CETRA[2020*] 20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

ELECTRO MOBILITY ACCEPTANCE: THE INFLUENCE OF POLITICAL BONUS AND MALUS FACTORS AND PREFERENCES FOR CHARGING STATIONS

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Abstract

As a considerable amount of greenhouse gas emissions are caused by the transport sector with road traffic being the biggest polluter, the German government has initiated programs to promote electric vehicles (EVs). Currently, the main activity is to install charging infrastructure and to provide a financial bonus for the purchase of EVs. As part of the project "Electric City Russelsheim", CAPI interviews have been conducted to determine the acceptance of EVs among the population. The survey aims to investigate the effects of possible bonus and malus factors to promote EVs. Moreover, it analyses people's preferences for the configuration of charging stations in a discrete choice experiment. In choice tasks, respondents indicate their preferences by choosing a charging station configuration between two alternatives. Preliminary results from a Multinomial Logit Model on a sample of 462 respondents are presented in this paper. As configuration, respondents mostly prefer Plug & Charge as authentification method, card-based payment method, billing according to the amount of charged electricity, and a higher share of energy from renewable sources.

Keywords: stated preferences, discrete choice experiment, electric vehicles, electric mobility, charging stations, charging infrastructure

1 Introduction

With a share of almost 20 %, the transport sector is one of the largest sources of greenhouse gas emissions in Germany, whereby road traffic is the biggest polluter within this sector [1]. One method to reduce the emission, is the promotion of alternative fuel vehicles [2]. Therefore, the German government initiated a program "Sofortprogramm Saubere Luft 2017-2020", which provides a financial bonus for the purchase of electric vehicles (EVs) and develops charging infrastructure. Within this program, a large-scale project "Electric City Russelsheim" has been initialized to equip the city Russelsheim with charging infrastructure all over the place. The installation of the charging stations for EVs is accompanied by a social research study, which aims to get insights about the acceptance of EVs and to derive recommendations for future practices to promote EVs in the population. This paper is part of the social research program and focuses on insights about people's preferences for charging infrastructure.
Currently, the charging stations are sparsely distributed across Germany, whereby this distribution shows spatial clusters with the highest density in few metropolitan cities [3]. However, for the spread of electric cars, it is not only necessary to install a nationwide charging infrastructure [4], but also to increase the user-friendliness of the charging stations. At present, the configurations of charging stations are very heterogeneous in Germany [5], making a

simple and user-friendly handling difficult. At the same time, findings show, that consumers are not only sensitive to the mere presence or density of charging stations, but are more concerned with attributes such as costs, location, duration and waiting times [3]. However, yet, preferences for charging stations have not been fully studied by mainly focussing on willingness-to-pay [3] or on preferences for the infrastructure [2] rather than on user-friendly configuration. To provide a customer-friendly charging, other attributes such as registration, authentication, and payment methods are important to investigate, since previous studies have shown that these attributes seem to have the largest discrepancy between desired configuration and current situation [6]. Therefore, the research question covered in this paper, is: Which preferences do potential users have for the design and configuration of charging stations? To answer this question a survey study including a stated preferences experiment to assess the preferences for the configuration of charging stations was conducted. Preliminary results from this survey effort are presented in the following.

2 Methodology

2.1 Study area, field work and sample

The survey area is Russelsheim am Main, surrounded municipalities and the city of Wiesbaden. Adults of 18 years and older have been recruited from a sample of 6,107 addresses. Potential respondents were contacted with an introduction letter and a follow-up recruitment phone call. An incentive of 20 Euros was offered to the respondents. Data were collected in computer-assisted personal interviews (CAPI), programmed as a Java application. The fieldwork started in January 2020 as Faceto-Face interviews in respondents´ household. Due to COVID-19, this procedure had to be stopped in March to be adopted to web-based CAPI-interviews conducted via an online video-based communication tool. The new field work period started in May to be finished in December 2020. A total sample of n = 462 respondents has been achieved after data cleaning.

2.2 Stated preference: Study design

To provide recommendations for the configuration of charging stations, this study aims to assess people's preferences by applying a stated preferences (SP) approach [7], where respondents are faced with pre-defined configurations of charging stations and can choose between pre-defined alternatives. To define the alternatives of charging station configurations, relevant attributes together with possible levels have to be specified [8]. This was done with reference to previous literature on possible configurations in Germany [5], [6] and preferences for configurations [3], [9]. In addition, a qualitative study was in the field in Russelsheim and collected peoples´ views on charging stations. Finally, the focus lies on the attributes authentification method, payment opportunities, billing method and share of electricity from renewable energy sources in the energy mix which is offered at the charging station. In this study, respondents need to choose between two alternatives of configurations. The alternatives are defined by experimental design, where for each attribute one of the possible levels is assigned. So, attribute levels are varied in the experiment. A brief description of the attributes, their functionality and the levels are presented in Table 1.

Table 1 Stated Preferences experiment: attributes, levels and description

Attribute	Level	Description of the level
Authentication	Plug & Charge	automatically by connecting the charging cable to the charging station
	RFID	by using a card from the provider with a Radio-frequency identification (RFID) chip
	App	via an app installed on a smartphone
Payment	web-based	via web-based services (e.g. PayPal)
	card-based	via card-based services (e.g. credit card)
	debit transfer	automatically via direct debit transfer (contract with the provider is necessary)
Billing	by electricity	price is based on the actual amount of electricity charged
	by time	price is based on the time (the longer you charge, the more expensive)
	fixed fee	fixed price for a charging process
	flat rate	unlimited charging at a fixed price (e.g. monthly)
Share of electricity from renewables	0%	0 % from renewable energy sources
	50%	50 % from renewable energy sources
	100%	100 % from renewable energy sources

An efficient experimental design [8], which uses only a subset of all possible choice tasks (combinations of attributes and levels), has been created with the software Ngene [10]. It resulted in 72 choice tasks split into six blocks with 12 choice situations in each block. Finally, every respondent was randomly assigned to one block and asked to answer the according choice situations. Hereby, as presented in the example in Table 2, respondents stated their preferences as discrete choices [8] between two unlabeled alternatives of charging stations "Configuration 1", "Configuration 2" and a labelled alternative "I do not choose configuration 1 or 2" (for more details on the study design please refer to previous work [11]).

Table 2 Stated Preference experiment: example of a choice task

Which configuration would you prefer for a charging station?			
Authentication	RFID	Plug & Charge	
Payment	web-based	debit transfer	
Billing	fixed fee	by electricity	
% of renewable energy	100%	50%	
	○ Configuration 1	○ Configuration 2	○ I do not choose configuration 1 or 2

In addition, the survey instrument collects information on the household, living situation, socio-economic and demographic characteristics, but also socio-psychological factors (e.g. intention to buy an EV, environmental awareness), since they are expected to have an impact on preferences for charging infrastructure [2].

2.3 Model specification

Discrete choice data are commonly analysed by applying Random Utility Maximization theory. It assumes that when completing a choice task as in Figure 1, respondents associate an utility with each alternative and are assumed to choose the alternative with the highest utility [12], [13]. In more detail: an individual n is confronted with j alternatives in t choice tasks. Hereby, an individual n associates an indirect utility U_{njt} for an alternative j in a choice task t and chooses the alternative with the highest utility. The utility of an alternative j is decomposed as

$$U_{njt} = V_{njt} + \varepsilon_{njt} = x'_{njt}\beta + \varepsilon_{njt} \quad (1)$$

Where U_{njt} is not observed, V_{njt} is the deterministic utility (known) of alternative j and ε_{njt} is a random error (cannot be measured directly). The deterministic utility V_{njt} can be specified by $x'_{njt}\beta$. Hereby x, is a vector of explanatory variables (e.g. attribute levels, socio-demographics), and β are the coefficients to be estimated, which indicate the utility associated with the explanatory variables in x.

In our experiment, respondents choose between three utilities associated with the J = 3 alternatives (configuration 1, configuration 2, neither configuration 1 nor 2). All alternatives are described by K = 4 attributes (authentification, payment, billing, share of renewables). Consequently, three utility functions (V_{njt}) need to be specified for each alternative to measure the utilities associated with the attribute levels. Hereby, the equations for the unlabelled alternatives are identical [14], since the options "Configuration 1" and "Configuration 2" themselves are generic and do not have a meaning and thus have the same utility for the respondents [8], [14]. For the labelled alternative "neither 1 nor 2" a constant β_0 (ASC) will be estimated.

The levels of the categorical attributes authentification, payment, and billing have been transformed to dummy variables (0 = not applicable, 1 = applicable). Hereby, for every attribute one level is omitted from analysis, which serves as reference category and whose utility is fixed to zero. Therefore, the parameter estimates for the remaining levels of the attribute capture the utility differences to the reference category [13], [14]. The attribute "share of renewable energy" has shown an approximately linear behaviour in the analysis and thus has been included as a continuous variable into the utility functions [13].

To assess differences in preferences of men and women, this study follows the segmentation approach used by previous studies [3], [15]. This aproach suggests to estimate separate models for males and females. Further, interactions with age have been tested for all dummies of the categorical attributes (authentification, payment, billing). Since the interaction parameters were not significant on the 95 % level and did not contribute to model improvement, the reduced model has been chosen as the best. As the attribute „share of renewables" is included as a continuous variable, a continuous interaction with age will be included into analysis following a technique applied by previous work [15]. Hereby, an interaction parameter $\lambda_{age,renewables}$ will be estimated to assess the sensitivity towards the attribute „share of renewable energy" in dependence to age and which answers the question: With increasing age, do people become more or less sensitive towards the share of renewables in the energy mix at charging stations?

3 Results

A multinominal logit model (MLM) [16] has been applied on the total sample (n = 462) which results in 5,603 observations (choice tasks), but also separately for males (n = 327 individuals, n = 3,972 observations) and for females (n = 135 individuals, n = 1,631 observations).

All analyses have been done with R using the package Apollo. The estimation results for the MLM models are presented in Table 2 and the preferences are visualized in Figure 2.
As mentioned previously, the parameter estimates for dummy-coded levels of each attribute capture the utility differences to the reference category [13], [14]. Thus, for each attribute only differences in utilities (preferences) between the attribute levels can be interpreted.
For Authentication, Plug & Charge has the highest positive estimate (β = 0.288) and thus the highest utility. The estimate of RFID card is lower (β = 0.139) and thus is less preferred than Pug & Charge, but it is positive, which means that it is more preferred than the reference category of an authentification via App. The difference in utilities for Plug & Charge to App is higher for males than for females.
Concerning payment, respondents prefer a card-based method most: When automatic debit transfer is used as reference category, the utility for card-based method is positive (β = 0.196) and thus has a higher utility. Web-based payment shows the least utility for respondents as the parameter is negative (β = -0.103) and is thus less preferred than automatic debit transfer. Especially women associate highest utility with card-based method, since the parameter estimate shows a larger difference to the reference category than for males.
As billing method, respondents mostly prefer to pay according to the amount of electricity they charged, since its parameter estimate has a higher utility (β = 0.876) in comparison to the reference category flat rate. Moreover, in comparison to the flat rate option the billing method by time (β = -0.312) or as a fixed fee (β = -0.401) show negative parameter estimates and thus lower associated utility. Especially females dislike the billing by time, since the difference of its estimate to the reference flat rate is larger for females than for males.
Finally, respondents prefer charging stations with higher share of electricity from regenerative sources as for each increase by 1 % of renewables, the associated utility increases by 1.533 points. The positive utility is true for males and females. With a negative value for $\lambda_{age,renewables}$ (λ = -0.842) the sensitivity to the share of green energy sources decreases when age increases [15]. Thus, when people become older, they become less sensitive towards the share of energy from renewable energy sources in the energy mix they would charge. This is true for both, males and females, since the estimate is negative for both subsamples.
The specified model for the total sample shows an adjusted Rho-squared (ρ^2) of 0.107. It can be considered as an adequate model fit, since values between 0.2 to 0.4 are recognized to be indicators of very good models [14, p. 54].

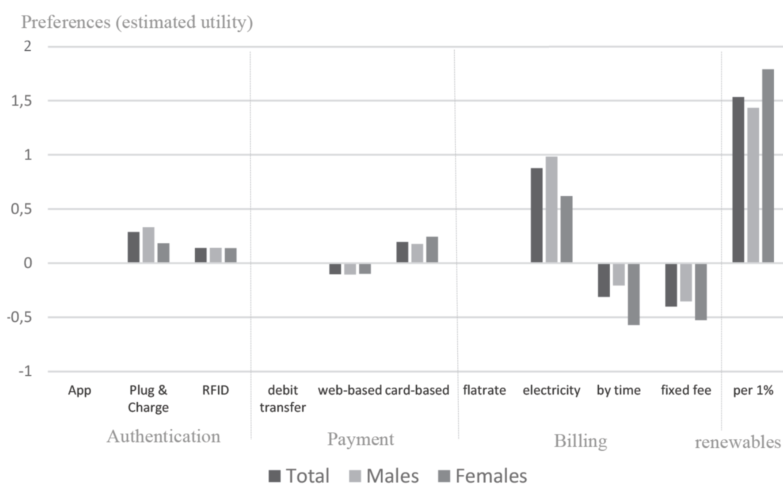

Figure 1 MNL results: Estimated preferences for the total sample, males and females

Table 3 Estimation results for MLM model for the total sample, males and females

	Total sample		Males		Females	
	est.	t-ratio	est.	t-ratio	est.	t-ratio
ASC (None)	0.685	9.015	0.714	7.865	0.614	4.411
Authentification (Reference level: App)						
Plug & Charge	0.288	4.736	0.332	-0.106	0.183	1.614
RFID	0.139	3.561	0.141	0.177	0.138	1.905
Payment (Reference level: debit transfer)						
web-based	-0.103	-1.946	-0.106	-1.682	-0.099	-1.012
card-based	0.196	3.838	0.177	2.921	0.243	2.554
Billing (Reference level: flat rate)						
by electricity	0.876	12.829	0.983	12.037	0.620	4.934
by time	-0.312	-4.488	-0.207	-2.504	-0.572	-4.419
fixed fee	-0.401	-5.736	-0.353	-4.228	-0.527	-4.083
renewable energy [%]	1.533	21.171	1.434	16.908	1.789	12.934
$\lambda_{age,renewables}$	-0.842	-8.423	-0.686	-4.983	-0.998	-6.643
Individuals:	462		327		135	
Observations:	5,603		3,972		1,631	
log-likelihood(Null):	-6155.525		-4363.688		-1791.837	
log-likelihood(Final):	-5484.732		-3891.389		-1582.708	
Adjusted ρ^2:	0.107		0.106		0.111	

4 Discussion

The survey study aims to perform analysis and provide insights on political bonus and malus factors and their impact on the promotion of EVs as well as preferences for configuration of charging stations. This paper presents preliminary results of the analyses of respondent's discrete choices between different charging stations. The initial results provide deep impressions of respondent's preferences with respect to configuration of charging stations: For authentication, Plug & Charge is the mostly preferred method. Respondents prefer to pay with a card-based method or via an automatic debit transfer (second preferred) and do not want to use web-based procedures. A billing according to the charged amount of electricity is the most preferred option. In addition, a higher share of electricity from regenerative sources is preferred, whereby people become less sensitive when getting older.

In future steps, interactions with additional socio-demographic variables (e.g. education, employment) will be tested. Moreover, since attitudinal constructs have been shown to explain preferences and evaluation of charging infrastructure [2], the surveyed socio-psychological constructs will be included in the analysis to achieve a deeper understanding and to provide recommendations.

Acknowledgement

The work is part of the project “Electric City Rüsselsheim”, funded by the German Federal Ministry for Economic Affairs and Energy; Grant number: 01MZ18008B.

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