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# The Relevance of Life-Cycle $CO_2$ Emissions for Vehicle Purchase Decisions: A Stated Choice Experiment for Germany




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# The relevance of life-cycle $CO_2$ emissions for vehicle purchase decisions: A stated choice experiment for Germany

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**Abstract**

This paper examines the individual preferences for a reduction of life-cycle $CO_2$ emissions in vehicle purchase decisions. The empirical analysis is based on data from a stated choice experiment with more than 1,100 citizens in Germany that refers to decisions between three types of electric vehicles and a conventional (i.e. gasoline or diesel) vehicle that are characterized by several attributes like purchase price or fuel costs. With respect to $CO_2$ emissions, we specifically examine emissions in vehicle production besides the commonly considered emissions in vehicle use. Our econometric analysis with flexible mixed logit models reveals a strong stated preference for the reduction of $CO_2$ emissions in both vehicle use and production, whereby the estimated willingness to pay for $CO_2$ emission reductions is higher for vehicle production. Furthermore, we find that conventional vehicles are significantly preferred over plug-in hybrid electric vehicles and particularly strongly significantly preferred over extended-range and pure electric vehicles. Surprisingly, environmental attitudes, i.e. environmental awareness and ecological policy identification, have no significant effects on the reduction of $CO_2$ emissions in both vehicle use and production. These results suggest that citizens in Germany with strong environmental identity do not consider reductions of $CO_2$ emissions in vehicle purchase decisions as an important direction for climate protection. Instead, this group rather tends to avoid the purchase of conventional vehicles since environmental attitudes have a significantly positive effect on the stated choice of electric vehicles, whereby this estimated effect is dominated by an ecological policy orientation instead of general environmental awareness. The latter result suggests the strong relevance of the controversial political discussion about the transition to electromobility in Germany. By considering economic preferences, the econometric analysis additionally reveals that individual trust is relevant for the purchase of plug-in hybrid electric vehicles.



**Keywords**

Vehicle purchase decisions, $CO_2$ emissions in vehicle use and production, climate protection, electric vehicles, stated choice experiment, mixed logit models

## 1. Introduction

Transportation has strong environmental impacts with respect to noise, ecosystems, or biodiversity. However, the main environmental challenges of transportation refer to air pollution and greenhouse gas emissions. In the European Union (EU) transportation is responsible for about one quarter of greenhouse gas emissions (e.g. European Environment Agency, 2022a). Since 2014, the greenhouse gas emissions from transportation in the EU have increased and are estimated to be about 29% above 1990 levels in 2018 (e.g. European Environment Agency, 2022c). In contrast, while transportation is still a significant source of air pollution, the corresponding emissions were significantly reduced between 1990 and 2017. In Germany, which is the focus of our study, transportation accounted for almost 40% of nitrogen oxide emissions, about one third of all carbon monoxide emissions, and about 20% of greenhouse gas emissions in 2020 (e.g. Umweltbundesamt, 2022a). This share of greenhouse gas emissions in Germany has increased by seven percentage points compared to 1990, which means that transportation is the only sector that could not reduce its emissions in recent decades (e.g. Umweltbundesamt, 2022b).

Under the German Federal Climate Protection Act ("Bundes-Klimaschutzgesetz"), the greenhouse gas emissions from transportation must almost halve (-48%) by 2030 compared to 2019 emissions. Accordingly, Germany must become greenhouse gas neutral by 2045, which presumably means reducing greenhouse gas emissions to zero in the transport sector (e.g. Umweltbundesamt, 2022b). With respect to transportation, the current German government, elected in 2021, generally intends to use the 2020s for a departure in policy and enabling sustainable, efficient, barrier-free, intelligent, and innovative mobility that is affordable for all. According to the coalition agreement, the transport policy goals in the context of climate policy include the expansion and modernization of infrastructure and further development of the framework conditions for a wide range of mobility options in cities and rural areas. The government also supports the transformation process of the German automotive industry against the backdrop of digitalization and decarbonization. It especially aligns the framework conditions and support measures so that Germany becomes the lead market for electromobility with at least 15 million electric vehicles by 2030.

Since a market penetration of low- and zero-emission vehicles (without prohibition of high-emission vehicles) needs a wide acceptance among car buyers, we consider the demand side and thus empirically analyze the preferences for lower $CO_2$ emissions in vehicle purchase decisions. We specifically consider decisions between different types of electric vehicles in this respect. However, while the number of newly registered electric vehicles (i.e. pure battery electric vehicles and plug-in electric vehicles) has strongly increased in the EU in the last years and especially between 2020 and 2021, it should be noted that its share among all newly registered cars is still less than 18% in 2021 (e.g. European Environment Agency, 2022b). Conventional vehicles which run on fossil fuels are thus still dominant in spite of a large range of different transport policy measures (e.g. subsidies) to support the purchase of electric vehicles. Germany had by far the highest number of new registrations of battery electric vehicles and plug-in electric vehicles in 2021. However, the corresponding share of about 26% among all newly registered cars (i.e. 681.410 registered electric vehicles among 2.622.132 registrations, see Bundesministerium für Digitales und Verkehr, 2022) is clearly smaller than in Scandinavian countries (e.g. Norway had the highest share with about 86% for both types of electric vehicles together). Furthermore, in spite of increasing numbers of new registrations, the stock of less than 1.2 million electric vehicles in Germany (among overall more than 48.5 million vehicles) at the beginning of 2022 reveals that the way to at least 15 million electric cars by 2030 is challenging.

Our empirical analysis is based on data from an experiment on stated choices among three types of electric vehicles and a conventional vehicle. Stated choice experiments are very useful for our purposes since the market penetration of electric vehicles in total, as discussed above, and especially of extended-range electric vehicles, which are also examined in our study, is still very low. Furthermore, we particularly analyze different dimensions of life-cycle $CO_2$ emissions as part of the vehicle purchase decisions, which prevents the consideration of data from revealed decisions in real-world situations. However, the use of data from stated choice experiments in this field is not new, but has been rather common for a long time. For example, the empirical studies of Ziegler (2012), Achtnicht (2012), or Achtnicht et al. (2012) are based on data on the stated choice among several alternative and conventional energy sources and propulsion technologies in vehicles. One common feature of stated choice experiments in this field (similar to other applications) is the inclusion of financial variables (mostly the purchase price and/or fuel costs, e.g. Beck et al., 2013) as attributes of different vehicle alternatives in the choice situations to analyze the willingness to pay (WTP) for specific vehicle types and the change of attributes (e.g. Ferguson et al., 2018, Brazil et al., 2019, Guerra and Daziano, 2020).

The additionally analyzed attributes in previous studies are diverse such as service station or charging availability (e.g. Ziegler, 2012, Achtnicht, 2012, Achtnicht et al., 2012, Egbue and Long, 2012, Hulshof and Mulder, 2020), recharging time (e.g. Noel et et al., 2019), driving range (e.g. Tanaka et al., 2014, Rezvani et al., 2015, Hackbarth and Madlener, 2016, Rotaris et al., 2021), or policy measures like subsidies or free parking (e.g. Hackbarth and Madlener, 2013, Soto et al., 2018, Qian et al. 2019). With respect to the focus of our empirical analysis, several previous studies also consider $CO_2$ emissions (e.g. Hidrue et al., 2011, Ziegler, 2012, Achtnicht, 2012, Achtnicht et al., 2012, Hackbarth and Madlener, 2013, 2016, Tanaka et al., 2014, Rezvani et al., 2015, Daziano et al., 2017, 2021, Alberini et al., 2018, Soto et al., 2018, Hulshof and Mulder, 2020), albeit only in vehicle use. Furthermore, these studies usually examine the relevance of individual characteristics like age, gender, education, or income for the preference for electric vehicles and/or the change of some vehicle attributes such as the reduction of $CO_2$ emissions. A major result of previous studies in this respect is the strong relevance of environmental attitudes, which mostly have a positive estimated effect on the stated choice of electric vehicles and/or the reduction of $CO_2$ emissions.

Based on these previous studies, we provide new empirical evidence on the preference for electric vehicles. The main contribution of our paper is two-fold: First, as discussed above, our paper systematically compares the relevance of two components of life-cycle $CO_2$ emissions for vehicle purchase decisions, i.e. $CO_2$ emissions in vehicle use and in vehicle production. Based on the corresponding estimated parameters, we specifically compare the estimated WTP for reductions of these two emission attributes over the life cycle of a typical vehicle with an average mileage. Second, we also examine the relevance of individual characteristics like common socio-demographics. In particular, we systematically compare the effects of two indicators for environmental attitudes, i.e. environmental awareness according to the New Ecological Paradigm (NEP, see Dunlap et al., 2000) and identification with ecological policy, on the choice of electric vehicles as well as on the reduction of $CO_2$ emissions in vehicle use and production. This analysis provides a clearer picture about the direction of citizens with strong environmental identity for climate protection in vehicle purchase decisions. In line with the conclusions in Ziegler (2021), we additionally control for the relevance of six economic preferences (i.e. risk and time preferences, altruism, trust, as well as positive and negative reciprocity) in our analysis of the effects of environmental attitudes.

The remainder of the paper is organized as follows: Section 2 presents the data and variables used in our empirical analysis. Section 3 describes the econometric approaches and the corresponding estimation results. Section 4 concludes and provides some policy implications.

## 2. Data and variables

### *2.1. Survey design*

The data for our empirical analysis were collected by means of large-scale computer-assisted web interviews among citizens in Germany. The survey was carried out by the German market research company Psyma during April and May 2021. The target population comprised adults, who were either solely or partially responsible for household decisions. The sample was stratified according to gender, age, place of residence, and education so that it is widely representative for the target population in Germany in terms of these characteristics. Across all respondents, the median completion time of the survey was about 31 minutes. Respondents, who did not pass some survey quality checks, which were embedded in random batteries of questions,[1] or indicated unrealistic values in the survey, are not considered in the empirical analysis. After some screening questions and some first socio-demographic variables, the first part of the questionnaire comprised questions on economic preferences, environmental attitudes, and planned vehicle purchase decisions in the future.

The main part of the survey referred to the stated choice experiment on the preferences for different vehicles. Each participant of the survey faced twelve different choice sets, each containing the choice among four hypothetical vehicles types, i.e. three electric vehicles and a conventional vehicle. The experiment included different experimental (e.g. information) treatments before the first and/or before the seventh choice sets. However, these treatments are not considered in this paper due to the focus on $CO_2$ emissions in both vehicle use and vehicle production. Consequently, only pre-treatment choices are included in our empirical analysis. We thus consider the first six choice sets for overall 1,128 respondents, respectively. The questions on environmental attitudes, economic preferences, and planned vehicle purchase decisions in the future were asked prior to the stated choice experiment to prevent the answers of the respondents from being influenced by the stated choices in the experiment. Finally, the last parts of the questionnaire comprised some questions about the Corona crisis, which are not considered in this paper, and some additional socio-economic and socio-demographic variables.

### *2.2. Stated choice experiment*

The main part of the survey for our empirical analysis referred to a stated choice experiment to examine individual preferences for different vehicle types and attributes. In each choice set, the

[1] Specifically, the respondents were asked to select a specific option to make sure that they were reading the instructions attentively.

participants of the experiment had to choose among four hypothetical vehicles, which were labeled according to their propulsion technology (e.g. Ferguson et al., 2018) to keep the experiment more realistic and enable the consideration of initial vehicle type preferences among the respondents (e.g. Louviere et al., 2000). Specifically, in each choice set, the participants of the experiment were asked to choose among one conventional (gasoline or diesel) vehicle with an internal combustion engine, one plug-in hybrid electric vehicle with a combination of an internal combustion engine and one or more small electric engines, one extended-range electric vehicle with one or more electric engines and a small internal combustion engine as range extender, and finally one pure electric vehicle with only one or more electric engines.

The alternative vehicles were characterized by the following eight different quantitative attributes:

- Purchase price (in Euro)
- Average $CO_2$ emissions caused in use per 100 km (in kg)
- Total $CO_2$ emissions caused in the production of the vehicle (in kg)
- Average range with a fully charged battery (in km)
- Average range with a full tank (in km)
- Average time to recharge the battery (in minutes)
- Average time to refuel the tank (in minutes)
- Average fuel costs per 100 km (in Euro)

With the exception of $CO_2$ emissions in vehicle production, the attributes and their levels are based on previous studies as discussed above. Furthermore, these attributes are found to be among the most important vehicle features for (stated) vehicle purchase decisions (e.g. Hackbarth and Madlener, 2013, 2016). On this basis, we expect a positive effect of vehicle range and a negative effect of purchase price, time to recharge the battery and refuel the tank, and of fuel costs on the choice among the four vehicle types. Furthermore, we expect a high preference for lower $CO_2$ emissions in vehicle use. With respect to the reduction of $CO_2$ emissions in vehicle production, it might be speculated that its WTP is lower than the WTP for the reduction of $CO_2$ emissions in use due to an overall lower public awareness and knowledge about the contribution of $CO_2$ emissions in the production to life-cycle $CO_2$ emissions of vehicles. The level ranges of the attributes were aligned to realistically fit the respective vehicle type. Table 1 gives an overview of all attributes and the corresponding attribute levels across the different vehicle types in the stated choice experiment.

To keep the hypothetical vehicle alternatives as realistic as possible, some attributes were customized or grounded to reality according to certain indications by the respondents (e.g. Hensher, 2010, Hensher et al., 2015). The purchase price levels were customized according to the average indicated Euro value the participants of the experiment were willing to pay in future purchase decisions, while the $CO_2$ emissions and operating cost levels were based on individual reference values of the preferred vehicle class. The purchase price levels as well as the levels of $CO_2$ emissions and operating costs thus differed across the respondents. To allow the respondents to compare the hypothetical vehicles in each choice set, the purchase prices and operating costs were presented in Euro and the $CO_2$ emissions were given in kg. The reference values for the emission levels in different vehicles were based on Wietschel et al. (2019). $CO_2$ emissions caused in vehicle production, i.e. the attribute of main interest in our empirical analysis, have not been considered in previous studies so far. Therefore, the range of the levels according to the reference values were defined along the line of $CO_2$ emissions in vehicle use.

Methodologically, a fractional factorial design was employed for the attribute combinations, whereby the statistical software Sawtooth was used to efficiently generate choice sets for all participants of the experiment. The order of the four vehicle types was randomized in each choice set, whereby the respondents always had to choose one of them. The complete survey including the stated choice experiment was pre-tested to ensure comprehensibility among the respondents. Table 2 shows a translated exemplary choice set, while Figure 1 presents the corresponding original (German) screenshot of it. To avoid or at least reduce the hypothetical bias of the stated choice experiment, a cheap talk script, alerting the respondents to strongly consider their financial situation when making a decision, was implemented at the beginning of the experiment (e.g. Mariel et al., 2021). Table 3 reveals that more than 42% of all stated choices refer to conventional vehicles, which suggests that the preferences for electric vehicles are lower than for conventional vehicles. However, these reported frequencies do not control for the included attributes and thus should be interpreted with caution.

### *2.3. Variables in the econometric analysis*

*Experiment-related variables*

Our dependent variable refers to the stated choice among the four vehicle types, i.e. conventional vehicles, plug-in hybrid electric vehicles, extended-range electric vehicles, and pure electric vehicles. Technically, alternative-specific constants for the three types of electric vehicles are included in the econometric analysis with mixed logit models as discussed below, considering conventional vehicles as base category. The experiment-related explanatory variables are based on the eight attributes as discussed above. While the first financial attribute is termed ‘purchase price (in 1000 Euro)’, the two emission-specific attributes are termed ‘$CO_2$ emissions in use per 100 km (in kg)’ and ‘$CO_2$ emissions in the production (in tons)’. We now examine the latter variable in tons to avoid very high parameter estimates in the econometric analysis. The two attributes for range are summarized in the variable ‘range with a fully charged battery and/or a full tank (in 100 km)’. The two time-specific attributes are termed ‘time to recharge the battery (in hours)’ and ‘time to refuel the tank (in minutes)’, whereby the former variable is now measured in hours to avoid very high parameter estimates in the econometric analysis. Finally, the second financial attribute is termed ‘fuel costs per 100 km (in Euro)’.

*Individual characteristics*

To analyze the heterogeneity of preferences for the different vehicle types and attributes, several individual characteristics are examined. First, we consider environmental awareness, measured with a NEP scale according to Dunlap et al. (2000). NEP scales are a standard instrument in the social and behavioral sciences including economics (e.g. Ziegler, 2021). In line with Whitmarsh (2011), our NEP scale is based on the following six statements: “Humans have the right to modify the natural environment to suit their needs”, “humans are severely abusing the planet”, “plants and animals have the same right to exist as humans”, “nature is strong enough to cope with the impacts of modern industrial nations”, “humans were meant to rule over the rest of nature”, and “the balance of nature is very delicate and easily upset”. The participants of the survey were asked how much they agree with these statements on a symmetric scale with the five ordered response categories “totally disagree”, “rather disagree”, “undecided”, “rather agree”, and “totally agree”. We assign increasing integers from one to five for the three environmentally positively worded statements and decreasing integers from five to one for the three environmentally negatively worded statements. The variable ‘NEP scale’ is the sum of these six values and thus can generally range between six and 30.

Environmental attitudes are not only addressed by ‘NEP scale’, but also by ecological policy identification. However, due to the possible interrelationship between different policy orientations, especially in Germany (e.g. Groh and Ziegler, 2022), we do not restrict our consideration on ecological policy identification or simple one-dimensional indicators for a left/right-wing policy identification. Instead, we examine three additional directions of policy identification. Specifically, the respondents were asked how much they agree with the following statements, again on a symmetric scale with five ordered response categories, ranging from "totally disagree" to "totally agree": "I identify with ecologically oriented policy", "I identify with socially oriented policy", "I identify with liberally oriented policy", and "I identify with conservatively oriented policy". The corresponding four dummy variables 'ecological policy orientation', 'social policy orientation', 'liberal policy orientation', and 'conservative policy orientation' take the value one if the respondent stated to identify with the respective policy orientations rather or totally. In line with previous studies as discussed above, we expect that environmental attitudes (i.e. 'NEP scale' and 'ecological policy identification') have a positive effect on the stated choice of electric vehicles and the reduction of $CO_2$ emissions. Due to the controversial political discussion about electromobility and its support in Germany,[2] it can additionally be expected that the effect of ecological policy identification is stronger than the effect of environmental awareness.[3]

Economic preferences are often examined in behavioral economics (e.g. Falk et al., 2018, 2023) and have been shown to play an important role not only for individual behavior like stock purchases (e.g. Dohmen et al., 2012), but especially for pro-environmental behavior (e.g. Kotchen and Moore, 2007, Qiu et al., 2014, Newell and Siikamäki, 2015, Ziegler, 2020, Falk et al., 2021, Fischbacher et al., 2021). In line with Ziegler (2021), we argue that omitting economic preferences in econometric analyses of the relationship between environmental attitudes (especially environmental awareness according to the NEP) and environmental protection activities (in our case the choice of electric vehicles and the reduction of $CO_2$ emissions in the vehicle purchase decisions) can lead to biased estimation results. To the best of our knowledge, our empirical analysis is the first that examines the relevance of economic preferences for stated vehicle purchase decisions. According to Falk et al. (2018), we specifically differentiate between time and risk preferences, altruism, trust, as well as positive and negative reciprocity in our econometric analyses.

Our variable for time preferences is based on a survey question according to Falk et al. (2023). The respondents were thus asked how willing they are to give up something that is beneficial for them today to benefit more from that in the future on a symmetric scale with the five ordered response categories "not at all willing", "rather not willing", "undecided", "rather willing", and

[2] For example, the targets for the total number of electric vehicles in Germany (which have repeatedly not been met in the past), the level of subsidies for electric vehicles, or hidden financial support for conventional instead of only electric vehicles (e.g. by subsidizing the use of company vehicles) are particularly controversial.

[3] Previous studies also reveal a dominance of the effect of ecological policy identification over environmental awareness, measured by a NEP scale, such as in the case of the demand for green electricity contracts (e.g. Ziegler, 2020).

"very willing". The dummy variable 'patience' takes the value one if the participant of the survey is rather or very willing. Our variable for risk preferences is based on a validated survey question (e.g. Dohmen et al., 2011, Vieider et al., 2015, Falk et al., 2018, 2023) according to the German Socio-Economic Panel (SOEP). The participants of the survey were thus asked how risk-taking they personally consider themselves on a symmetric scale with the five ordered response categories "not at all willing to take risks", "rather not willing to take risks", "undecided", "rather willing to take risks", and "very willing to take risks". The dummy variable 'risk-taking preferences' takes the value one if the respondent is rather or very willing to take risks.

Our variable for altruism is also based on a survey question according to Falk et al. (2023). The participants of the survey were thus asked how willing they are to give for charity without expecting anything in return, again on a symmetric scale with five ordered response categories, ranging from "not at all willing" to "very willing". The dummy variable 'altruism' takes the value one if the respondent indicated one of the latter two categories. In line with, for example, Dohmen et al. (2012), our variable for trust is based on the following three statements from the SOEP: "In general, one can trust people", "these days one cannot rely on anybody else", and "when dealing with strangers, it is better to be careful before one trusts them". The respondents were asked how much they agree with these statements on a symmetric scale with the five ordered response categories, ranging from "totally disagree" to "totally agree". We assign increasing integers from one to five for the first statement and decreasing integers from five to one for the two latter statements. The variable 'trust' is the sum of the single values for the three statements and thus can vary between three and 15.

Our variables for positive and negative reciprocity are in line with, for example, Dohmen et al. (2008, 2009) or Caliendo et al. (2012) and thus with survey questions from the SOEP. The variable for positive reciprocity is based on the following three statements: "If someone does me a favor, I am ready to return it", "I particularly try to help someone who has helped me before", and "I am willing to incur costs to help someone who has helped me before". The variable for negative reciprocity is based on the following three statements: "If I am treated with a great injustice, I will take revenge at the first occasion, no matter what the cost", "if someone puts me in a difficult position, I will do the same to him", and "if someone offends me, I will also offend him".[4] The respondents were again asked how much they agree with these statements on a symmetric scale with the five ordered response categories, ranging from "totally disagree" to "totally agree". Again, we assign increasing integers from one to five for all six statements. The variables 'positive reciprocity' and 'negative reciprocity' are the sums of the single values for the three statements, respectively, so that both variables can thus vary between three and 15.

Finally, we control for several socio-economic and socio-demographic variables. With respect to income, the respondents were asked for their monthly net household income in Euro among overall 21 income classes. For each income class, we consider the midpoints.[5] Specifically, we consider the concept of equivalized income to account for scale effects in the household (e.g. Groh and Ziegler, 2022). Our approach refers to a modified OECD equivalence scale (e.g. Horsfield, 2015), which weights the first adult in the household with the factor one, children up to the age of 13 years with the factor 0.3, and other older household members with the factor 0.5. The corresponding variable is termed 'equivalized income'. Furthermore, the dummy variable 'high education' takes the value one if the respondent has at least graduated from high school (i.e. passed the German Abitur). In addition, the dummy variable 'female' takes the value one if the respondent is a woman, the variable 'age' indicates the age of the respondent in years, and the dummy variable 'Eastern Germany' takes the value one if the respondent lives in one of the Eastern federal states of Germany including Berlin. Table 4 reports some descriptive statistics of these explanatory variables.

## 3. Empirical analysis

### *3.1. Econometric approach*

We use mixed logit models (e.g. McFadden and Train, 2000, Hensher and Greene, 2003), i.e. random parameters logit models as specific variants, in our econometric analysis, which are in contrast to common multinomial logit models much less restrictive and more flexible by including random parameters of the explanatory variables. Mixed logit models are particularly able to capture unobserved taste heterogeneity and correlations due to the panel nature of the data since each respondent was faced with over six choice sets. Incorrectly neglecting taste

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[4] Due to the word-for-word adoption of the statements from the SOEP questionnaire (for 2015), it should be noted that they are not gender neutral, but refer to the male gender (the original German wording of the two corresponding statements is "wenn mich jemand in eine schwierige Lage bringt, werde ich das Gleiche mit ihm machen" and "wenn mich jemand beleidigt, werde ich mich ihm gegenüber auch beleidigend verhalten").

[5] In line with Feldman (2010), we consider one and a half times of the lower bound of the open top class and thus assign 15,000 Euro to all respondents who indicated this household income class.

heterogeneity and/or correlations in multinomial logit models assuming fixed parameters of the explanatory variables can therefore lead to distorted estimation results due to the underlying model misspecification. In contrast to the case in multinomial logit models, the maximum likelihood (ML) estimation of mixed logit models using deterministic numerical integration methods is generally not feasible since the probabilities for the stated choice among the four alternative vehicles are characterized by multiple integrals. Instead, the probabilities can be approximated by simulation methods, which leads to the simulated maximum likelihood (SML) estimation (e.g. Revelt and Train, 1998, Train, 2009). For our SML estimation of mixed logit models we assumed normally distributed parameters and used the Stata command "mixlogit", which was written by Hole (2007). Furthermore, we used 1000 Halton draws in the SML estimation.

The estimation of the WTP for the vehicle attributes (including the alternative-specific constants) in our stated choice experiment refers to the purchase price. The mean (marginal) WTP is the change of the purchase price that keeps the underlying utility for the different alternatives constant for a marginal change of the attribute of interest.[6] It can be estimated by the ratio between the negative value of the estimated parameter of the attribute of interest and the estimated parameter of the purchase price. However, this procedure would refer to the standard approach with fixed parameters like in the case of multinomial logit models. In our mixed logit models, the mean WTP for attributes with assumed random parameters is estimated by the ratio between the negative values of the estimated means of these random parameters and the estimated fixed parameter (e.g. Revelt and Train, 1998) of the purchase price.[7] With respect to individual characteristics, it should be noted that their effects on some attributes are estimated by including interaction terms in the mixed logit models. The parameters of these interaction terms are typically assumed to be non-random so that the corresponding (additional) mean WTP is simply estimated by the ratio between the negative value of the estimated parameter of the interaction term and the estimated parameter of the purchase price.

### *3.2. Estimation results for vehicle types and attributes*

Table 5 reports the SML estimation results in a mixed logit model that only includes alternative-specific constants for the three different electric vehicle types and the vehicle attributes as ex-

[6] Conceptually, it can be derived by setting the total derivative of the utility function with respect to the attributes and the purchase price to zero (assuming that all other attributes are held fixed).
[7] This estimation of the WTP might be problematic if the parameter of the purchase price would be random in reality. In this case, the use of the more flexible so-called WTP space (instead of the preference space) approach, which specifies the distributions for the WTP so that the estimated parameters are directly estimated WTP, would be more appropriate. We will discuss some estimation results in the WTP space in our robustness checks.

planatory variables. While the parameter estimates and the corresponding robust z-statistics in the first column refer to the mean of the random parameters, the second column refers to the estimated standard deviations of the random parameters and the corresponding robust z-statistics, whereby no standard deviation is estimated for the parameter of the purchase price, which is assumed to be fixed. The third column comprises the mean WTP estimates in terms of the purchase price, measured in Euro. These estimates are calculated by the ratio between the negative values of the estimated means of the random parameters and the estimated fixed parameter of the purchase price, multiplied by 1,000 due to the purchase price scale (which is measured in 1,000 Euro) in the SML estimation of the mixed logit model. The only exception refers to the $CO_2$ emissions in use per 100 km. In line with, for example, Achtnicht (2012) and Hulshof and Mulder (2020), we adjust the common formula in terms of the estimated mean WTP for the $CO_2$ emissions in use over the life cycle, measured in tons.[8] This value can then directly be compared with the mean WTP estimate for the (life-cycle) $CO_2$ emissions in the production.

Methodologically, the second column of Table 5 shows that all estimated standard deviations of the parameters are significantly different from zero, which indicates strong unobserved heterogeneity in the estimated preferences and especially confirms the superiority of the application of mixed logit models compared to multinomial logit models that implicitly assume standard deviations of zero due to the underlying fixed parameters. According to the first column of the table, the purchase price has the expected significantly negative effect on the choice of a vehicle. The significance of this price effect allows us to consider the mean WTP estimates for the other attributes if the means of the corresponding parameters are significantly different from zero. In line with previous studies (e.g. Hackbarth and Madlener, 2013, 2016), the time to recharge the battery and fuel costs have a significantly negative effect and the driving range with a fully charged battery and/or a full tank has a significantly positive effect on the choice of a vehicle. In contrast, the time to refuel the tank has no significant effect, which is, however, not very surprising due to the very small attribute values between one minute and six minutes in the stated choice experiment. In particular, and in line with our expectations, however, both

[8] Specifically, the calculation of the estimated mean WTP for $CO_2$ emissions in use per 100 km is based on the average planned mileages of the respondents in the sample and the average age of vehicles in Germany, i.e. 14,583 km over about ten years which leads to an overall lifetime mileage of 145,830 km. The value of -158.53 Euro in Table 5 is based on the ratio between the two parameter estimates -0.019 and -0.084 (whereby not these rounded, but the original unrounded values are used), multiplied by 1,000 (due to scale of the purchase price, which is measured in 1,000 Euro), multiplied by 1,000 (since we consider the estimated mean WTP in tons instead of kg), divided by the lifetime mileage of 145,830 km, which is in turn divided by 100 km due to the scale of the $CO_2$ emissions in use.

$CO_2$ emissions in use and in the production have a significantly negative effect on the choice of a vehicle.

According to the mean WTP estimates in the third column of Table 5, citizens are on average willing to pay about 2,000 Euro for an increase of the driving range with a fully charged battery and/or a full tank by 100 km, more than 2,500 Euro for a decrease of the time to recharge the battery by one hour, and more than 1,500 Euro for a decrease of the fuel costs per 100 km by one Euro. With respect to our main research question, the estimated mean WTP imply that citizens are on average willing to pay more than 158 Euro for the reduction of $CO_2$ emissions in use per 100 km by one ton, which is in line with previous studies (e.g. Achtnicht, 2012, Alberini et al., 2018, Hulshof and Mulder, 2020). In contrast, our results imply that citizens are willing to pay more than 353 Euro for the reduction of $CO_2$ emissions in the production by one ton. Therefore, our estimation results suggest a strongly higher WTP estimate by a factor of more than two for the reduction of $CO_2$ emissions in the production compared to $CO_2$ emissions in use, which is surprising and in contrast to our expectations as discussed above.

While both WTP might be overestimated due to the hypothetical setting in stated choice experiments, it can commonly not be expected that differences in estimated WTP are affected in this respect. However, in our specific case, it can be argued that the hypothetical bias is stronger for $CO_2$ emissions in the production due to the lack of knowledge and higher uncertainty about these emissions. Furthermore, it is possible that the measurement unit (kg) for $CO_2$ emissions matters. The much higher values for $CO_2$ emissions in the production in the stated choice experiment compared to $CO_2$ emissions in use (measured per 100 km and not for the life cycle of a vehicle) could have led some respondents to pay somewhat more attention to $CO_2$ emissions in the production. On the other hand, however, the difference in the WTP estimates is based on an average age of ten years for vehicles in Germany. The consideration of the average lifetime of vehicles instead of the average age would lead to a higher overall lifetime mileage and thus to a lower estimated WTP for a reduction of $CO_2$ emissions in use. This approach would therefore even increase the difference in the WTP estimates with respect to life-cycle $CO_2$ emissions.

Finally, the estimation results for the alternative-specific constants reveal strong initial preference for conventional vehicles since the means of the parameters for all three electric vehicle types are strongly significantly negative. The estimated stated preference is especially low for extended-range and pure electric vehicles. The differences in the estimated preferences between the four vehicle types are not only statistically, but also economically significant. The third column reveals estimated mean WTP of about -9,300 Euro for plug-in hybrid electric vehicles, about -13,700 Euro for pure electric vehicles, and even about -15,200 Euro for extended-range electric vehicles compared to conventional vehicles. These results are in line with Hackbarth and Madlener (2013, 2016) for Germany, but in contrast to other countries like Italy and Slovenia (e.g. Rotaris et al., 2021). They imply, for example, that the purchase price for pure electric vehicles has to be almost 14,000 Euro lower than the purchase price for conventional vehicles to ensure that citizens are on average indifferent between two completely identical vehicles which only differ in these two propulsion technologies. On the basis of these estimation results, it is not very surprising that the sales figures for electric and especially pure electric vehicles are still rather low in Germany in spite of subsidies up to 9,000 Euro (at the time of the survey), which are obviously not high enough for a higher competitiveness of electric vehicles.

To examine the reliability of our estimation results, we have conducted a series of robustness checks. For example, we have considered different numbers of Halton draws in the SML estimation of the mixed logit models, included correlations in the random parameters, and conducted SML estimations in the WTP space. However, the main estimation results remain qualitatively very consistent.[9]

### *3.3. Estimation results for individual characteristics*

Table 6 reports the SML estimation results in a mixed logit model that not only includes alternative-specific constants and the vehicle attributes as explanatory variables, but additionally also individual characteristics. To analyze the effects of individual characteristics on the preferences for the four different vehicle types as well as on $CO_2$ emissions in use and in the production, we specifically include interaction terms between the individual characteristics and the three alternative-specific constants and the two attributes. Again, the estimated means and standard deviations of the parameters (in the latter case only for random parameters) as well as the corresponding robust z-statistics are reported in the first two columns. The third column again comprises the (additional) mean WTP estimates, whereby the values are only reported if the corresponding means of the parameters are significantly different from zero. However, it should be noted that the interpretation of the estimated mean WTP for the three alternative-specific constants and the two attributes without interaction with individual characteristics is

[9] The estimation results are not reported for brevity, but are available upon request. It should be noted that the SML estimation in the WTP space is more difficult in our mixed logit models since the simulated loglikelihood function often does not converge to a maximum (especially when individual characteristics are considered, see the next subsection).

not very useful since these values only refer to the hypothetical and artificial case that all individual characteristics are zero (which e.g. includes an age of zero years).

In contrast to the strong unobserved heterogeneity in the estimated preferences for the different vehicle attributes, Table 6 reveals surprisingly low observed heterogeneity, i.e. most means of the interaction parameters are not significantly different from zero. With respect to socio-economic and socio-demographic variables, the upper part of the table shows that females have a significantly lower preference for all three electric vehicle types, equivalized income has a significantly positive effect on the preference for extended-range and pure electric vehicles, and age has a significantly negative effect on the preference for extended-range electric vehicles.[10] Furthermore, trust has a significantly positive effect on the preference for plug-in hybrid electric vehicles,[11] whereas the other five economic preferences have no significant effects on the choice among the four vehicles. These results are rather surprising in light of the strong relevance of economic preferences for other individual behavior including environmental protection activities. According to the lower part of the table, socio-economic and socio-demographic variables as well as economic preferences also have no strong relevance for the preference to reduce $CO_2$ emissions in use and especially in the production. Only two means of interaction parameters are significantly different from zero, whereby the corresponding results for trust and positive reciprocity provide no clear picture since these two economic preferences only have a significant effect on $CO_2$ emissions in use.

The main results in Table 6 refer to environmental attitudes. Similar to, for example, Hackbarth and Madlener (2013) for Germany or Rotaris et al. (2021) for Italy and Slovenia, they have a significantly positive effect on the preference for all three types of electric vehicles. In line with our expectations and previous studies (e.g. Ziegler, 2020), this estimated effect is dominated by the identification with ecological policy.[12] This result suggests the strong relevance of the controversial political discussion about the transition to electromobility in Germany as discussed above. According to the third column in the upper part of Table 6, the estimated mean WTP for plug-in hybrid, extended-range, and pure electric vehicles (compared to conventional vehicles)

[10] In addition, high education has a weakly significantly positive effect on the preference for plug-in hybrid electric vehicles.

[11] With respect to the other two vehicle types, the effect is only slightly insignificant, which might be affected by lacking power due to the relatively small sample size.

[12] In fact, environmental awareness, measured with the NEP scale, also has a significantly positive effect on the preference for all three types of electric vehicles if ecological policy identification is not included. The corresponding estimation results are not reported for brevity, but are available upon request. These results are obviously distorted due to omitted variable bias since Table 6 shows that these effects of environmental awareness become less significant if both environmental attitudes variables are jointly included.

is more than 6,800 Euro, more than 11,300 Euro, and even more than 16,300 Euro higher for citizens with high ecological policy identification compared with citizens with medium or low ecological policy identification. These results suggest that environmental attitudes are particularly relevant for the preference for pure electric vehicles.[13] In this case, the difference in the mean WTP estimates is higher than the corresponding negative mean estimate for all citizens (see Table 5). This estimation result thus suggests that only for the subgroup of citizens with high environmental attitudes, pure electric vehicles (but not plug-in hybrid and extended-range electric vehicles) are generally competitive with conventional vehicles.

According to the lower part of Table 6, neither environmental awareness nor ecological policy identification has any significant effect on $CO_2$ emissions in use and in the production. These estimation results are surprising and in contrast to our expectations since environmental attitudes mostly have strong positive effects on pro-environmental behavior in previous studies. Interestingly, high ecological policy identification has a significantly positive effect on the reduction of $CO_2$ emissions in use when only the interaction terms between the individual characteristics and the two attributes are included, i.e. when the interaction terms between the individual characteristics and the three alternative-specific constants are excluded.[14] These results are obviously distorted due to omitted variable bias. In sum, these estimation results thus suggest that citizens with strong environmental identity do not consider reductions of $CO_2$ emissions in vehicle purchase decisions as an important direction for climate protection.[15]

## 4. Conclusions

Based on data from a stated choice experiment with more than 1,100 citizens in Germany, this paper empirically examines the individual preferences for a reduction of life-cycle $CO_2$ emissions in vehicle purchase decisions. The choice setting refers to decisions between three types of electric vehicles and a conventional vehicle that are characterized by several attributes like purchase price or fuel costs. Our econometric analysis with flexible mixed logit models reveals

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[13] This conclusion is strengthened by the additional (weakly) significantly positive effect of environmental awareness on the preference for pure electric vehicles besides the corresponding strongly significant effect of ecological policy identification.

[14] The corresponding estimation results are not reported for brevity, but are available upon request.

[15] It could be argued that the estimation results in Table 6 may also be biased since the underlying mixed logit model does not include the interaction terms between the individual characteristics and the other four attributes. In a further robustness check and in line with, for example, Galassi and Madlener (2017), we have also considered a mixed logit model including the interaction terms between the individual characteristics and all six attributes and the three alternative-specific constants. However, even in this extended model, which could be affected by multicollinearity problems, ecological policy identification has a robust significantly positive effect on the preference for all three types of electric vehicles (only the estimated WTP are slightly smaller). These estimation results (which are not reported for brevity, but are available upon request) thus support our main conclusion.

strong preferences for conventional vehicles compared to electric vehicles and especially compared to extended-range and pure electric vehicles. Specifically, the estimated mean WTP for conventional vehicles compared to pure electric vehicles, which are the main direction in the transition to electromobility, is almost 14,000 Euro. This estimation result is in line with the still very low shares of electric vehicles among all newly registered cars in Germany and imply that subsidies up to 9,000 Euro at the time of the survey and currently only up to 6,750 Euro are obviously not sufficient for a higher competitiveness of electric vehicles. Therefore, a strong or even the only focus on subsidies is possibly not a successful strategy for transport, environmental, and climate policy to strongly increase the demand for electric and especially pure electric vehicles. Instead, the reduction of well-known barriers like restricted charging availability or long charging times should rather be addressed. Furthermore, it might be necessary to phase-out conventional vehicles with internal combustion engines in the long run.

Our estimation results support the need for reduced charging times and longer driving ranges with a fully charged battery since the time to recharge the battery has a strongly significantly negative effect and the driving range with a fully charged battery and/or a full tank has a strongly significantly positive effect on the choice of a vehicle. With respect to our main research question, the econometric analysis shows a strong stated preference for the reduction of $CO_2$ emissions in both vehicle use and vehicle production, whereby the estimated WTP for $CO_2$ emission reductions is higher for vehicle production. This unexpected result is rather surprising since it might have been argued that the preferences for the reduction of $CO_2$ emissions in use are on average higher than in the production due to an overall lower public awareness and lower knowledge about $CO_2$ emissions caused in the production of the vehicle. These estimation results provide important practical policy implications. Since 2004, car sellers in Germany are obligated to disclose the $CO_2$ emissions in use for their vehicles offered. Furthermore, car sellers have to inform about the corresponding (highly criticized) $CO_2$ efficiency labels since 2011. However, our estimation results suggest that mandatory information about $CO_2$ emissions in vehicle production in addition to or instead of the current obligations to inform might have stronger effects on the demand for vehicles with less $CO_2$ emissions over the life cycle.

Our econometric analysis additionally reveals that most economic preferences have no significant effects on the choice among the different vehicles and on reductions in $CO_2$ emissions. Only trust has a significantly positive effect on the preference for plug-in hybrid electric vehicles. This estimation results suggests information campaigns, initiated by car sellers or policy, to increase the trustworthiness of electric vehicles, which are still considered by a large group of car buyers as a relatively new and unknown technology. In particular, environmental attitudes have a significantly positive effect on the stated preference for all three types of electric vehicles, whereby this estimated effect is dominated by ecological policy orientation instead of general environmental awareness according to the NEP, obviously due to the strong relevance of the controversial political discussion about the transition to electromobility in Germany. The relevance of environmental attitudes is particularly strong for the preference for pure electric vehicles, which are the main direction in the transition to electromobility, as aforementioned.

In contrast, environmental attitudes surprisingly have no significant effects on the reduction of $CO_2$ emissions in both vehicle use and vehicle production. These results suggest that citizens in Germany with strong environmental identity do not consider reductions of $CO_2$ emissions in vehicle purchase decisions as an important direction for climate protection. According to our estimation results, this group rather tends to purchase electric vehicles instead of conventional vehicles. Therefore, it seems that the demand for electric vehicles at least partly crowds out the demand for vehicles with lower $CO_2$ emissions. These implications conform with corresponding estimation results for electricity demand in Germany. Previous studies reveal strong positive effects of environmental attitudes and especially of ecological policy identification on the demand for green electricity contracts (e.g. Ziegler, 2020), whereas environmental attitudes have no significant effects on electricity consumption (e.g. Groh and Ziegler, 2022).

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## Tables

Table 1: Attributes and attribute levels across different vehicle types in the stated choice experiment

| Attributes | Attribute levels | Vehicle types |
|---|---|---|
| Purchase price | 70%, 80%, 90%, 100%, 110%, 120%, 130% of stated reference value (in Euro) | Conventional vehicle, plug-in hybrid electric vehicle, extended-range electric vehicle, pure electric vehicle |
| $CO_2$ emissions in use per 100 km | 60%, 80%, 100%, 120%, 140% of reference value according to stated vehicle class (in kg) | Conventional vehicle, plug-in hybrid electric vehicle, extended-range electric vehicle |
| | 0%, 30%, 60%, 80%, 100%, 120%, 140% of reference value according to stated vehicle class (in kg) | Pure electric vehicle |
| $CO_2$ emissions in production | 60%, 80%, 100%, 120%, 140% of reference value according to stated vehicle class (in kg) | Conventional vehicle, plug-in hybrid electric vehicle, extended-range electric vehicle, pure electric vehicle |
| Range with fully charged battery | -- | Conventional vehicle |
| | 50 km, 75 km, 100 km, 150 km, 200 km | Plug-in hybrid electric vehicle |
| | 100 km, 200 km, 250 km, 300 km, 400 km | Extended-range electric vehicle |
| | 150 km, 200 km, 300 km, 450 km, 600 km | Pure electric vehicle |
| Range with full tank | 450 km, 600 km, 750 km, 900 km, 1050 km | Conventional vehicle |
| | 300 km, 400 km, 500 km, 600 km, 700 km | Plug-in hybrid electric vehicle |
| | 50 km, 100 km, 150 km, 200 km, 250 km | Extended-range electric vehicle |
| | -- | Pure electric vehicle |
| Time to recharge battery | -- | Conventional vehicle |
| | 15 minutes, 30 minutes, 60 minutes, 120 minutes | Plug-in hybrid electric vehicle |
| | 30 minutes, 60 minutes, 120 minutes, 140 minutes | Extended-range electric vehicle |
| | 45 minutes, 90 minutes, 180 minutes, 360 minutes | Pure electric vehicle |
| Time to refuel tank | 3 minutes, 5 minutes, 6 minutes | Conventional vehicle |
| | 2 minutes, 3 minutes, 5 minutes | Plug-in hybrid electric vehicle |
| | 1 minute, 2 minutes, 3 minutes | Extended-range electric vehicle |
| | -- | Pure electric vehicle |
| Fuel costs per 100 km | 60%, 80%, 100%, 120%, 140% of reference value according to stated vehicle class (in Euro) | Conventional vehicle, plug-in hybrid electric vehicle, extended-range electric vehicle, pure electric vehicle |

Table 2: Exemplary choice set in the stated choice experiment

| Let us start with the first set of choices. Which of the following four cars would you most likely choose? | | | | |
|---|---|---|---|---|
| | Vehicle 1: Pure electric vehicle [Mouse click: Car powered exclusively by one or more electric motors] | Vehicle 2: Electric vehicle with range extender [Mouse click: Car powered by a combination of one or more electric motors plus a small gasoline or diesel engine for range extension] | Vehicle 3: Gasoline or diesel vehicle [Mouse click: Car powered exclusively by a gasoline or diesel engine] | Vehicle 4: Plug-in hybrid vehicle [Mouse click: Car powered by a combination of one or more small electric motors and a gasoline or diesel engine] |
| $CO_2$ emissions in use per 100 km | 10.1 kg | 11.2 kg | 22.9 kg | 21.2 kg |
| $CO_2$ emissions in production | 5,000 kg | 5,800 kg | 6,000 kg | 8,600 kg |
| Range with fully charged battery | 300 km | 400 km | - | 150 km |
| Range with full tank | - | 50 km | 900 km | 400 km |
| Time to recharge battery | 180 minutes | 60 minutes | - | 120 minutes |
| Time to refuel tank | - | 2 minutes | 3 minutes | 5 minutes |
| Fuel costs per 100 km | 3.50 Euro | 7.20 Euro | 5.50 Euro | 7.50 Euro |
| Purchase price | 8,400 Euro | 15,600 Euro | 14,400 Euro | 12,000 Euro |
| My choice | □ | □ | □ | □ |
| | | | | |
| Would you rather not choose any of the cars shown above and prefer another car instead?<br>□ Yes<br>□ No | | | | |

Table 3: Frequencies for the stated choice of vehicle types, 1,128 respondents, six choice sets, 6768 observations (choices)

| Conventional vehicle | Plug-in hybrid electric vehicle | Extended-range electric vehicle | Pure electric vehicle |
|---|---|---|---|
| 2,875 (42.48%) | 1,631 (24.10%) | 823 (12.16%) | 1,439 (21.26%) |

Table 4: Descriptive statistics of individual characteristics, 1,128 respondents

| Variables | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| NEP scale | 24.567 | 3.95 | 9 | 30 |
| Ecological policy identification | 0.379 | 0.49 | 0 | 1 |
| Social policy identification | 0.605 | 0.49 | 0 | 1 |
| Liberal policy identification | 0.302 | 0.46 | 0 | 1 |
| Conservative policy identification | 0.245 | 0.43 | 0 | 1 |
| Patience | 0.537 | 0.499 | 0 | 1 |
| Risk-taking preference | 0.258 | 0.438 | 0 | 1 |
| Altruism | 0.642 | 0.480 | 0 | 1 |
| Trust | 8.268 | 2.315 | 3 | 15 |
| Positive reciprocity | 12.508 | 1.782 | 3 | 15 |
| Negative reciprocity | 7.565 | 2.793 | 3 | 15 |
| Equivalized income | 1,816.15 | 1,215.21 | 75.76 | 15,000 |
| High education | 0.254 | 0.44 | 0 | 1 |
| Female | 0.493 | 0.50 | 0 | 1 |
| Age | 49.396 | 16.29 | 18 | 88 |
| Eastern Germany | 0.235 | 0.42 | 0 | 1 |

Table 5: SML estimation results in a mixed logit model for the choice among four vehicle types, explanatory variables: alternative-specific constants (base category: conventional vehicle), vehicle attributes, 1,128 respondents, six choice sets, 6,768 observations (choices), 1,000 Halton draws

| Explanatory variables | Estimates (robust z-statistics) | | Mean WTP estimates in Euro (based on purchase price) |
|---|---|---|---|
| | Mean of the parameter | Standard deviation of the parameter | |
| Purchase price (in 1000 Euro) | -0.084***<br>(-9.77) | -- | -- |
| Plug-in hybrid electric vehicle | -0.782***<br>(-7.91) | 1.821***<br>(18.35) | -9,321.65 |
| Extended-range electric vehicle | -1.276***<br>(-9.37) | 1.141***<br>(10.73) | -15,201.19 |
| Pure electric vehicle | -1.152***<br>(-6.56) | 0.756***<br>(3.52) | -13,729.12 |
| $CO_2$ emissions in use per 100 km (in kg) | -0.019***<br>(-4.02) | 0.082***<br>(9.49) | -158.53 |
| $CO_2$ emissions in production (in tons) | -0.030***<br>(-3.09) | 0.079***<br>(3.89) | -353.15 |
| Range with fully charged battery / full tank (in 100 km) | 0.171***<br>(12.14) | 0.212***<br>(10.66) | 2,036.62 |
| Time to recharge battery (in hours) | -0.217***<br>(-6.45) | 0.382***<br>(8.00) | -2,586.92 |
| Time to refuel tank (in minutes) | -0.029<br>(-1.40) | 0.413***<br>(14.04) | -- |
| Fuel costs per 100 km (in Euro) | -0.131***<br>(-11.19) | 0.244***<br>(14.05) | -1,556.84 |

Note: * (**, ***) means that the appropriate estimated parameter is different from zero at the 10% (5%, 1%) significance level, respectively.

Table 6: SML estimation results in a mixed logit model for the choice among four vehicle types, explanatory variables: alternative-specific constants (base category: conventional vehicle), vehicle attributes, individual characteristics, 1,128 respondents, six choice sets, 6,768 observations (choices), 1,000 Halton draws

| Explanatory variables | Estimates (robust z-statistics) | | Mean WTP estimates in Euro (based on purchase price) |
|---|---|---|---|
| | Mean of the parameter | Standard deviation of the parameter | |
| Purchase price (in 1000 Euro) | -0.084*** (-9.67) | -- | -- |
| Plug-in hybrid electric vehicle | -4.282*** (-4.57) | 1.696*** (17.73) | -51,190.14 |
| x NEP scale | 0.036 (1.36) | -- | -- |
| x ecological policy identification | 0.574*** (2.85) | -- | 6,855.93 |
| x social policy identification | 0.207 (1.04) | -- | -- |
| x liberal policy identification | 0.088 (0.44) | -- | -- |
| x conservative policy identification | -0.020 (-0.09) | -- | -- |
| x patience | 0.146 (0.79) | -- | -- |
| x risk-taking preferences | 0.254 (1.20) | -- | -- |
| x altruism | 0.017 (0.08) | -- | -- |
| x trust | 0.126*** (3.03) | -- | 1,504.76 |
| x positive reciprocity | 0.010 (0.29) | -- | -- |
| x negative reciprocity | 0.080 (1.43) | -- | -- |
| x equivalized income | 0.033 (0.39) | -- | -- |
| x high education | 0.322* (1.65) | -- | 3,844.03 |
| x age | 0.002 (0.32) | -- | -- |
| x female | -0.433** (-2.34) | -- | -5,170.93 |
| x Eastern Germany | -0.193 (-0.75) | -- | -- |
| Extended-range electric vehicle | -2.768** (-2.47) | 1.098*** (10.88) | -33,084.84 |
| x NEP scale | 0.042 (1.35) | -- | -- |
| x ecological policy identification | 0.950*** (3.89) | -- | 11,356.30 |
| x social policy identification | 0.175 (0.75) | -- | -- |
| x liberal policy identification | -0.037 (-0.15) | -- | -- |
| x conservative policy identification | -0.021 (-0.08) | -- | -- |
| x patience | 0.277 (1.27) | -- | -- |
| x risk-taking preferences | 0.080 (0.33) | -- | -- |
| x altruism | 0.056 (0.24) | -- | -- |
| x trust | 0.086 (1.61) | -- | -- |
| x positive reciprocity | 0.011 (0.27) | -- | -- |
| x negative reciprocity | 0.027 (0.41) | -- | -- |
| x equivalized income | -0.176* (-1.96) | -- | -2,106.85 |
| x high education | 0.259 (1.11) | -- | -- |
| x age | -0.018** (-2.52) | -- | -211.53 |
| x female | -0.454** (-2.05) | -- | -5,427.46 |
| x Eastern Germany | -0.123 (-0.39) | -- | -- |
| Pure electric vehicle | -3.472** (-2.47) | -0.914*** (-4.61) | -41,509.60 |
| x NEP scale | 0.068* (1.77) | -- | 809.26 |
| x ecological policy identification | 1.368*** (4.64) | -- | 16,349.20 |
| x social policy identification | -0.126 (-0.45) | -- | -- |
| x liberal policy identification | 0.019 (0.07) | -- | -- |
| x conservative policy identification | -0.052 (-0.17) | -- | -- |
| x patience | 0.336 (1.27) | -- | -- |
| x risk-taking preferences | 0.240 (0.83) | -- | -- |
| x altruism | 0.269 (0.94) | -- | -- |
| x trust | 0.103 (1.54) | -- | -- |
| x positive reciprocity | -0.006 (-0.11) | -- | -- |
| x negative reciprocity | -0.000 (-0.00) | -- | -- |
| x equivalized income | -0.217** (-2.00) | -- | -2,595.65 |
| x high education | 0.473 (1.62) | -- | -- |
| x age | -0.009 (-1.04) | -- | -- |
| x female | -0.654** (-2.40) | -- | -7,819.95 |
| x Eastern Germany | -0.395 (-1.00) | -- | -- |

*Table 6 (continued)*

| | | | |
|---|---|---|---|
| $CO_2$ emissions in use per 100 km (in kg) | 0.030 (0.56) | 0.079*** (10.02) | 243.86 |
| x NEP scale | -0.001 (-0.64) | -- | -- |
| x ecological policy identification | -0.016 (-1.29) | -- | -- |
| x social policy identification | -0.006 (-0.53) | -- | -- |
| x liberal policy identification | -0.005 (-0.45) | -- | -- |
| x conservative policy identification | -0.017 (-1.44) | -- | -- |
| x patience | -0.013 (-1.32) | -- | -- |
| x risk-taking preferences | 0.011 (0.97) | -- | -- |
| x altruism | 0.016 (1.46) | -- | -- |
| x trust | -0.005** (-2.24) | -- | -42.61 |
| x positive reciprocity | 0.005** (2.50) | -- | 40.16 |
| x negative reciprocity | -0.002 (-0.85) | -- | -- |
| x equivalized income | -0.002 (-0.59) | -- | -- |
| x high education | -0.007 (-0.67) | -- | -- |
| x age | 0.000 (1.33) | -- | -- |
| x female | 0.011 (1.04) | -- | -- |
| x Eastern Germany | -0.012 (-0.74) | -- | -- |
| $CO_2$ emissions in production (in tons) | 0.033 (0.32) | 0.082*** (3.73) | 399.54 |
| x NEP scale | -0.000 (-0.01) | -- | -- |
| x ecological policy identification | 0.000 (0.00) | -- | -- |
| x social policy identification | -0.023 (-1.09) | -- | -- |
| x liberal policy identification | 0.002 (0.10) | -- | -- |
| x conservative policy identification | 0.005 (0.21) | -- | -- |
| x patience | -0.010 (-0.49) | -- | -- |
| x risk-taking preferences | -0.017 (-0.78) | -- | -- |
| x altruism | 0.015 (0.67) | -- | -- |
| x trust | 0.001 (0.17) | -- | -- |
| x positive reciprocity | 0.001 (0.39) | -- | -- |
| x negative reciprocity | -0.007 (-1.27) | -- | -- |
| x equivalized income | 0.009 (1.26) | -- | -- |
| x high education | 0.028 (1.28) | -- | -- |
| x age | -0.000 (-0.27) | -- | -- |
| x female | 0.010 (0.49) | -- | -- |
| x Eastern Germany | 0.006 (0.20) | -- | -- |
| Range with fully charged battery / full tank (in100 km) | 0.168*** (11.78) | 0.220*** (11.15) | 2.012,67 |
| Time to recharge battery (in hours) | -0.213*** (-6.60) | 0.384*** (8.62) | -2,550.02 |
| Time to refuel tank (in minutes) | -0.028 (-1.36) | 0.341*** (10.68) | -- |
| Fuel costs per 100 km (in Euro) | -0.134*** (-11.47) | 0.236*** (13.90) | -1,600.82 |

Note: * (**, ***) means that the appropriate estimated parameter is different from zero at the 10% (5%, 1%) significance level, respectively

# Figures

Figure 1: Original screenshot of an exemplary choice set in the stated choice experiment