emission transport goals (*4*). However, BEVs have several restrictions such as lower driving range, higher recharging duration, and also lack of charging infrastructure which might be the source of different route and charging preferences of the BEV drivers.

Charging points can be classified into slow and fast charging based on the recharging time. As the terminology reveals, the former takes longer to recharge an EV. On average, an electric car needs 6-8 hours and half an hour to be recharged with a slow charger and a fast charger, respectively (*5*). Slow charging is most often used when a driver intends to stay at a particular place such as his/her home or office while fast charging points have been mostly installed in the main streets to enable EV drivers to recharge their cars during their travel as needed to complete their trips (much like today's gas stations).

There is a growing body of literature that explores the implications of electric travelling in both demand and supply sides (*6*–*9*). However, to the best of our knowledge, investigation of the possible distinctive travel behaviour of BEV drivers caused by the mentioned restrictions is fairly missing in the literature. This research aims to capture the EV drivers' preferences for road types and charging methods simultaneously with examining the possible scenarios.

In this study, a stated preference (SP) survey is conducted to investigate BEV drivers' route choice between freeways, arterials ways, and local streets and charging preference for fast charging during travel or slow charging at the destination in a fixed OD pair. Hence, three experiments with unique specifications have been set up to recognise the most effective factors that influence the driver's behaviour.

2. STUDY SPECIFICATIONS

We categorised roads into three groups: freeways, arterial ways, and local streets. On the other hand, slow charging and fast charging are currently two common charging methods. Literature shows that flexible charging such as fast charging may affect route choice behaviour while fixed charging method has the minimum effect (*10*). Therefore, routes can be divided into routes with and without fast charging. It should be noted that statistics show that electric vehicles are mostly used for making short business trips at the present time (*11*). Therefore, respondents were requested to select between six routes namely freeway, arterial way, and local streets with and without fast charging to perform a daily commuting trip (e.g., from home to work).

SOC at the origin, electricity consumption, travel time, and travel cost were considered as attributes of all routes while recharging duration, waiting time in the queue of a charging point were alternative-specific attributes of the routes with fast charging.

SOC at the origin and destination are the most important indicators which can influence the drivers' decision on the route and charging behaviour. SOC at the destination is derived from subtracting the initial SOC and the electricity consumption. When these two are roughly equivalent (i.e., SOC at the destination approaches zero), significant different driving behaviour is expected to be observed, especially for whom have high range anxiety.

On the other hand, the availability of a slow charging point at the destination can play an important role in route and charging choice of users. If one prefers to recharge his/her vehicle during a trip, fast charging can be a possible option. Therefore, fast charging duration and waiting time in the queue were considered in the routes with fast charging.

Respondents were explained that if they select a route with fast charging, they must recharge their car during the trip. Moreover, since the fast charging cost is higher than slow charging (roughly twice depending on charging speed and capacity of the infrastructure), the associated cost was embedded in the travel cost of routes with fast charging.

3. SURVEY DESIGN

Efficient design was selected to minimise the standard errors of the parameter estimates in case the asymptotic variance-covariance (AVC) matrix is determined (*12*). This method aims at minimising so-called $D_p - error$ (*12*):

$$D_p - error = \det\left(\Omega_1\left(X, \tilde{\beta}\right)\right)^{1/K}$$

Where K indicates the number of parameters to be estimated. $\tilde{\beta}$ is set to the best estimation of parameters. To obtain priors, a pilot study was conducted, then the survey was redesigned accordingly. The choice experiments have been constructed using the software package NGENE (*12*).

Furthermore, Fiori et al. (*13*) concluded that BEV energy consumption might increase in a faster route. Based on the speed range, we assumed that travel time is lower in freeways than arterial ways and local streets while electricity consumption and travel cost are higher in freeways than arterial way and local streets. Moreover, fast charging during travel increases total time and cost in freeway than arterial way and local streets due to lower SOC at the time of charging.

Based on the SOC at the origin and electricity consumption, three possible scenarios can be considered:

1- SOC at the origin is much higher than electricity consumption during the trip
2- SOC at the origin and electricity consumption are roughly equivalent
3- SOC at the origin is lower than or equal to electricity consumption (fast charging is required)

To address all the aforementioned scenarios, three different experiments were designed. It is postulated that a commuting trip is conducted between a certain origin-destination pair in all experiments. SOC at the origin differs significantly in each experiment, for example, 90% in the first experiment, 30% in second experiment, and 15% in third one. It is assumed that if a traveller selects a route with fast charging, he/she has to recharge his/her car with the fast charger point. Each experiment has 24 treatment combinations in 6 blocks of 4 choice tasks. Figure 1 illustrates an example of a choice set.

Figure 1: Example of a choice set in Experiment 1

Percentage of battery capacity available at the origin is 85%.
There is no available slow charger at the destination.
If you select a route with fast charging, you have to charge during your travel.

Alternatives / Attributes	Routes WITHOUT fast charging			Routes WITH fast charging		
	Mostly freeway (1)	Mostly Arterial way (2)	Mostly Local Streets (3)	Mostly freeway with charging (4)	Mostly Arterial way with charging (5)	Mostly Local Streets with charging (6)
Percentage of battery capacity available at the origin	85%	85%	85%	85%	85%	85%
Percentage of battery capacity consumed for making your trip	30%	25%	15%	30%	20%	15%
Travel costs (euro)	3.5	2	1.5	6.5	5.5	5
Route travel time excluding charging time (min)	20	25	30	20	25	40
Charging time to be fully charged (min)	There is no available slow charger at the destination			10	8	6
Waiting time in the line of charging (min)				6	3	9
Total travel time (min) (Route travel time+charging time+waiting time)				36 (20+10+6)	36 (25+8+3)	55 (40+6+9)
Charger Location				In the middle	Close to the origin	Close to the destination

*

	Your choice					
	Freeway (1)	Arterial way (2)	Local Way (3)	Freeway with fast charging (4)	Arterial way with fast charging (5)	Local way with fast charging (6)
Your Choice	○	○	○	○	○	○

4. DISCERET CHOICE MODELLING

Random Utility Maximization (RUM) hypothesizes that alternative i is chosen by individual n when the associated utility is the highest compared to the other options (*14*, *15*). The utility functions for all alternatives are defined using Eq. 1.

$$U_i = \sum_m \beta_{im}.x_{im} + \sum_k \beta_{ik}.x_{ik} + \varepsilon_i \quad (1)$$

Where the first component of the utility function is associated with the route, vehicle-related, and charging attributes including SOC at the origin, electricity consumption, travel time, travel cost, charging time, waiting time, and availability of slow charging at the destination. It should be mentioned that SOC at the origin and the availability of slow charger are included as the context variables. β_{im} is a vector of coefficients that indicates the importance of the exploratory variables x_{im}.

The second term corresponds to the factors that are related to the individuals. β_{ik} is a vector of coefficients that implies the importance of various socio-economic variables. The error term, the last component in the utility function, represents unexplained variation.

In order to consider the taste heterogeneity amongst individuals as well as the correlation between choices made by the same individual, we estimated a mixed logit model with panel effects using the software package PythonBiogeme (*16*).

5. RESULTS

In total, the data of 505 respondents were collected. Table 1 summarises the results of the maximum likelihood estimation of the mixed logit model with considering the panel effect and 1000 Halton draws.

Table 1: Results of the mixed logit model

Name	Value	Robust Std err	Robust t-test
ASC_FREEWAYS_C	4.85	0.717	6.77
ASC_ARTERIAL WAYS_C	4.80	0.659	7.29
ASC_LOCAL STREETS_C	3.67	0.584	6.28
B_TT	-0.0310	0.00644	-4.81
B_TC	-0.178	0.0417	-4.27
B_CT	-0.0818	0.0225	-3.63
B_WT	-0.0271	0.0102	-2.65
B_SOC_C	-0.0345	0.00462	-7.48
B_CP_C	-0.365	0.0821	-4.44
B_E1_FREEWAY	0.120	0.0939	1.28
B_E2_LOCALSTREET	0.225	0.112	2.00
B_E3_ARTERIAL WAY	0.568	0.120	4.73
B_GENDER_W/C	-0.849	0.213	-3.99
B_AGE_W/C	0.0233	0.00724	3.22
B_INCOME_W/C	-0.140	0.0474	-2.96
B_EDUCTATION_W/C	-0.663	0.207	-3.20
SIGMA_FREEWAYS_C	1.03	0.156	6.59
SIGMA_ARTERIAL WAYS_C	0.922	0.109	8.48
SIGMA_LOCAL STREETS_C	0.887	0.139	6.39
SIGMA_CT	0.171	0.0118	14.43
SIGMA_TC	0.316	0.0502	6.31
SIGMA_TT	-0.104	0.00655	-15.93
Number of observations	6060		
Final log likelihood	-8163.21		
Rho-square	0.186		

Each parameter has been labelled by a prefix and a suffix in order to enable readers to grasp the type of the estimated parameter and the associated utility function. As the prefix, B indicates the estimated marginal value of a parameter while SIGMA represents the standard deviation of a random parameter. The suffix W/C and C show that the corresponding exploratory variable has been associated to the routes without and with fast charging, respectively. Furthermore, when a parameter ends with a road category such as freeways, it represents the associated utility function (freeways) that the variable has been incorporated.

The coefficients of Alternative Specific Characteristics (ASCs) are significant and positive. They are included in the routes with fast charging, so the positive sign supports the existence of unobserved preferences towards routes with fast charging. This tendency might be due to various attitudinal factors such as range anxiety, trust in electric travelling, etc. Furthermore, the significant SIGMAs bold the heterogeneity amongst observed as well as unobserved utility.

Unsurprisingly, travel time and travel cost as the classic route attributes have negative effects on the utility of all route alternatives. Furthermore, charging time and waiting time lead to the disutility of the routes with fast charging.

Having a negative sign as a context variable incorporated into the utility functions of routes with fast charging, SOC at the origin can be a crucial determinant to select a route with/without fast charging. The higher SOC at the origin increases the probability of choosing a route without fast charging.

We examined the road type preference of the EV drivers within the designed experiments. Local streets appear to be favoured by travellers who end up with running out of battery power in the second experiment. In the third experiment in which users must recharge their car during the trip, they may tend to select arterial ways. Arterial ways are assumed to have lower consumption than freeways and lower travel time than local streets, so travellers may select them in order to ensure that they can arrive at a fast charging point while total travel time is taken into account.

The negative marginal value of charging point (CP) shows that the availability of a slow charging point at the destination is a significant factor to select a route without fast charging. This is because when a charging opportunity is provided at the destination, drivers may feel more comfortable to perform their trip without fast charging.

Gender coefficient has a negative value of -0.849 which is the most effective factor amongst other SDC variables. It suggests that female drivers are more likely to select routes with fast charging owing to their higher sensitivity to the battery power status than men. Age has an inverse relationship with routes with fast charging so older people might prefer slow charging. Results represent that one with higher income and education level tends to choose the routes with fast charging.

6. CONCLUSIONS

This study intends to demonstrate the impact of electric driving on the route choice and charging behaviour of BEV drivers. Collecting the data of 505 respondents through an SP survey, we estimated a mixed logit model expressing the underlying influences on the BEV drivers' choice behaviour. The results suggest that the EV drivers' route and charging preferences are dependent on the route attributes, vehicle-related variables, charging characteristics, and socio-economic factors.

Classic route attributes including route travel time and travel cost as well as fast charging-related variables such as charging time and waiting time are significant determinants that any increase in the value of each of them in a specific route leads to a negative effect on the selection of that route.

According to the estimation results, higher SOC at the origin can stimulate drivers to select a route without fast charging. This is because the high level of initial SOC gives more confidence to the driver in order to make the trip without any need for fast charging. On the other hand, routes without fast charging might be preferred if a slow charging opportunity is provided at the destination. In summary, the probability of choosing a route without fast charging has a strong direct relationship with SOC at the origin as well as the availability of a slow charging point at the destination. Thus, developing a trip planner application which is able to estimate the electricity consumption in different routes between a pair of OD and also show the availability of slow charging points could be a promising tool helping EV users to select an efficient route and charging method.

Local streets are preferred over freeways and arterial ways when SOC at the destination approaches zero. This is because drivers have a tendency to select a route with the lowest consumption in this condition. While arterial ways are favoured in which drivers are forced to recharge their car via a fast charging point due to the higher electricity consumption during the trip than the initial SOC.

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