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Willingness-to-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany

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Abstract

In the light of European energy efficiency and clean air legislations, as well as an ambitious electric mobility goal of the German government, we examine consumer preferences for alternative fuel vehicles (AFVs), based on a Germany-wide discrete choice experiment among 711 potential car buyers. We estimate consumers' willingness-to-pay (WTP) and contingent variation (CV) for improvements in vehicle purchase price, fuel cost, driving range, refueling infrastructure, CO_2 emissions and governmental monetary and non-monetary incentives, hereby accounting for diminishing marginal returns for some of the attributes and taking taste differences in the population into account by applying a latent class model with 6 distinct consumer segments. Our results indicate that almost 36% of the consumers are open-minded towards at least one AFV option, with 15% being AFV-affine insomuch that they show a high probability of choosing AFVs despite their current shortcomings. Our results suggest that German car buyers' WTP for improvements of the various vehicle attributes varies considerably across consumer segments and that the vehicle features have to meet some minimum requirements so that AFVs are shortlisted. Furthermore, the CV values show that decision-makers in the administration and industry should focus on the most promising consumer group of 'AFV aficionados' and their needs, that some vehicle attribute improvements could increase AFV demand rather cost-effectively, and that consumers would accept surcharges for some vehicle attributes at a level, which could enable their economic provision and operation (e.g. fast-charging infrastructure), while others might need governmental subsidies to substitute the insufficient consumer WTP (e.g. battery capacity).

Keywords: Discrete choice, Stated preferences, Latent class model, Alternative fuel vehicles, Germany, Electric mobility, Willingness-to-pay, Contingent variation

JEL Classification: C25, D12, M38, Q58, R48

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1 Introduction

In the past decades, the transportation sector came increasingly to the fore of policy-makers and energy efficiency and greenhouse gas mitigation legislation in the US, the EU, and other countries.[1] This can be explained by its strong dependence on fossil fuels used in internal combustion engines. Therefore, it contributes not only significantly to climate change and local air pollution but also plays an important role in energy security considerations. From the start, especially road transport has been in the focus of regulatory activities, as it almost exclusively relies on carbon-based fuels, and thus is very vulnerable to fluctuations in crude oil prices and shocks in oil supply, as revealed in the 1970s and early 1980s during the two oil crises. The resulting strong increases in the gasoline price in turn led to significant new developments in vehicle technologies and improvements in fuel efficiency. Over the following decades, the continuous tightening of fuel efficiency standards was additionally driven by environmental considerations and the resulting introduction of clean-air legislation. The oil price rally at the end of the last decade led to a reinforced attempt of policy-makers to tackle the oil dependency of road transport and to bring alternative fuel vehicles (AFVs)[2] into the market. For instance, the European Union has defined legally binding CO_2 emission abatement targets for newly registered vehicles, i.e. the fleet average emission limit was set to 130 grams of CO_2 per kilometer to be achieved by 2015 and 95 g CO_2/km by 2021, respectively. Additionally, to incentivize the production of low-emission cars, vehicle manufacturers are granted so-called super-credits, which allow that cars with CO_2 emissions below 50 g CO_2/km are multiply counted (e.g. 2.5 times in 2014), and thus will facilitate the attainment of the vehicle fleets' average emission targets (EC, 2014). Furthermore, the German government stipulated the very ambitious aim of 1 million registered BEVs by the year 2020 (Federal Government, 2009). This goal was to be accompanied by all kinds of governmental monetary and non-monetary purchase incentives, such as a motor vehicle tax

[1] A comprehensive overview on the evolution of worldwide fuel economy and GHG emissions regulations over the years is given in, e.g. An et al. (2004), Onoda (2008), Atabani et al. (2011), or Kodjak et al. (2012).

[2] AFVs encompass vehicles that do not run on conventional fuels (gasoline and diesel), or are propelled electrically at least to some extent, e.g. biofuel vehicles (BVs), natural gas (liquefied petroleum gas, LPG, or compressed natural gas, CNG) vehicles (NGVs), hydrogen (fuel cell electric) vehicles (FCEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fully battery electric vehicles (BEVs).

exemption, and the funding of fuel cell and battery technology research programs. As a first result, a growing BEV model line-up, progress in battery technology, and a steadily densified refueling station network can be recorded.

However, despite these efforts on the part of vehicle manufacturers and policy-makers, the reluctance of car buyers towards all kinds of AFVs, especially BEVs, stays very high, so that consumer demand has to increase drastically in the upcoming years to reach the diffusion targets and to meet the requirements of the European clean-air legislation. For instance, today, only a small fraction of the postulated electric mobility goal is accomplished – e.g. at the end of 2013 only about 12,000 BEVs were registered in Germany, mainly by commercial users (KBA, 2014) – and also other AFVs exhibit a poor market penetration. Hence, detailed information on the main reasons for such an absence of a widespread adoption of AFVs, especially by buyers of privately used personal cars, and the possibilities to circumvent them, is needed even more urgently. Presumable taste differences of a heterogeneous population of private car buyers concerning the importance of specific vehicle attributes (e.g. purchase price, driving range, CO_2 emissions), the thresholds they have to meet, and their different impacts on the potential demand of AFVs are of special interest. Knowledge about such taste differences could be particularly instructive for the German legislature and decision-makers in the automotive industry to accelerate the adoption of AFVs in the future by specifically customizing their products or incentive schemes subject to the differences in preferences between these consumer segments.

The aim of this paper is to determine the amount that different groups of vehicle buyers are willing to pay for improving important vehicle characteristics, e.g. a range extension or fast-charging infrastructure for BEVs, and how and why the willingness-to-pay (WTP) differs between the groups. Further, the compensating variation (CV) is calculated for several scenarios to additionally comprehend the heterogeneity of car buyers' preferences and monetary valuation of vehicle attribute improvements, by explicitly taking the diverse choice probabilities of the various vehicle alternatives into account. The results are then compared to current market prices for a provision of such attribute improvements (e.g. market prices for every kWh of additional battery capacity), to calculate the potential need for governmental action and to direct the (financial) forces into the right channels in an economically efficient way. Furthermore, the monetary and non-monetary incentives already granted today or planned by the German government are evaluated regarding their effectiveness to accelerate vehicle adoption. Finally, the characteristics of the potential car buyers that are open for all kinds of AFVs or such governmental incentives are analyzed.

Our empirical analysis is based on a nation-wide web-based stated preferences discrete choice experiment (DCE), carried out in Germany among 711 potential car buyers in July and August of 2011 for a broad range of hypothetical alternatively and fossil-fueled vehicles. To take the preference heterogeneity in the population into account, we apply a latent class model (LCM), which allows for taste differences between consumer segments. LCMs are advantageous compared to standard multinomial logit models (MNL) for several reasons. For one thing, they are able to partly overcome the restrictive independence of irrelevant alternatives (IIA) assumption, and correlations of repeated choices of a single respondent can be handled. Furthermore, recent studies (e.g., Greene and Hensher, 2003; Lee et al., 2003; Hynes and Hanley, 2005; Shen, 2009; Hess et al., 2011; Sagebiel, 2011; Keane and Wasi, 2013) have concluded that LCMs also seem to be advantageous over mixed logit models, as they (1) do not need assumptions about the distributions of the parameters and are thus less prone to specification errors, (2) have a less complex estimation procedure (they have a closed form solution and thus do not require time-intensive simulations), while at the same time performing at least as well as mixed logit models, (3) reveal the size of the different consumer segments in the population, which could guide decisions about the optimal allocation of resources, e.g. for marketing purposes, and (4) seem to produce WTP values with smaller variation, which is important for more accurate policy recommendations.

Our study is more detailed than previous ones focusing on preferences for AFVs in Germany, at least in four respects: Firstly, we use an LCM to evaluate German car buyers' vehicle choices, which allows for a segmentation of the population into distinct consumer groups depending on the manifestation of their preferences, a specification of the size of these consumer segments, and their detailed description by socio-demographic characteristics and attitudes. Secondly, we exhaustively analyze the WTP for the main vehicle attributes, especially recharging time, vehicle range and governmental incentives. Thirdly, we calculate CV values for a number of vehicle-specific attribute improvement scenarios, which are more informative for decision-makers than unspecific WTP values alone. Finally, as suggested by several authors (e.g. Ewing and Sarigöllü, 1998, 2000; Hidrue et al., 2011; Dimitropoulos et al., 2013; Daziano, 2013), we consider the effect of decreasing marginal utilities in our model, which is a more realistic representation of human behavior, and among others assess this non-linear functional form of the WTP for recharging time and CO_2 emissions.[3]

The remainder of this paper is organized as follows: In section 2, we give an overview of the DCE literature regarding the demand for AFVs with a focus on studies considering the German situation or applying an LCM. Section 3 describes the survey generation and the data gathered. In section 4, the methodological approach is introduced. Empirical results are reported in Section 5 and discussed in Section 6. Section 7 concludes.

2 Literature Review

Our research builds on a comprehensive body of stated preferences DCE literature on the demand for AFVs, which was mainly conducted in the US and Canada (e.g. Bunch et al., 1993; Brownstone and Train, 1999; Ewing and Sarigöllü, 1998, 2000; Potoglou and Kanaroglou, 2007; Hidrue et al., 2011), Asia (e.g. Kuwano et al., 2005; Ahn et al., 2008; Dagsvik and Liu, 2009; Qian and Soopramanien, 2011; Shin et al., 2012; Ito et al., 2013), Australia (e.g. Hensher and Greene, 2006, Beck et al., 2011), and Europe (e.g., Dagsvik et al., 2002; Batley et al., 2004; Caulfield et al., 2010; Mabit and Fosgerau, 2011; Lebeau et al., 2012), to name but a few. The studies by Achtnicht (2012), Achtnicht et al. (2012), Ziegler (2012), and Daziano and Achtnicht (2013), which all make use of the same data, as well as the works of Eggers and Eggers (2011) and Hackbarth and Madlener (2013) are, to the best of our knowledge, the only ones focusing on Germany.

Achtnicht (2012) applied a mixed (random parameters) logit model to analyze the importance of CO_2 emissions in vehicle choice decisions and the differences in the WTP for an emission mitigation between groups of potential car buyers (distinguishable by gender, age, and education). Their results indicate, that German car buyers are willing to pay up to about €130 for an emission mitigation of 1 g CO_2/km, and that the importance of a vehicle's pollution varies heavily in the population. Achtnicht et al. (2012) use an MNL and lay their focus on the influence of fuel availability and the impact of socio-demographic characteristics (e.g. age and environmental awareness) on vehicle choice. Their results suggest that the density of the fuel station network positively influences the demand for the AFVs considered,

[3] Achtnicht et al. (2012) regarded a quadratic representation for fuel station density, while Eggers and Eggers (2011) accounted for non-linearity in purchase price and driving range.

and that, other things being equal, German car buyers prefer conventional fuels over alternative ones. Daziano and Achtnicht (2013) examine the impact of an enhancement of the electric recharging and hydrogen refueling infrastructure on the market shares of all kinds of AFVs in general, and BEVs and FCEVs in particular, and make use of a flexible multinomial probit model. They find that a scaling-up of the corresponding fuel availability to 100% would more than triple the market shares of BEVs and FCEVs. Ziegler (2012), also applying multinomial probit models with flexible substitution patterns, investigates the influence of individual characteristics on vehicle choice and shows that some socio-demographic variables (e.g. age, gender, and environmental awareness) increase the choice probability of otherwise disfavored AFVs, such as NGVs, BVs, FCEVs, and BEVs. Based on individual-level preferences estimated by use of hierarchical Bayes procedures, Eggers and Eggers (2011) predict the adoption and diffusion process of AFVs over time under various future scenarios. Their results suggest that PHEVs and BEVs are much less likely to be purchased than HEVs, which are expected to dominate the vehicle market at the end of the forecasting horizon, and that BEVs have to satisfy a minimum driving range and recharging infrastructure, as well as a maximum purchase price surcharge requirement to be adopted. Hackbarth and Madlener (2013) analyze the impact of several vehicle characteristics and socio-demographic variables on the potential demand for AFVs and calculate the WTP for the improvement of these vehicle attributes, by adopting a mixed (error components) logit modeling approach. In a subsequent scenario analysis the impact of monetary and non-monetary attribute improvement measures on vehicle choice probabilities is simulated. The results show that younger, well-educated, and environmentally aware car buyers having a high share of city trips and appreciating a small car are more likely to adopt AFVs, and that households' WTP for improved car features is substantial. The scenario results further suggest that the conventional fuel (gasoline, diesel) vehicles (CFVs) will keep their dominant market position and that FCEVs and BEVs will remain unpopular, unless massive and multiple policy interventions are implemented, or the driving range of BEVs is extended largely.

The works of Abdoolakhan (2010), Hidrue et al. (2011), and Beck et al. (2013) are, to the best of our knowledge, the only ones applying an LCM approach. Abdoolakhan (2010) make use of a nested logit model and a 2-class LCM, in which the population of car buyers is segmented according to their valuation of fuel efficiency, to examine and forecast changes in vehicle choice of Australians in times of rising gasoline prices and their effect on the composition of the national vehicle fleet. The results suggest that a major demand shift will occur, away from conventionally fueled vehicles to NGVs and BVs, although the dominance of CFVs will at least prevail for the coming 20 years. In an LCM with two distinct classes, Hidrue et al. (2011) examine the determinants of choosing a BEV rather than a conventional one, and calculate the WTP for five BEV attributes, i.e. driving range, charging time, fuel cost savings, pollution reduction and vehicle performance. They are able to characterize a BEV-oriented group of US car buyers. These are willing to pay substantial amounts of money for BEVs with the most desirable vehicle attributes, are younger, well-educated, more environmentally aware, prefer small cars, like new products, occasionally drive longer distances, have a parking-lot equipped with an electric outlet, plan to buy an HEV on their next purchase, and expect rising gasoline prices in the next years. They further find that despite such an open-minded consumer group, battery costs have to drop drastically before BEVs are able to conquer the mass market. Finally, Beck et al. (2013) assess the impact of an emissions charge (consisting of a fixed and a variable component) on vehicle choice of recent car buyers in Sydney, Australia, taking individuals' environmental attitudes and socio-demographics, such as age and the number of children, into account in a 3-class and 4-class LCM, respectively. Their results indicate that it is especially the variation in this 'greenness' across consumer groups that causes the variation in preferences, and that the inclusion of attitudinal information allows for a deeper understanding of the population of car buyers (one additional consumer group in the model). They conclude that such attitudinal variables should be included in vehicle choice modeling, and that individuals indeed react very differently to an emission charge, which should be taken into account by policy-makers.

As mentioned above, several studies have indicated that the linear representation of vehicle features in the utility functions should be scrutinized already in the modeling phase, since the influence of some vehicle attributes might be described more accurately and more appropriately with a non-linear specification, i.e. by the utilization of part-worths (effects-coded or dummy-coded variables) or logarithmic, quadratic, or square root transformations.[4]

[4] Dimitropoulos et al. (2013), for example, investigated consumers' WTP for changes in the driving range of AFVs (especially BEVs) by performing a meta-analysis of the stated preferences literature. They found that the marginal WTP for driving range non-constantly decreases with increasing driving range, and thus concluded that driving range should be considered in a non-linear way in the utility functions.

For instance, non-linear specifications have been employed for driving range (Bunch et al., 1993; Ewing and Sarigöllü, 1998, 2000; Kavalec, 1999; Brownstone et al., 2000; Eggers and Eggers, 2011; Hidrue et al., 2011; Mabit and Fosgerau, 2011; Hess et al., 2012; Link et al., 2012; Axsen et al., 2013; Daziano, 2013), fuel availability (Bunch et al., 1993; Potoglou and Kanaroglou, 2007; Achtnicht et al., 2012), refueling or recharging time (Ewing and Sarigöllü, 1998, 2000; Hidrue et al., 2011; Link et al., 2012; Axsen et al., 2013), pollution (Bunch et al., 1993; Ewing and Sarigöllü, 1998, 2000; Potoglou and Kanaroglou, 2007; Hidrue et al., 2011), purchase price (Eggers and Eggers, 2011; Link et al. 2012), fuel cost (Link et al., 2012), and vehicle performance (Ewing and Sarigöllü, 1998, 2000; Kavalec, 1999; Mabit and Fosgerau, 2011; Hidrue et al., 2011; Link et al., 2012; Jensen et al., 2013). Furthermore, the results concerning a positive influence of governmental incentives on vehicle choice are split in the literature, and thus should be investigated in detail also for the case of Germany. Non-economic governmental incentives, such as free parking or access to express or bus lanes, have a negligible influence on the demand for AFVs, as several studies revealed (exceptions are the studies of Adler et al., 2003; Horne et al., 2005; Daziano and Bolduc, 2013; Hackbarth and Madlener, 2013), whereas sales or vehicle tax reductions and governmental purchase subsidies were found to always do (e.g. Adler et al., 2003; Horne et al., 2005; Potoglou and Kanaroglou, 2007; Mau et al., 2008; Axsen et al., 2009; Qian and Soopramanien, 2011; Hess et al., 2012; Hoen and Koetse, 2012; Daziano and Bolduc, 2013; Hackbarth and Madlener, 2013; Glerum et al., 2013). In our research, all these findings from previous related studies were taken into consideration or tested.

In the following, the survey and discrete choice experimental design on which the econometric analysis is grounded, is presented in more detail.

3 Survey Design and Data

The examination of new car buyers' potential demand for AFVs is based on data collected in a Germany-wide survey that was conducted in July and August 2011 (see also Hackbarth and Madlener, 2013). Participants were recruited from a commercial online panel, provided their intention to purchase a new car within the next year or an actual purchase in the last 12 months. A comparison of our sample (711 respondents completed the web-based survey) with the German population statistics depicted in Table 1 shows many similarities, but also some minor differences.

Table 1: Household and vehicle characteristics of the sample vs. the German population

Variable	Value	Sample (%)	Population (%)
Household characteristics			
Gender	Female	50.4	50.9
	Male	49.6	49.1
Age	18 to 24	8.4	9.8
	25 to 44	49.4	31.3
	45 to 64	38.0	34.3
	65 or above	4.2	24.6
Education	No form of school leaving qualification	0.1	7.7
	Secondary general school leaving qualification	6.6	37.3
	Intermediate school leaving qualification	29.8	29.0
	Higher education entrance qualification or university (of applied sciences) degree	63.5	26.0
Household income per month	Less than €2,000	17.9	49.5
	€2,000 to €5,999	60.4	40.3
	€6,000 or more	2.7	2.7
	Not stated and others	19.0	7.5
Number of persons in household	1	15.3	40.2
	2	39.8	34.2
	3	23.5	12.6
	4	15.6	9.5
	5 or more	5.8	3.4
Type of residence	Owner	47.7	45.7
	Tenant	52.3	54.3
Type of location	Urban	38.3	28.9
	Suburban	53.7	56.5
	Rural	8.0	14.6
Number of household vehicles	0	5.2	17.7
	1	52.5	53.0
	2	35.6	24.2
	3	5.6	4.0
	4 or more	1.1	1.0
Vehicle characteristics			
Vehicle purchase	Vehicle purchase in past 12 months	47.3	-
	Vehicle purchase planned within 12 months	52.7	-
Reason for vehicle purchase	Replacement for old vehicle	82.7	81.0
	Additional vehicle	12.1	11.0
	Initial vehicle purchase	5.2	8.0
Purchase price	Less than €20,000	55.3	34.0
	€20,000 to €40,000	35.7	51.0
	€40,000 or more	9.0	15.0
Vehicle segment	Mini / small cars	23.3	26.5
	Medium cars	27.6	27.2
	Large cars	21.0	18.3
	Executive cars	6.5	5.4
	Luxury cars	1.5	0.6
	Multi-purpose cars	11.0	8.8
	SUVs	4.4	4.8
	Sport coupés and others	4.7	8.4
Annual mileage	Less than 10,000 km	30.8	36.7
	10,000 km to 20,000 km	41.9	41.4
	20,000 km or more	27.3	21.9

Source: Own calculations; German population shares computed on the basis of Infas/DLR (2010), BBSR (2012), DAT (2012), KBA (2012), Destatis (2012a, 2012b)

For instance, our sample over-represents younger and higher educated individuals with high income, which live in multi-person households, own a car, live in urban areas, have an above-average annual mileage, and a below-average willingness to spend money for their next vehicle, which needs to be taken into account when interpreting the results.

Our survey was constructed in order to gather information on respondents': (1) existing and planned car ownership, such as vehicle fuel type and vehicle segment; (2) driving habits, such as daily and annual mileage; (3) familiarity with AFVs; (4) environmental concern, degree of environmental behavior and technophilia; (5) socio-economic characteristics, such as age, income, or educational level; and (6) hypothetical choices in the DCE as core of the survey, following a detailed explanation of the alternative propulsion technologies considered in the experiment.

The stated preferences DCE included seven different vehicle types, six AFVs (NGVs, HEVs, PHEVs, BEVs, BVs, and FCEVs) and CFVs, to cover all currently or anytime soon commercially available propulsion technologies. They were described by up to eight attributes, which were found to be the most important vehicle features affecting the car purchasing process in Germany (Dena, 2010): (1) purchase price; (2) fuel cost; (3) CO_2 emissions; (4) driving range; (5) fuel availability; (6) refueling time; (7) battery recharging time; and (8) policy incentives. Table 2 shows the attributes used and their levels by fuel type.

Table 2: Vehicle attributes and levels used in the DCE

Variable	Vehicle types (Fuel types)	No. of levels	Levels
Purchase price	All	3	75%, 100%, 125% of stated reference value (in €)
Fuel cost per 100 km	All	3	€5, €15, €25
CO_2 emissions	CFV, NGV, HEV	3	50%, 75%, 100% of average vehicle
	PHEV, BEV, BV, FCEV	3	0%, 50%, 100% of average vehicle
Driving range	CFV, NGV, HEV, PHEV, BV, FCEV	3	400 km, 700 km, 1,000 km
	BEV	3	100 km, 400 km, 700 km
Fuel availability	CFV, HEV	2	60%, 100% of all stations
	NGV, PHEV, BEV, BV, FCEV	3	20%, 60%, 100% of all stations
Refueling time	CFV, NGV, HEV, PHEV, BV, FCEV	2	5 min, 10 min
Battery recharging time	PHEV, BEV	3	10 min, 1 h, 6 h
Policy incentives	PHEV, BEV, BV, FCEV	3	None, No vehicle tax, Free parking and bus lane access

In order to increase significance of the hypothetical vehicle choices and to reduce task complexity, several actions have been taken in the course of designing the final experiment: (1) the purchase price variable was adjusted to respondents' stated price range of their latest or next vehicle purchase, respectively, and varied around this value by ±25%; (2) a single fuel cost unit (€/100 km) was used for the different vehicle alternatives to increase their commensurability; (3) a fixed, unrealistic car class-invariant (e.g. gram of CO_2 per kilometer) and alternative-unspecific (e.g. zero emissions for CFVs) measure for CO_2 emissions was avoided; (4) the driving range variable accounted for current limitations in battery technology and was restricted for BEVs compared to all other vehicles; (5) an alternative-specific fuel availability variable was considered to allow for lower densities of the service station network for some AFVs; (6) refueling and recharging time were displayed as separate attributes to meet the requirements of the different propulsion technologies, especially PHEVs; (7) the current situation in Germany regarding governmental incentives was reflected, since a motor vehicle tax exemption for BEVs already came into force (BMF, 2012) and non-monetary incentives (permission for bus lane usage, special parking areas) for some AFVs are being considered (Federal Government, 2011); and (8) respondents had to choose from only four out of the seven different vehicle alternatives in every choice tasks.

In the final, completely randomized fractional factorial design, which was generated using the *Sawtooth* software, each respondent had to complete 15 separate choice tasks, thus resulting in 10,665 observations. A pretest, which was conducted in May 2011 with 128 participants, showed that the cognitive burden of the experiment was well manageable.

4 Methodological Approach and Model Specification

Our empirical analysis of the stated preference DCE data follows the random utility modeling framework, in which the utilities decision-makers obtain from the alternatives available for choice are treated as random variables, since they are unknown to the researcher (McFadden, 1974). Our evaluation is further based on two different model specifications: A standard MNL and an LCM. While, due to its simplicity, the MNL is very appealing and the most widely applied model, and thus also used in this study for the purpose of comparison, it suffers from three major drawbacks. First, it is unable to account for preference heterogeneity in the population. Second, the restrictive IIA property is used. Third, multiple consecutive choices of a single respondent are not taken into consideration. The LCM specification remedies these shortcomings, since it is able to account for taste heterogeneity of decision-makers by assuming that the population is composed of a finite but unknown number of different segments or classes. Moreover, the LCM partly relaxes the restrictive IIA assumption (although it still holds within classes), and takes the panel nature of DCEs into account (Swait, 2007). Hence, the general methodological approach of the LCM is described briefly in the following, drawing directly from Swait (1994, 2007), Boxall and Adamowicz (2002), Greene and Hensher (2003), Bujosa et al. (2010), and Hess et al. (2011).

As already mentioned, the main assumption in the LCM framework is the existence of *S* unknown segments in the population, where the individuals within each and every group are characterized by unique and homogeneous utility functions or tastes, while the preferences and hence the welfare measures (e.g. WTP and CV) can differ between classes. Unfortunately, class membership is latent, i.e. not observable by the analyst, so that the assignment of individuals to their specific and true segments has to be made probabilistically, for instance based on their socio-demographic or psychometric (e.g. environmental awareness and technophilia) characteristics. Furthermore, and as also already mentioned, the utility functions of the respondents are only partially known to the researcher as well, so that again solely probabilistic statements can be made about the influence alternatives' attributes wield on respondents' choice decisions. Hence, an LCM consists of two separate probabilistic models, which are estimated simultaneously: (1) a choice model, which explains individuals' choice among the alternatives available in the different choice occasions, conditional on their membership to a specific segment; and (2) a class membership model, which allocates the decision-makers to the *S* segments.

Beginning with the choice model, and assuming utility-maximizing behavior, individual *n* selects alternative *j* from a finite set of *J* alternatives (e.g. passenger cars, as in our case) that yields the highest level of utility in choice situation *t*. The utility function U_{njt} is then assumed to be given by

$$U_{njt} = V_{njt} + \varepsilon_{njt}, \tag{1}$$

where $V_{njt} = \beta_s' X_{njt}$ is the observable, deterministic part of utility – described by X_{njt}, a vector of the vehicle alternatives' attributes (e.g. purchase price, driving range etc.), and β_s', a class-specific vector of parameters – and ε_{njt} is the unobserved, random portion of utility. Assuming firstly that the error terms are independent and identically distributed (iid) according to the type I extreme value or Gumbel distribution, which leads to the standard MNL, and secondly, that the class membership of each decision-maker is given, we can express the probability of alternative j being chosen by decision-maker n in choice occasion t as

$$P_{njt|s} = \frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})}. \tag{2}$$

If decision-makers are repeatedly observed in choice situations, such as in our survey in 15 consecutive choice tasks, this panel effect should be taken into account. When independence of the t sequential choice situations is assumed, the joint probability of the observed sequence of choices of decision-maker n belonging to class s is given by

$$P_{nj|s} = \prod_{t=1}^{T} P_{njt|s}. \tag{3}$$

Turning to the class membership model, and assuming iid type I extreme value error terms in the membership likelihood function as well, the probability that decision-maker n belongs to class s is

$$H_{ns} = \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)}, \tag{4}$$

with observable socio-demographic or attitudinal characteristics of the decision-maker Z_n, and the class-specific parameter vector θ_s'. To attain model identification, one of the s parameter vectors has to be normalized to zero.

The unconditional probability or likelihood that a randomly chosen decision-maker n selects a sequence of alternatives $j = (j_1, ..., j_T)$ is then obtained by multiplying eqs. (3) and (4), which yields

$$P_{nj} = \sum_{s=1}^{S} H_{ns} P_{nj|s} = \sum_{s=1}^{S} \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)} \prod_{t=1}^{T} \left[\frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})} \right]. \tag{5}$$

Accordingly, the log likelihood for the sample is given by

$$\ln L = \sum_{n=1}^{N} \ln P_{nj} = \sum_{n=1}^{N} \ln \left[\sum_{s=1}^{S} H_{ns} \left(\prod_{t=1}^{T} P_{njt|s} \right) \right]. \tag{6}$$

One last issue that arises in the specification of an LCM is the choice of the number of classes, since the correct or true number of classes is again unknown to the analyst, and neither estimable nor testable and, consequently, has to be specified by the analyst *a priori*, based on his/her judgment and experience. However, in doing so, several decision criteria have been recommended to guide the selection of *S*, such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC).

The common procedure in the class selection process is that the final model specification is estimated with varying numbers of classes. The solution, which minimizes the different selection criteria, is the one that should be preferred. However, as indicated above, the final model and the final number of segments should not only be chosen based on statistical reasons, but also in such a way that it meets certain requirements concerning the interpretability and usefulness of the estimated parameters, i.e. by enhancing the understanding of the underlying behavioral process. That way, results leading to very small classes or many groups with mainly insignificant coefficients can be discarded.

5 Empirical Results

5.1 Variables and class selection criteria

The variables that were included in the deterministic part of the utility and the class assignment functions of our final models are given in Table 3. CO_2 emissions, driving range, fuel availability, and recharging time were logarithmically transformed to account for their non-linear impact on utility.[5] Vehicle segments were primarily ordered by purchase price and only secondarily by size, leading to the following ascending order: Mini / small cars, medium cars, large cars, multi-purpose cars and SUVs, executive cars, luxury cars, and sports cars. Technophilia was measured with the level of agreement, which had to be indicated on a 5-level Likert scale, to the following question: ‘I like to engage myself with the way new technologies function’. Environmental awareness was determined with a scale developed by

[5] Wald tests of non-linear restrictions were performed for all attributes with more than two levels, but were found to be significant only for CO_2 emissions, driving range, fuel availability and recharging time. Besides the ultimately selected logarithmic transformation, also other functional forms were tested, e.g. quadratic, square root, and inverse. However, compared to the logarithmic transformation they not only performed poorer statistically regarding log likelihood but also visually in reproducing the distribution of the part-worths.

Preisendörfer (1999), which is also used by the German Federal Ministry for the Environment and the Federal Environment Agency to biannually quantify the 'greenness' of the German population (see e.g. UBA, 2010). The scale assesses environmental consciousness by adding up the degree of agreement to 9 questions on a 5-level Likert scale.

Table 3: Variables used in the model

Variables	Definition
NGV	1 if fuel type is natural gas, 0 otherwise
HEV	1 if fuel type is hybrid electric, 0 otherwise
PHEV	1 if fuel type is plug-in hybrid electric, 0 otherwise
BEV	1 if fuel type is battery electric, 0 otherwise
BV	1 if fuel type is biofuel, 0 otherwise
FCEV	1 if fuel type is hydrogen (fuel cell), 0 otherwise
Purchase price	Purchase price in thousands of €
Fuel cost	Fuel cost in € per 100 km
CO_2 emissions	Natural logarithm of the fraction of CO_2 emissions of a comparable average current vehicle of the respondents' favorite car segment in percent
Driving range	Natural logarithm of driving range on a full tank/battery in km
Fuel availability	Natural logarithm of the percentage of filling/recharging stations with proper fuel
Refueling time	Refueling time in minutes
Battery recharging time	Natural logarithm of battery recharging time in minutes
Incentive 1	1 if incentive (no vehicle tax) is granted, 0 otherwise
Incentive 2	1 if incentive (free parking, bus lane usage) is granted, 0 otherwise
Vehicle segment	Respondents' favorite vehicle segment ordered by purchase price
Technophilia	Respondents' score on a 5-level Likert scale capturing enthusiasm for new technologies
Environmental awareness	Respondents' score on the environmental consciousness scale by Preisendörfer (1999)
Age	Age of the respondent in years
Daily mileage	Daily mileage of respondents in 5 categories
Educational level	Educational level of respondent in 6 categories
Additional vehicle	1 if vehicle is an additional one, 0 otherwise

The average daily distance respondents drive their vehicles was quantified with a scale composed of 5 distinct categories, which ranged from 'up to 50 km' to 'more than 200 km'. The educational level was measured with a 6-level scale, stretching from 'no form of school leaving qualification' to 'university (of applied sciences) degree'. Finally, a dummy variable entered the model that indicates if the new vehicle was/will be an additional one or a replacement, thus increasing the household's vehicle fleet or not.

The LCM was estimated over two to seven classes. Several different statistical class selection criteria were calculated that show mixed results. As can be seen in Table 4, the model with 6 latent classes is best regarding BIC, while all other selection criteria are indicative of the presence of at least 7 distinct classes in the population. We nevertheless decided for the LCM with 6 classes as best model to portray heterogeneity in the population due to two reasons. First, the BIC is slightly preferred over other selection criteria, as it strives for parametrically parsimonious models by penalizing larger numbers of parameters, in contrast to, e.g. the log-likelihood (LL) function or the AIC. Second, the LCM with seven classes led to a very small segment with a selection probability of below 1%, while leaving all other classes almost unchanged, and thus did not add to the explanatory power of the model.

Table 4: Class selection criteria

Classes	**1 (MNL)**	**2**	**3**	**4**	**5**	**6**	**7**
LL	-12874.32	-12,322.87	-11,879.30	-11,579.14	-11344.08	-11,190.55	-11,121.43
BIC	25,887.8	24,998.2	24,324.4	23,937.4	23,680.6	23,586.8	23,661.9
AIC	25,778.6	24,721.7	23,880.6	23,326.3	22,902.2	22,641.1	22,548.9
$\rho^2(0)$	0.380	0.406	0.428	0.442	0.453	0.461	0.464
$\rho^2(c)$	0.091	0.130	0.162	0.183	0.199	0.210	0.215
Parameters	15	38	61	84	107	130	153

McFadden's ρ^2 and the LL values in Table 4 further indicate that the final 6-segment LCM greatly and statistically significantly outperforms the MNL specification. Thus, for the following in-depth analysis of the estimation results and the subsequent welfare analysis the LCM with 6 distinct classes is used and compared to the standard MNL results.

5.2 Discrete choice model

The final estimation results of the standard MNL and the LCM with 6 distinct classes are shown in Table 5. Looking at the results for the MNL first, it can be seen that all parameters (except the alternative-specific constant (ASC) of PHEVs and refueling time) are highly significant and impact vehicle choice in the expected direction, i.e. the choice probability is negatively influenced by purchase price, fuel cost, CO_2 emissions, refueling time and recharging time, and positively affected by driving range, fuel availability, and governmental incentives. Furthermore, it can be seen that all ASCs are negative, i.e. CFVs are highly preferred to all AFVs, except PHEVs, who have an insignificant ASC parameter.

Turning to the LCM, the picture is slightly more ambiguous, suggesting that considerable taste heterogeneity exists in the population, which was overlooked by the MNL specification. As can be seen in Table 5, some of the coefficients vary considerably between the six different groups. Furthermore, the number and structure of attributes that significantly influence vehicle choice differ across the classes. The only exceptions are purchase price, fuel cost, and driving range, which are the attributes that enter the car buyers' utility functions statistically significantly in all segments. More specifically, in class 1, for instance, respondents have a stronger preference than car buyers in any other class for a long driving range, large fuel availability, and a short recharging time. In contrast, purchase price, fuel cost and the two governmental incentives only have an intermediate influence on vehicle choice, compared to other classes, while refueling time and most ASCs (except NGV, BV) are even insignificant. Consumers in class 2, on the other hand, appraise fuel costs as more important than members of any other group. But also purchase price and CO_2 emissions, driving range, and the non-monetary governmental incentive exert a great influence on vehicle choice. In contrast, refueling and charging time, as well as all ASCs, do not seem to have much impact on the decision process. In segment 3, decisions are mainly based on the availability of both governmental incentives and on the large and negatively signed ASCs (except for BEVs, for which the coefficient estimates are insignificant), indicating a pronounced reluctance towards the adoption of AFVs. Purchase price, fuel cost, and driving range also influence vehicle choice, but the coefficients are comparably small. Interestingly, consumers in segment 3 are the only ones who consider refueling time in their vehicle choice decisions. Car buyers in segment 4 show the largest or second-largest negative parameter values for almost all ASCs, except for HEVs and PHEVs. The latter even have a positive parameter and thus are even more preferred than CFVs by individuals in this segment. Vehicle emissions and fuel availability are also rather important, compared to other consumer groups, while driving range, purchase price and fuel costs are relatively unimportant, although they exert a significant influence on vehicle choice. Both governmental incentives, as well as the recharging and refueling time, do not enter the utility function significantly. In class 5, purchase decisions are mainly influenced by the price of the vehicle, its fuel costs and recharging time, and the ASC of BEVs. Driving range, fuel availability, CO_2 emissions and the monetary governmental incentive, as well as the ASCs of BVs and FCEVs, on the other hand, only have an average influence on vehicle choice. Refueling time, the non-monetary governmental incentive, and the remaining ASCs do not impact the vehicle choice process significantly.

Table 5: Estimation results

	MNL	LCM					
		Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Class-specific parameters							
NGV	-0.2648***	-0.3914**	0.0371	-0.6511***	-1.7498***	-0.0508	0.1276
HEV	-0.2949***	-0.0742	0.0199	-1.3858***	0.0782	-0.2390	0.1252
PHEV	-0.0910	0.2003	0.0423	-2.5097***	1.0260***	0.2947	0.5931***
BEV	-0.2155**	0.1535	-0.4887	-2.4808***	-1.2298***	-0.0637	1.0618***
BV	-0.4069***	-0.2273*	-0.0413	-1.7913***	-0.8525***	-0.2626*	0.4066***
FCEV	-0.4227***	-0.1260	-0.2533	-1.5091***	-1.1995***	-0.5335***	0.3467**
Purchase price	-0.0519***	-0.0399***	-0.0786***	-0.0282***	-0.0192**	-0.2665***	-0.0165***
Fuel costs	-0.0480***	-0.0446***	-0.1988***	-0.0224***	-0.0291***	-0.0681***	-0.0142***
CO_2 emissions (logarithmic)	-0.0489***	-0.0608***	-0.0640***	0.0186	-0.0625**	-0.0444**	-0.0855***
Driving range (logarithmic)	0.4939***	1.3803***	0.7395***	0.4240***	0.1871	0.4845***	0.1458**
Fuel availability (logarithmic)	0.2203***	0.7661***	0.1352**	0.0428	0.2485***	0.1872***	0.0820**
Refueling time	-0.0043	-0.0016	-0.0213	-0.0241*	-0.0008	0.0091	-0.0018
Recharging time (logarithmic)	-0.0651***	-0.1493***	-0.0519	-0.0847	-0.0246	-0.1221***	-0.0546**
Incentive 1	0.2104***	0.2692***	0.2494*	0.4884***	0.0020	0.2788***	0.2914***
Incentive 2	0.1458***	0.1768*	0.2214*	0.3992***	0.1360	0.0755	0.2207***
Class assignment parameters							
Constant		-1.6810	-4.5600**	-2.0268	-8.3148***	-3.1742*	0
Vehicle segment		0.6100***	0.3800**	0.6202***	0.5161**	0.4004**	0
Technophilia		-0.5853**	0.6170**	-0.1224	0.6255*	-0.2102	0
Environmental awareness		-0.1334***	-0.0703*	-0.1177***	-0.0061	-0.0783*	0
Age		0.0696***	0.0659***	0.0800***	0.0897***	0.1028***	0
Daily mileage		-0.3003	-0.4943*	-0.7443**	-0.6615	-0.7515**	0
Educational level		0.4987**	0.2257	0.1883	0.2599	0.3479*	0
Additional vehicle		0.3531	0.3411	0.6457	0.3430	1.3071*	0
Class probabilities		0.174	0.196	0.084	0.206	0.190	0.150

Notes: ***, **, * indicate significance at the 1%, 5%, 10% level; Incentive 1 = No vehicle tax; Incentive 2 = Free parking and bus lane access

Finally, segment 6 consists of car buyers, who have a strong preference for vehicles with low CO_2 emissions and especially for non-fossil-fueled AFVs, as indicated by the positive and significant ASCs for PHEVs, BEVs, BVs, FCEVs. In contrast, charging time and both governmental incentives only show a relatively moderate impact, compared to other groups, while purchase price, fuel cost, driving range and service station density even seem to be quite unimportant factors in the decision process of this consumer group, although they enter the utility function significantly.

Hence, our findings so far can be summarized as follows: (1) only one of the six distinct consumer groups favors all kinds of AFVs, and at the same time considers CO_2 emissions important (class 6); (2) two of the groups consist of individuals for whom monetary attributes (purchase price and fuel cost) are the most decisive factors in vehicle choice (classes 2 and 5); (3) car buyers in segment 1 are very concerned with the vehicles' mobility and thus lay the highest weight of all segments on driving range, recharging time, and fuel availability; (4) some consumers base their vehicle choice mainly on ASCs (fuel types) and governmental incentives, leaving all other attributes aside (class 3); and (5) consumers in segment 4 have a strong preference for PHEVs, which is in contrast to car buyers in segment 3, while also disliking all other AFVs and mainly basing their decision on ASCs.

The socio-demographic and attitudinal variables that describe the class membership are crucial for a better understanding of the behavioral differences found between classes. Therefore, we now look at the class assignment parameters in more detail. To ensure model identification, the coefficients of one segment have to be normalized to zero – in our case class 6 – and the parameters of all other segments have to be interpreted in relation to that base group. The first salient feature is that individuals in classes 1-5 are not only older and planning to buy a larger (more expensive) vehicle but also less environmentally aware (except for consumers in segment 4) than car buyers in the base group (class 6). Furthermore, individuals in classes 2, 3, and 5 have a lower daily mileage than car buyers in the base group, who drive as much as members of classes 1 and 4. Consumers in segments 1 and 5 have a higher educational level than respondents in the base group, while car buyers in segments 2 and 4 are more, and those in segment 1 are less interested in new technologies than individuals in segment 6. Additionally, respondents in class 5 can be further characterized as being looking for an additional car. Thus, we can conclude that the base group (class 6) is composed of younger, more environmentally aware, slightly less educated buyers of smaller/cheaper cars, who have a high daily mileage and a moderate technical interest.

By pointing out the most noticeable preferences of every segment, and combining them with their socio-economic and attitudinal characterizations, we can further explain the observed choice behavior, and assess its reasonability:

(1) Car buyers in class 1 value the three mobility attributes driving range, fuel availability, and recharging time, highest, which can be explained by their high annual mileage, a feature that is comparable to the base group.

(2) Individuals in segment 2 are strongly influenced by monetary attributes, especially fuel costs, and by vehicles' driving range. Since they drive less than the base group, this finding seems to be unusual and can only partially be explained by the fact that individuals in this group are planning to buy a larger car.

(3) AFVs are highly rejected by members of class 3; the latter are highly influenced in their preferences by governmental incentives. The strong reluctance towards all kinds of AFVs can be explained by the fact that individuals in this group are ecologically unaware buyers of larger cars.

(4) Members of segment 4 highly reject all AFVs except PHEVs, and are thus the only ones (besides car buyers of the base group) who at least rate one AFV positively, although individuals in this group are older and planning to buy a larger and more expensive car than the base group, and are thus comparable to members of the remaining segments. However, they are equally environmentally aware and, maybe even more important, more technophile than the reference group.

(5) For individuals in class 5, planning to buy an additional car for their household (and a more expensive one than that purchased by the base group), purchase price is the most important vehicle attribute.

(6) The base group (class 6) shows sympathy for non-fossil-fueled AFVs and a high importance of vehicle emissions; this seems reasonable, as this group contains younger and environmentally aware buyers of small cars.

Hence, overall we find that individuals, who on the first glance share many socio-demographic characteristics, do behave quite differently. In a nutshell, the results can be further summarized as follows: (1) purchase price and fuel cost are relatively unimportant for those individuals who prefer AFVs; (2) vehicle attributes are evaluated very differently in the different groups, i.e. attributes that are important in one class are irrelevant in another class; (3) incentives have a large impact on vehicle choice; (4) on average, AFVs are disliked in the population (as can be seen by the negative ASCs in the MNL), but two segments exist who favor at least some AFVs (viz. PHEVs, BEVs, BVs, and FCEVs in class 6 and PHEVs in class 4).

Note that in order to put these findings on a common basis, i.e. making the parameter values comparable, we need a different measure, such as marginal effects, elasticities, or criteria derived from welfare analysis. Thus, in the following, we will monetize car buyers' appreciation by calculating the marginal WTP and subsequently the CV for improvements in the different vehicle attributes. This enables us to make profound policy recommendations, and to get a grasp on the leeway for additional taxation, or need for monetary incentives, respectively, to accelerate the adoption of AFVs.

5.3 Willingness-to-pay

Following Louviere et al. (2000) and Daziano (2013) directly, the WTP is a measure to derive the monetary amount that an individual is willing to disburse to acquire benefits or prevent costs from specific (policy) actions, such as the marginal improvement of a vehicle attribute, leaving the level of utility unchanged. It is hence able to display car buyers' appreciation for specific vehicle features. In our linear model specification, the WTP is derived from the ratio of two utility parameters, i.e. the (class-specific) coefficient of a specific vehicle attribute β_X and the (class-specific) coefficient of an attribute measured in monetary units β_C, such as purchase price or fuel cost, holding everything else constant:

$$WTP = -\frac{\beta_X}{\beta_C}. \tag{7}$$

Further, the WTP of the logarithmically transformed attributes has to consider their non-linear influence on utility, and thus has to take the base level *x* of the attribute, from which the improvement starts out, into account, so that the WTP is a function of the attribute level, i.e.

$$WTP = -\frac{\beta_{\ln(X)}}{\beta_C}\frac{1}{x}. \tag{8}$$

Based on the estimation results depicted in Table 4, consumers' marginal WTP for improvements of the most important vehicle characteristics is calculated using eqs. (7) and (8), and shown in Tables 6 and 7. In Table 6, the WTP is expressed as additional purchase price, and in Table 7 as additional fuel cost per 100 km that individuals are willing to spend for marginal changes in different attributes' levels. As can easily be seen, the WTP values differ significantly across the consumer segments.

Table 6: Marginal WTP for changes in vehicle attributes (in € of purchase price surcharge)

	MNL	LCM					
		Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Fuel cost reduction of €1/100 km	926.64	1117.30	2528.52	793.97	1516.70	255.71	864.79
Incentive 1 (No vehicle tax)	4058.70	6749.78	3171.83	17,309.00	105.63†	1046.17	17,712.21
Incentive 2 (Free parking and bus lane access)	2811.24	4432.38	2815.96	14,147.83	7074.97†	283.44†	13,410.50
CO_2 emissions abatement by 1%							
at 100%	9.43	15.24	8.14	-6.61†	32.51	1.67	51.98
at 50%	18.86	30.49	16.28	-13.22†	65.02	3.33	103.96
at 1%	942.95	1524.39	814.06	-660.93†	3250.84	166.53	5197.90
Driving range increase by1 km							
at 100 km	95.25	346.13	94.04	150.28	97.39†	18.18	88.59
at 500 km	19.05	69.23	18.81	30.06	19.48†	3.64	17.72
at 1000 km	9.53	34.61	9.40	15.03	9.74*	1.82	8.86
Fuel availability increase by 1%							
at 20%	212.48	960.60	85.97	75.79†	646.60	35.12	249.26
at 60%	70.83	320.20	28.66	25.26†	215.53	11.71	83.09
at 99%	42.93	194.06	17.37	15.31†	130.63	7.09	50.36
Battery recharging time reduction by 1 min							
at 6 h	3.49	10.40	1.83†	8.34†	3.55†	1.27	9.21
at 1 h	20.93	62.40	11.01†	50.05†	21.30†	7.64	55.26
at 10 min	125.60	374.39	66.06†	300.29†	127.80†	45.81	331.54

Notes: † indicates WTP values based on insignificant attribute coefficients

Starting with the WTP expressed in terms of purchase price surcharge car buyers would accept to pay extra for the improvement of vehicle features, the WTP for a fuel cost reduction of €1 per 100 km ranges from €255 in class 5 to €2528 in class 2, while the WTP value calculated with the MNL coefficients is somewhere in between (€926).

The WTP for monetary and non-monetary governmental incentives has a large bandwidth. For instance, the WTP for a vehicle tax exemption varies by a factor of 16 and is lowest in segment 5 (€1046) and highest in segment 6 (€17,712). Likewise, the WTP for the allowance to use bus lanes and free parking spaces is five times larger in class 3 (€14,147) than in class 2 (€2815). The WTP of the MNL is €4058 and €2811 for the monetary and the non-monetary incentive, respectively, and on average much lower than the WTP of the LCM. The WTP for the non-monetary incentive calculated from the MNL parameters is even lower than the WTP of the group willing to pay least in the LCM (class 2).

The WTP for improvements of CO_2 emissions, driving range, service station density, and battery recharging time not only differs between segments but, due to its logarithmic shape, also depending on the value set as a base for the improvement. For instance, the WTP for a one percent reduction of vehicles' CO_2 emissions ranges from less than €2 (class 5) to €52 (class 6) for the first percent, and between €167 to €5200 for the last percent (resulting in a zero emission vehicle), reflecting a much higher valuation of large CO_2 mitigations and the relatively low impact on utility of only small emission reduction measures in the *status quo*. However, the WTP values have to be treated with caution for at least two reasons. First, emission mitigation is a socially desirable action, so that it is probable that respondents tend to overstate their appreciation and WTP for such an attribute. Second, due to the logarithmic transformation of the attribute, which necessitates that the starting point of the emission reduction (the location on the emission curve) is taken into account in the calculation of the WTP (*1/x* in eq. (8)), small attribute levels automatically lead to very high WTP values, which actually approach infinity when moving the attribute levels infinitesimally close towards zero.

The marginal WTP for an increase in driving range of 1 km stretches from €18 (class 5) to €346 (class 1) for a small cruising radius of 100 km, and from below €2 to €35 for a driving range of 1000 km. This reflects a higher disutility of small cruising ranges and certain requirements regarding the vehicles' range on a full tank or battery that have to be met. Further, individuals in segment 1 are willing to pay more for the further improvement of vehicles' long driving ranges than car buyers in segment 5 are for extensions of very short ranges.

The WTP for the improvement of the fuel availability by one additional percentage point amounts to between €7 (class 5) and €194 (class 1) to reach a fuel station network with full density (100% fuel availability), or between €35 (class 5) and €960 (class 1) to increase the amount of fuel stations serving the proper fuel from 20% to 21%. Again, one group exists (class 1), which is willing to spend a larger extra amount for the last percent of fuel availability than respondents in two other segments (classes 2 and 5) for the first percent. In this case, the WTP is even more than twice (class 5) and more than five times (class 2) as high, respectively.

The WTP for a decrease in recharging time by 1 minute ranges from slightly more than €1 (class 5) to €10 (class 1) when the duration of the recharging process lasts 6 hours, and from €46 (class 5) to €374 (class 1) when it only takes 10 minutes. Again, this reflects a higher disutility of time-consuming battery recharging activities and certain requirements regarding the speed of the recharging process that have to be met, for being valued or appreciated by consumers.

Expressing the WTP as the amount car that buyers are willing to spend extra for fuel per 100 km, it can be seen in Table 7 that the WTP for a decrease in the purchase price by €1 ranges from €0.40 in segment 2 to €3.90 in segment 5, while the value from the MNL lies in between these values, albeit closer to the lower bound (€1.10). Governmental incentives again cover a wide WTP span, ranging from €1.25 in class 2 to €20.50 in class 6 for vehicle tax exemptions, and €1.10 (class 2) to €17.80 (class 3) for non-monetary governmental benefits. The WTP calculated from the MNL coefficients are €4.40 and €3.00 for the monetary and the non-monetary incentive, respectively, and are thus on average much lower than in the LCM.

Again, the WTP for improvements of CO_2 emissions, driving range, service station density, and battery recharging time not only differs between classes, but, due to its logarithmic shape, also with regard to the base of the improvement. For instance, the WTP for a one percent reduction of vehicles' CO_2 emissions ranges from less than 1 €-cent (segments 2 and 5) to 6 €-cents (segment 6) for the first percent, and between €0.30 to €6 for the last percent (leading to an emission-free vehicle), reflecting the much higher valuation of large CO_2 reduction measures and the relatively low appreciation of only small emission reduction measures related to current vehicles. However, as before and for the same reasons, these WTP values have to be treated with caution.

Table 7: Marginal WTP for changes in vehicle attributes (in €/100 km of fuel cost increase)

	MNL	**LCM**					
		Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Purchase price reduction of €1000	1.079	0.895	0.395	1.259	0.659	3.911	1.156
Incentive 1 (No vehicle tax)	4.380	6.041	1.254	21.800	0.070†	4.091	20.481
Incentive 2 (Free parking and bus lane access)	3.034	3.967	1.114	17.819	4.665†	1.108†	15.507
CO_2 emissions abatement by 1%							
at 100%	0.010	0.014	0.003	-0.008†	0.021	0.007	0.060
at 50%	0.020	0.027	0.006	-0.017†	0.043	0.013	0.120
at 1%	1.018	1.364	0.322	-0.832†	2.143	0.651	6.011
Driving range increase by 1 km							
at 100 km	0.103	0.310	0.037	0.189	0.064†	0.071	0.102
at 500 km	0.021	0.062	0.007	0.038	0.013†	0.014	0.020
at 1000 km	0.010	0.031	0.004	0.019	0.006†	0.007	0.010
Fuel availability increase by 1%							
at 20%	0.229	0.860	0.034	0.095†	0.426	0.137	0.288
at 60%	0.076	0.287	0.011	0.032†	0.142	0.046	0.096
at 99%	0.046	0.174	0.007	0.019†	0.086	0.028	0.058
Battery recharging time reduction by 1 min							
at 6 h	0.004	0.009	0.001†	0.011†	0.002†	0.005	0.011
at 1 h	0.023	0.056	0.004†	0.063†	0.014†	0.030	0.064
at 10 min	0.136	0.335	0.026†	0.378†	0.084†	0.179	0.383

Notes: † indicates WTP values based on insignificant attribute coefficients

The marginal WTP for an increase in driving range of 1 km reaches from 4 €-cents (class 2) to 30 €-cents (class 1) for a small cruising radius of 100 km, and from below 1 €-cent (classes 2 and 5) to 3 €-cents (class 1) for a long driving range of 1000 km. This again reflects the higher disutility of short cruising ranges and is a hint for certain requirements regarding vehicles' range on a full tank or battery that at least have to be met.

The WTP for the improvement of the density of the fuel station network by one additional percentage point amounts to between less than 1 €-cent (class 2) and 17 €-cents (class 1) to reach a fuel availability of 100%; it spans between 3 €-cents (class 2) and slightly less than €1 (class 1) for increasing the amount of fuel stations serving the proper fuel by 1% to 21%. Again, one group of vehicle adopters exists (segment 1), which is willing to spend a much greater amount for the last percent of fuel station network extension than respondents in two other groups (segments 2 and 5) for the first percent. Interestingly, when WTP is expressed in terms of fuel cost, the result is even more pronounced than when expressing WTP in terms of purchase price. As an illustration, respondents in segment 1 are willing to pay more than six times and even more than 28 times as much as individuals in segments 5 and 2, respectively.

The WTP for a decrease in battery recharging time lies between below 1 €-cent (class 5) or around 1 €-cent (classes 1 and 6) when the recharging process takes six hours, and ranges from 20 €-cents (class 5) to 40 €-cents (class 6) when it takes 10 minutes. Again, this reflects a higher reluctance towards time-consuming battery recharging activities and a certain minimum requirement regarding the duration of the recharging process, which has to be met in order to be appreciated by car buyers.

Summarizing the results, we find that German car buyers are willing to pay significant amounts for the improvement of vehicle attributes, and that the distinct consumer groups attach different importance to these vehicle features, so that not every attribute improvement might be valued with its actual cost in every consumer group. However, although the WTP values measure the economic welfare and reveal the accepted maximum additional cost for technical progress, they also suffer from a drawback. WTP values do not account for the choice probabilities of the different vehicle alternatives before and after the improvement, i.e. it is assumed that certainty exists about which particular vehicle option is chosen, which usually is not the case in DCEs, or that every vehicle alternative undergoes the exactly same attribute improvement, which is very unrealistic in the case of highly heterogeneous vehicle alternatives. Thus, only when the specific choices of every individual are definitely known, eqs. (7) and (8) meaningfully assess the WTP for quality changes of attributes (Louviere et al., 2000; Train, 2003). Therefore, more revealing, more realistic, and more important for policy-makers and car manufacturers is an economic welfare measure which accounts for this uncertainty and the potentially highly dissimilar selection probabilities of the different vehicle options, e.g. by portraying the current market situation and the implications of specific policy action, as well as the fact that a change in an alternative's attribute does not only have an influence on its own utility level but also on the probability of all other alternatives for being selected.

5.4 Compensating variation

Drawing directly from Small and Rosen (1981), Louviere et al. (2000), Train (2003), Lancsar and Savage (2004), and de Jong et al. (2007), the compensating variation (CV), also known as expected change in consumer surplus, is a monetary measure to determine the economic welfare impact of a specific policy. The CV thus indicates the change in income or a comparable monetary measure, such as in our case purchase price or fuel costs, needed to compensate changes in utility after the change in a vehicle attribute's level occurred, leaving individuals equally well off in the initial situation as under the new conditions. Therefore, for an improvement of vehicle attributes the CV is the monetary amount car buyers are willing to forfeit to retain the improvement. In a logit model (both MNL and LCM) with a linear-in-utility monetary attribute, i.e. a constant utility parameter regarding income (or investment and operating cost, as in our model specification), the CV for a representative individual *n* is calculated as a comparison of the (class-specific) indirect utility functions before (V_{nj}^0) and after (V_{nj}^1) the attribute change, scaled by the (class-specific) marginal utility of money, which is given by the negative of the inverse of one of the coefficients expressed in monetary units in the utility functions (β_C):

$$CV = -\frac{1}{\beta_C}\left[\ln\left(\sum_{j=1}^{J} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{J} e^{V_{nj}^0}\right)\right], \tag{9}$$

with *j* indicating the number of choice alternatives.

The CV is computed based on the estimation results of the MNL and LCM (Table 4) and on a particular choice scenario, which represents the *status quo* of the German market conditions, so that this measure is expressly useful for policy-makers and car manufacturers who want to compare costs and benefits of specific vehicle attribute improvements, and thus the assessment of their reasonableness from an economic viewpoint.

In the following scenarios, representative individuals (of each segment) are assumed to choose between seven differently fueled vehicle alternatives, which in the underlying base scenario are described by the attribute levels depicted in Table 8. The base scenario describes the current to near-term German vehicle market by defining average cars for every fuel type, based on market data and recent research (for further details on the database see Hackbarth and Madlener, 2013).

Table 8: Attribute levels of base scenario by vehicle type

	Purchase price (€)	Fuel cost (€)	CO_2 emissions (%)	Driving range (km)	Fuel availability (%)	Refueling time (min)	Battery recharging time (min)	Incentive 1	Incentive 2
CFV	21,800	9.0	100	1000	100	5			
NGV	23,900	6.5	84	1000	50.9	5			
HEV	26,700	7.5	77	1000	100	5			
PHEV	30,200	5.5	31	750	43.3	5	240	0	0
BEV	36,800	4.0	0	175	14.1		480	0	1
BV	22,900	9.0	23	750	2.3	5		0	0
FCEV	33,800	7.5	0	750	0.2	5		0	0

Given the attribute values of the base scenario in Table 8 and the estimation results in Table 4, we can calculate individuals' (class-specific) choice probabilities of the different vehicle alternatives, which are shown in Table 9.

Table 9: Choice probabilities in the base scenario by vehicle type

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
CFV	0.315	0.405	0.211	0.497	0.224	0.463	0.113
NGV	0.213	0.170	0.282	0.250	0.034	0.265	0.123
HEV	0.198	0.336	0.201	0.111	0.234	0.111	0.123
PHEV	0.118	0.069	0.134	0.018	0.426	0.034	0.137
BEV	0.043	0.005	0.032	0.013	0.029	0.002	0.258
BV	0.080	0.013	0.099	0.059	0.038	0.122	0.133
FCEV	0.033	0.002	0.040	0.050	0.015	0.004	0.114

As can be seen, the selection probabilities of the distinct vehicle alternatives vary considerably between segments. For instance, while the principally fossil-fueled vehicles (CFVs, NGVs, HEVs) have a combined market share of 91.1%, 85.8%, and 83.9% in classes 1, 3, and 5, respectively, they account for only 35.9% of the potential demand in class 6. Moreover, the vehicle technology favored most varies between groups as well. While CFVs are the most probably chosen option in segments 1, 3 and 5, it is NGVs in segment 2, PHEVs in segment 4, and BEVs in segment 6. However, despite this particular appreciation of BEVs in class 6, it can be stated that BEVs and FCEVs, and to a lesser extent also BVs (who only gain a market share of more than 10% in classes 5 and 6) are the vehicle alternatives disliked most in the population. Interestingly, in segment 4 NGVs are as much rejected as these three alternatives. Comparable to BEVs, BVs, and FCEVs, PHEVs are rejected in classes 1, 3, and 5, too, but can gain a market share of more than 10% in the other three classes, with a maximum of 42.6% in class 4.

In the following, the expected CV for several attribute improvements is calculated for the specific vehicle alternatives, taking the considerable choice probability differences in the six distinct consumer groups into account. Starting with the CV expressed as a purchase price surcharge car buyers would have to pay extra to secure their gain in utility (consumer surplus), it can be seen in Table 10 that fuel cost reductions for biofuels and hydrogen, e.g. due to governmental tax reliefs, which would cut mobility costs of vehicles running on these alternative fuels down to the same level as cars fueled with natural gas, are not valued highly. The CV ranges from about €37 (class 1) to €788 (class 2) for BVs and from only about €1 (class 5) to €112 (class 2) for FCEVs.

Governmental granting of monetary and non-monetary incentives is, on the other hand, much more appreciated by German car buyers, although also dependent on the vehicle alternative for which the incentive is established and the consumer group. The CV for the monetary incentive of a vehicle tax exemption stretches from only about €5, €40, and €98 to €2301, €2752, and €2666 for FCEVs, PHEVs and BVs, respectively. Apparently, the lowest CV values are always found in segment 5 (except for BVs, where individuals in class 1 value tax exemptions even less), while car buyers in segment 6 show the highest appreciation for vehicle tax exemptions for all AFVs. Looking at the non-monetary incentives, we can observe a comparable distribution of the CV values, which range from about €9, €22, €61, and €314 to €1688, €3753, €1957, and €2020, for FCEVs, BEVs, BVs, and PHEVs, respectively. Again, the highest CV values can be found in segment 6, while in this case individuals in segment 1 almost always show the lowest valuation for free parking and the allowance to use bus lanes.

Turning to the CV for a CO_2 emissions abatement measure that reduces the pollution caused by the different exclusively fossil-fueled vehicle alternatives from their current level to half of an average present-day car, we can observe that individuals in segment 5 show the lowest appreciation for such a measure for all three vehicle alternatives considered, while respondents in segments 4 and 6 value such an emission mitigation most. The CV stretches from €8 for HEVs, €23 for NGVs, and €54 for CVs (class 5) to €332 (class 4), €338 (class 6), and €513 (class 4), respectively.

Table 10: CV for changes in vehicle attributes (in € of purchase price surcharge)

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Fuel cost reduction							
BV (€9/100 km → €6.5/100 km)	197.03	37.29	787.81	120.08	149.26	83.85	290.95
FCEV (€7.5/100 km → €6.5/100 km)	31.22	2.06	112.34	40.51	23.21	1.08	99.25
Incentive 1 (No vehicle tax)							
PHEV	524.66	532.38	473.04	402.06	45.01†	40.49	2751.67
BV	360.06	97.64	352.61	1291.02	4.02†	144.00	2665.59
FCEV	148.13	13.96	144.49	1108.94	1.60†	4.94	2301.12
Incentive 2 (Free parking and bus lane access)							
PHEV	353.08	334.56	414.86	313.66	3131.18†	9.92†	2020.11
BEV	129.90	21.98	99.53	232.00	219.39†	0.72†	3752.55
BV	241.97	61.16	309.06	1009.92	287.20†	35.65†	1956.54
FCEV	99.37	8.74	126.52	867.00	114.21†	1.21†	1687.68
CO_2 emissions abatement							
CFV (100% → 50%)	208.38	433.79	121.45	-227.09†	512.84	53.86	416.54
NGV (84% → 50%)	105.03	136.04	120.67	-85.52†	58.85	23.06	338.17
HEV (77% → 50%)	81.35	223.31	71.47	-31.70†	331.72	8.02	280.55
Driving range increase							
BEV (175 km → 350 km)	336.14	181.70	267.11	161.72	208.68†	3.64	1644.37
BEV (175 km → 750 km)	854.49	723.54	756.48	402.63	470.45†	9.34	3596.26
Fuel availability increase							
NGV (50.9% → 60%)	150.71	565.34	80.49	62.57†	74.52	30.92	101.44
PHEV (43.3% → 60%)	168.48	489.76	76.49	9.02†	1838.33	7.96	225.19
BEV (14.1% → 60%)	309.72	230.17	86.90	30.30†	649.86	2.84	1945.99
BV (2.3% → 60%)	1566.43	3308.50	680.98	311.19†	2413.15	365.68	2421.33
FCEV (0.2% → 60%)	1533.46	3299.62	582.73	490.83†	2398.58	29.21	4000.49
NGV (50.9% → 100%)	646.76	2730.67	338.72	259.01†	325.59	131.49	424.23
PHEV (43.3% → 100%)	454.51	1518.95	202.25	23.40†	4887.15	21.41	588.41
BEV (14.1% → 100%)	443.24	393.36	121.67	41.44†	938.28	4.04	2673.31
BV (2.3% → 100%)	1912.98	4876.05	813.26	363.71†	2984.72	441.42	2852.53
FCEV (0.2% → 100%)	1777.37	4756.35	658.27	540.54†	2815.68	33.66	4442.26
Battery recharging time reduction							
PHEV (4 h → 1 h)	213.37	397.42	126.40†	79.95†	761.88†	23.28	650.07
BEV (8 h → 1 h)	120.09	41.38	45.90†	91.29†	79.04†	2.64	1854.64
PHEV (4 h → 5 min)	640.37	1327.25	373.41†	248.41†	2164.66†	75.73	1925.37
BEV (8 h → 5 min)	285.41	110.86	107.41†	223.30†	178.77†	6.81	4278.42

Notes: † indicates WTP value based on insignificant attribute coefficient

The CV for an extension of a vehicle's driving range is calculated for BEVs only, since today very short driving ranges (175 km) only occur in BEVs. CV values are calculated for an extension of the cruising radius to 350 km and 750 km, respectively. Although not showing the lowest valuation for such improvements, individuals in segment 1, which had the highest WTP for driving range extensions, have a much lower CV than individuals in segment 6, who value them most, showing a CV of about €1644 up to €3596. Again, respondents in class 5 have the lowest CV, with only €4 to €9 for a doubling or even more than a quadrupling of

BEVs' cruising radius, respectively. Regarding the appreciation of an increased density of the refueling network, it is also individuals in segment 5 who exhibit the lowest CV, regardless of the actual expansion or the vehicle alternative for which the fuel station network is improved, ranging from about €3-4 for a BEV charging station density of 60% and 100%, respectively, to €366-441 for a an identical increase of the availability of biofuels at fuel stations. At the other end of the CV range, car buyers in class 1 have the highest appreciation for an improvement of the fuel station density of all non-electrified AFVs, ranging from €565-2731 for an extension of the fuel station network of NGVs to 60% and 100%, respectively, €3309-4876 for BVs, and €3300-4756 for FCEVs. Concerning PHEVs, car buyers in segment 4 have the highest CV, stretching from €1838-4887 for a fuel availability of 60% and 100%, respectively, while individuals in segment 6 show the highest valuation of such an improvement for BEVs (€1946-2673) and FCEVs (€4000-4442). Finally, the acceleration of the battery recharging process, e.g. through the installation of fast-charging or battery swapping stations, evaluated separately for PHEVs and BEVs, shows a familiar picture. While car buyers in class 5 consistently exhibit the lowest willingness to spend extra amounts of money of all consumer groups for a shortening of the recharging process, members of class 6 behave the opposite. The CV value of individuals in segment 5 ranges from only about €3 for reducing the time to fully recharge the battery of a BEV to 1 hour to €76 for a 5-minute recharging duration in the case of PHEVs. Vehicle buyers in segment 6, on the other hand, have a CV, stretching from €650 to €4278 for a recharging time of 1 hour for PHEVs and 5 minutes for BEVs, respectively.

Comparable to the calculation of individuals' WTP, we can also express the CV in fuel costs per 100 km that individuals are willing to spend for attribute improvements of specific vehicle alternatives, so that their utility level is kept constant. Beginning with purchase price reductions, induced, for example, by governmental subsidies or technical progress due to increases in demand, which lower the up-front expenditure for BEVs and FCEVs to €30,000 in a first step and €21,800 in a second step, we can observe in Table 11 that individuals in class 1 have the lowest CV values for BEVs (about 3 €-cents to 8 €-cents for a reduction to €30,000 and €21,800, respectively) and FCEVs (less than 1 €-cent to about 3 €-cents) in both cases, while respondents in class 6 always exhibit the highest CV value, namely €2.11 to €4.90 for BEVs and €0.52 to €1.73 for FCEVs, depending on the size of the purchase subsidy. The results of a policy measure, which separately leads to a purchase price of €21,800 for all remaining AFVs, are not that clear-cut. For instance, the lowest CV values for NGVs can be found in class 4 (5 €-cents), for HEVs in class 2 (45 €-cents), for PHEVs in class 3 (22 €-cents), and for BVs in class 1 (1 €-cent). On the other hand, individuals in segment 5 consistently have the highest appreciation for these four AFVs, and would accept an increase in fuel costs per 100 km of about €2.66, €3.88, €3.65, and €0.60 for NGVs, HEVs, PHEVs, and BVs, respectively.

Table 11: CV for changes in vehicle attributes (in €/100 km of fuel cost increase)

	MNL	LCM					
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Purchase price reduction							
BEV (€36,800 → €30,000)	0.376	0.032	0.111	0.126	0.139	0.182	2.114
FCEV (€33,800 → €30,000)	0.149	0.007	0.070	0.254	0.039	0.105	0.515
NGV (€23,900 → €21,800)	0.503	0.330	0.249	0.677	0.048	2.657	0.303
HEV (€26,700 → €21,800)	1.160	1.573	0.454	0.732	0.783	3.824	0.722
PHEV (€30,200 → €21,800)	1.296	0.612	0.593	0.216	2.469	3.654	1.412
BEV (€36,800 → €21,800)	1.029	0.083	0.347	0.314	0.331	1.795	4.900
BV (€22,900 → €21,800)	0.098	0.013	0.045	0.083	0.028	0.596	0.170
FCEV (€33,800 → €21,800)	0.583	0.025	0.309	0.899	0.134	1.347	1.728
Incentive 1 (No vehicle tax) implementation							
PHEV	0.566	0.476	0.187	0.506	0.030†	0.158	3.182
BV	0.389	0.087	0.139	1.626	0.003†	0.563	3.082
FCEV	0.160	0.012	0.057	1.397	0.001†	0.019	2.661
Incentive 2 (Free parking and bus lane access) implementation							
PHEV	0.381	0.299	0.164	0.395	2.064†	0.039†	2.336
BEV	0.140	0.020	0.039	0.292	0.145†	0.003†	4.339
BV	0.261	0.055	0.122	1.272	0.189†	0.139†	2.262
FCEV	0.107	0.008	0.050	1.092	0.075†	0.005†	1.952
CO_2 emissions abatement							
CFV (100% → 50%)	0.225	0.388	0.048	-0.286†	0.338	0.211	0.482
NGV (84% → 50%)	0.113	0.122	0.048	-0.108†	0.039	0.090	0.391
HEV (77% → 50%)	0.088	0.200	0.028	-0.040†	0.219	0.031	0.324
Driving range increase							
BEV (175 km → 350 km)	0.363	0.163	0.106	0.204	0.138†	0.014	1.901
BEV (175 km → 750 km)	0.922	0.648	0.299	0.507	0.310†	0.037	4.159
Fuel availability increase							
NGV (50.9% → 60%)	0.163	0.506	0.032	0.079†	0.049	0.121	0.117
PHEV (43.3% → 60%)	0.182	0.438	0.030	0.011†	1.212	0.031	0.260
BEV (14.1% → 60%)	0.334	0.206	0.034	0.038†	0.428	0.011	2.250
BV (2.3% → 60%)	1.690	2.961	0.269	0.392†	1.591	1.430	2.800
FCEV (0.2% → 60%)	1.655	2.953	0.230	0.618†	1.581	0.114	4.626
NGV (50.9% → 100%)	0.698	2.444	0.134	0.326†	0.215	0.514	0.491
PHEV (43.3% → 100%)	0.490	1.359	0.080	0.029†	3.222	0.084	0.680
BEV (14.1% → 100%)	0.478	0.352	0.048	0.052†	0.619	0.016	3,091
BV (2.3% → 100%)	2.064	4.364	0.322	0.458†	1.968	1.726	3.299
FCEV (0.2% → 100%)	1.918	4.257	0.260	0.681†	1.856	0.132	5.137
Battery recharging time reduction							
PHEV (4 h → 1 h)	0.230	0.356	0.050†	0.101†	0.502†	0.091	0.752
BEV (8 h → 1 h)	0.130	0.037	0.018†	0.115†	0.052†	0.010	2.145
PHEV (4 h → 5 min)	0.691	1.188	0.148†	0.313†	1.427†	0.296	2.226
BEV (8 h → 5 min)	0.308	0.099	0.042†	0.281†	0.118†	0.027	4.947

Notes: † indicates WTP value based on insignificant attribute coefficient

Governmental monetary and non-monetary incentives show a comparable range of CV values across consumer groups and vehicle alternatives for which the incentive is granted. The CV for a vehicle tax exemption stretches from only about 1 €-cent, 9 €-cents, and 16 €-cents to €2.66, €3.08, and €3.18 for FCEVs, BVs, and PHEVs, respectively. The lowest valuations of such a monetary support scheme are found in class 1 for FCEVs and BVs, and in class 5 for PHEVs, while individuals in class 6 show the highest appreciation for vehicle tax exemptions for all AFVs considered. Concerning non-monetary incentives, a comparable distribution of the CV values can be observed, which range from less than 1 €-cent, 6 €-cents, 2 €-cents, and 16 €-cents to €1.95, €2.26, €4.34, and €2.34 for FCEVs, BVs, BEVs, and PHEVs, respectively. As for monetary incentives, the highest CV values can be found in segment 6, while respondents in segment 1 almost consistently have the lowest valuation for free parking and the allowance for bus lane usage, which is only undercut for PHEVs by car buyers in segment 2. Individuals in this class also exhibit the lowest valuation regarding CO_2 emission reductions for all exclusively fossil-fueled vehicle alternatives. The CV values lie in the area of about 3-5 €-cents, depending on the fuel type considered, while it is again car buyers in class 6 who have the highest CV, amounting to 32-48 €-cents for HEVs, NGVs, and CFVs.

The CV for an extension of the cruising radius of BEVs from 175 km to 350 km and 750 km, respectively, ranges from about 1 €-cent and 4 €-cents in segment 5 to €1.90 and €4.16 in segment 6. Such clear-cut results do not exist concerning the valuation of a refueling network extension to either 60% or 100% of fuel stations serving the proper fuel, although some patterns can be observed. For instance, the lowest CV values can be found in class 2 for NGVs, PHEVs, and BVs, and class 5 for BEVs and FCEVs, while individuals in class 1 show the highest CV for NGVs and BVs, class 4 for PHEVs, and class 6 for BEVs and FCEVs, regardless of the size of the fuel network expansion. The CV for an improvement of the fuel station density for the specific vehicle alternatives from their current base to 60% and 100%, respectively, ranges from about 3 €-cents and 13 €-cents to €0.51 and €2.44 for NGVs, 3 €-cents and 8 €-cents to €1.21 and €3.22 for PHEVs, around 1 €-cent to €2.25 and €3.09 for BEVs, 27 €-cents and 32 €-cents to €2.96 and €4.36 for BVs, and 11 €-cents and 13 €-cents to €4.63 and €5.16 for FCEVs. These huge differences in car buyers' CV also reflect the great variances in fuel availability across vehicle alternatives in the *status quo*.

Finally, the appreciation of a reduction of the battery recharging time is lowest in class 5 and highest in class 6. Thus, regarding a reduction of the recharging time to 1 hour and 5 minutes, respectively, individuals in segment 5 have a CV that ranges from 9 €-cents to 31 €-cents for PHEVs and from 1 €-cent to 3 €-cents for BEVs. Respondents in class 6, on the other hand, show a CV in the range from €0.75 to €2.23 for PHEVs and from €2.15 to €4.95 for BEVs, for the two fast-charging options.

6 Discussion

WTP calculations show that German car buyers are willing to forfeit substantial amounts of money for all kinds of attribute improvements, which in some cases by far exceed the current cost for their production or provision. However, the interpretation of WTP values is only valid if certainty about individuals' choices exists. Thus, for instance, respondents in class 1 would be willing to pay almost €24,000 and €50,400 for an extension of the driving range from 175 km to 350 km and to 750 km, respectively, if they had chosen a car with a limited driving range of 175 km (which today is equivalent to a BEV). This, however, is somewhat unrealistic or irrelevant, since car buyers in segment 1 would almost never choose BEVs (choice probability of 0.5%). A second possibility for interpreting WTP values is that they describe the willingness of car buyers to expend money for the identical improvement of a vehicle attribute in all vehicle alternatives simultaneously. However, in this case a problem with very heterogeneous alternatives exists, as they usually possess very dissimilar characteristics (e.g. CO_2 emissions and fuel availabilities show a great variation between vehicle alternatives), as can be seen in the German *status quo* figures depicted in Table 8. Furthermore, car buyers are usually not willing to pay for an improvement of a vehicle attribute for an alternative they will not select. For example, a person that intends to purchase a CFV does not care about the density of charging stations, nor is it willing to forfeit money for its improvement.

Albeit these notable shortcomings of WTP values, they are very valuable for displaying and describing the decreasing marginal utilities and returns of the improvement of non-linear attributes. Furthermore, they visualize the heterogeneity in the importance and valuation of the different vehicle attributes, both within and between groups, as they put attributes with different units of measurement on a common basis. Therefore, the functional form of the statistically significant WTP values for the different segments is illustrated in Figures 1 and 2.

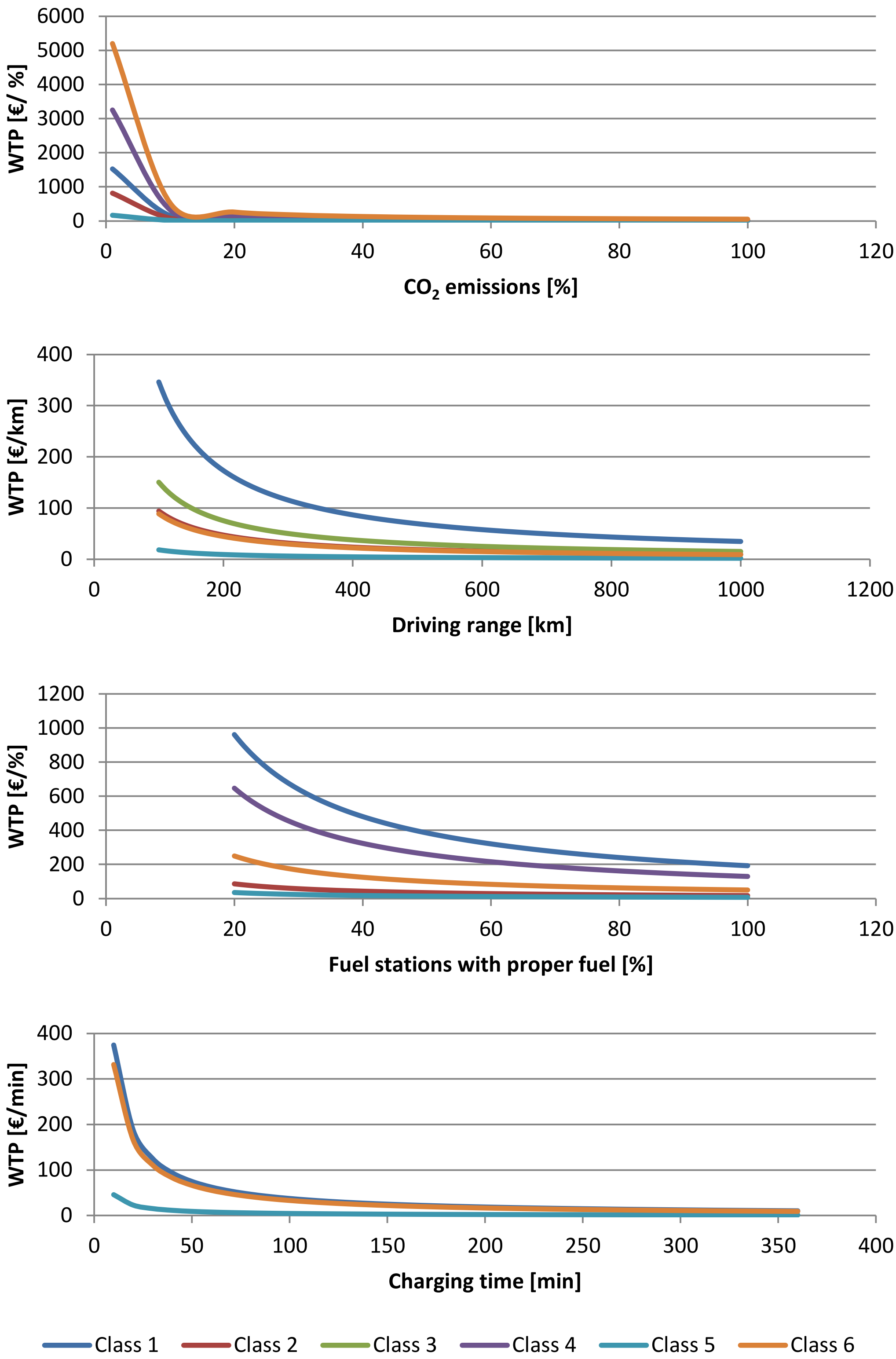

Figure 1: Marginal WTP for changes in vehicle attributes (in € of purchase price surcharge)

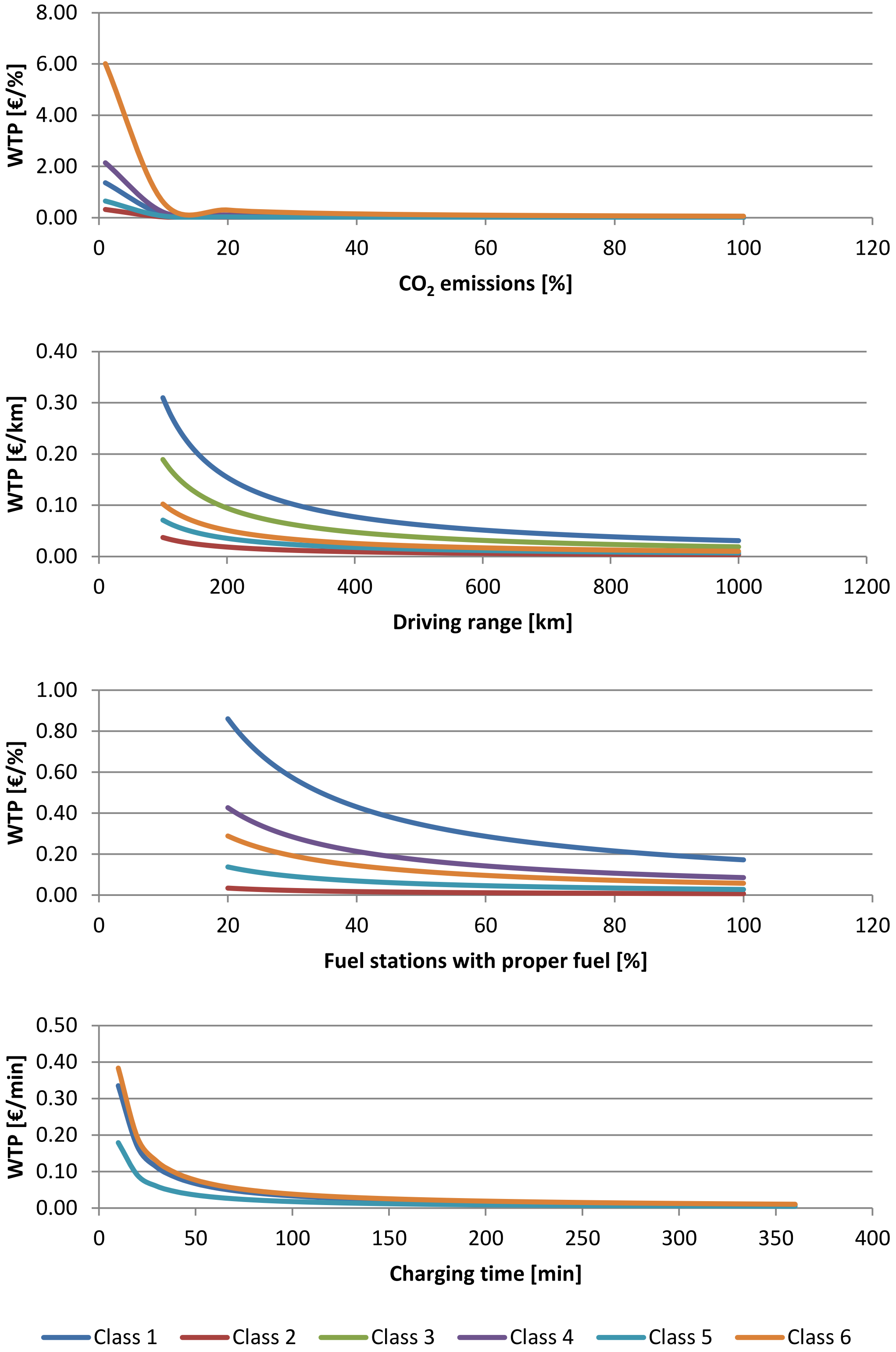

Figure 2: Marginal WTP for changes in vehicle attributes (in €/100 km of fuel cost increase)

The diminishing marginal utility is clearly visible, as is the in some cases marked differences in the WTP across the groups. It can also be seen that consumers have some minimum requirements, which have to be met so that they are willing to pay money for improvements of vehicle attributes, and that improvements outside these borders are rather unimportant and not appreciated as much. As an example, the WTP for a reduction of CO_2 emissions by 1% starts to accelerate when the vehicles' CO_2 emissions are about to drop below 10-15% of the emissions of a current average car. Comparably, the WTP for fast-charging increases sharply when the recharging process undercuts the 30-minute mark. The WTP function for driving range and fuel availability does not have such an extreme threshold, although it also shows long tails with a relatively low WTP. The differences in the WTP across segments are also highlighted in Figures 1 and 2. For example, the high importance of all vehicle attributes that enable and simplify long trips in class 1 (driving range, fuel station density, and recharging time), or the high valuation of substantial emission mitigation measures and fast-charging stations in class 6.

In the following discussion, we focus on the implications of the results of the CV calculations, as they are more informative than the WTP values. As already mentioned in section 5.4, fuel tax reductions for BVs and FCEVs, leading to competitiveness regarding operating costs of these two vehicle alternatives with currently already fuel tax-advantaged NGVs, are not highly valued on the consumer side, e.g. maximally about €800 in segment 2 for a reduction in biofuel costs of €2.5/100 km, which is equivalent to a payback period of slightly more than two years, assuming the annual mileage of an average German driver of 14,210 km (DAT, 2014). This result suggests that car buyers in our sample undervalue fuel cost savings of AFVs and thus seem to act myopically.[6]

[6] However, this myopic behavior cannot be observed when we look at the WTP for a fuel-unspecific operating cost reduction of €1/100 km (Table 6). In general, the literature on consumers' valuation of fuel economy measures does not show entirely consistent results, although taken together they point in the same direction. For instance, in his review article, Greene (2010a) reports a wide bandwidth of consumers' WTP for fuel economy improvements, with a prevalence of an undervaluation of fuel efficiency gains, which is also reflected in consumers' requirement for short payback periods of 1.5-2.5 years for fuel-saving investments (Greene, 2010b). This underestimation of fuel cost differences between vehicles is also found in the majority of the most recent studies on this topic. They report implicit discount rates of around 15%, which can be explained by slight myopic behavior, but also by rational decisions, given the uncertainty about future fuel prices and annual

Hence, fuel price cuts do not seem to be able to increase AFV demand, and the costs (loss in fuel tax revenues) would probably exceed the monetized environmental benefits. However, a reverse approach, i.e. making conventional fuels more expensive, could still be a possible way to accelerate the diffusion of AFVs, although it is questionable if such a measure would be politically enforceable, especially in Germany with its powerful automotive lobby. Contrary to this, a compensation of purchase price subsidies through higher mobility costs is accepted in at least two consumer groups (classes 5 and 6). Interestingly, the accepted amount of such a surcharge on fuel or electricity costs per 100 km ranges from maximally €2 (FCEVs) to €5 (BEVs), which, when added to the *status quo* values, would result in mobility costs of about €9, i.e. the average fuel costs per 100 km of CFVs. Unfortunately, it seems that such a purchase price subsidy is not a revenue-neutral option to increase the demand for AFVs, as, for instance, in the case of BEVs the €15,000 purchase price reduction would need a lifetime mileage of around 300,000 km to be fully compensated. However, such a measure could nevertheless be noteworthy to increase AFV diffusion, since, as mentioned above, German car buyers seem to perceive upfront costs of AFVs more negatively than their running costs.

Monetary governmental incentives are highly appreciated in class 6 (and to a somewhat lesser extent in class 3), amounting up to about €2750, depending on the vehicle alternative, while individuals of other segments do not. In other words, the willingness to pay for such a tax exemption is higher than the forgone tax revenues, so that at least in one consumer group the benefits of the incentive are higher than its costs. In terms of fuel cost reductions, individuals are willing to forfeit up to €3 for a vehicle tax exemption. This incentive would thus only be revenue-neutral when individuals have a certain annual mileage. Nevertheless, a change in the taxation system from motor vehicle taxes to fuel taxes, which can take the different environmental effects of the fuel types into account, could be desirable for the government, as the drivers are punished who actually use the highways or harm the environment more than others by driving a lot, and not those who potentially do by owning a rarely used gas-guzzling car. However, it is again doubtful if such an action would be politically enforceable. Non-monetary governmental incentives are again only appreciated by

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mileage, or commensurate interest rates for credit-financed vehicle purchases (e.g. Helfand and Wolverton, 2011; Allcot and Wozny 2012; Busse et al., 2013; Allcott, 2013; Gillingham et al., 2014).

individuals in segment 6, and to a lesser extent in segment 3. Consumers are willing to pay up to €3750 or €4.30/100 km for free parking and the allowance to use bus lanes. Thus, such a policy measure could increase the demand especially for BEVs in a quite cost-effective way, as these monetary amounts by far exceed the losses in parking fees. Taken together, German car buyers value these two governmental incentives with an amount that is comparable to the purchase subsidies other European countries grant for electric cars (i.e. €5000, see e.g. ACEA, 2013), while being less costly for the German government compared to such a purchase price reduction. However, the decision for allowing the usage of bus lanes and enabling free parking cannot be made by the German government alone, but due to Germany's federalist structure, has to be backed by the local administration. This could be problematic, if uniform nation-wide solutions are hampered, and might need some compensating mechanism to offset the financial losses of, for example, lost parking fees.

The CV for a CO_2 emissions mitigation measure of (mainly) fossil-fueled vehicles is quite low, i.e. maximally only about €500 or €0.5/100 km for halving the pollution of CFVs (in classes 4 and 6). One possible explanation for this finding is that individuals who value emission reduction actions high are unlikely to choose fossil-fueled vehicles, while individuals who have a high choice probability for fossil-fueled cars do not care that much about CO_2 emissions, and thus are not willing to spend money for their improvement. It thus could be more expedient to promote more environmentally friendly vehicles by emphasizing their fuel efficiency instead of their 'greenness'. On the other hand, assuming an average fuel consumption of 5.9 l/100 km for CFVs, car buyers would be willing to forfeit a surcharge of around 8 €-cents/l for low-emission vehicles.

The CV for an extension of the driving range of BEVs reaches from maximally €1644 for 175 additional kilometers to about €3600 for 575 additional kilometers (segment 6), or between €55.3 and €36.8 per kWh, respectively, assuming a consumption of 17 kWh/100 km. This is far less than the current battery prices of €250-300 per kWh. Put differently, even BEV-affine consumers are far away from being willing to spend high extra amounts for a driving range expansion. In terms of fuel costs per 100 km, individuals (in class 6) are willing to forfeit around €1.9 to €4.2 for such increases in cruising radius, which corresponds to 0.1-0.4 €-cents per kWh, so that the additional battery costs for improvements of the driving range on the side of the vehicle manufacturer or mobility providers could not be offset through higher operating costs.

Increases in fuel availability are not valued homogeneously, but depending on the consumer group, and the vehicle alternative, for which the fuel station network is expanded, so that the CVs for NGVs and BVs are highest for individuals in class 1, for PHEVs in class 4, and BEVs and FCEVs in class 6, and amount up to at most around €5000 or €5/100 km for a fully developed network. Since vehicle manufacturers are usually not the same as the providers of the respective fuel, the measure displayed in operating costs gives a better insight into the potential of business models regarding a refueling infrastructure expansion. For instance, assuming a fuel consumption of 6.9 l/100 km for NGVs, 8.3l/100 km for BVs, 17 kWh/100 km for BEVs, and 1 kg/100 km for FCEVs, for 100% fuel availability German car buyers are currently willing to forfeit extra up to €0.35/l and €0.53/l for NGVs and BVs, respectively, as well as €0.18/kWh and €5.14/kg for BEVs and FCEVs, respectively. Concerning FCEVs and BEVs, this is equivalent to an accepted increase in fuel or electricity price by more than ⅔ and ¾, respectively, compared to the *status quo*. These numbers indicate that the potential for private investors exists to provide an area-wide refueling and recharging infrastructure in a cost-efficient manner. However, the analysis of the economic feasibility of potential business models, the amount of additional vehicles and their aggregated mileage needed to profitably carry on the fuel station network, is beyond the scope of this research.

Finally, the CV for a charging time reduction to 1 hour and 5 minutes, respectively, is noteworthy only for car buyers in segment 1 (PHEVs) and segment 6 (PHEVs and BEVs). It maximally amounts up to about €2000 and €4000 for a resulting charging duration of BEVs of 1 hour and 5 minutes, respectively (segment 6). Again, it is more sensible to display the results in terms of costs per 100 km, to assess the business potential of individuals' valuation for fast-charging opportunities. The CV then at most amounts to €2.15 and €4.95 for such an acceleration in charging time to 1 hour and 5 minutes, respectively, which in the latter case results in operating costs per 100 km which are comparable to CFVs. Assuming again an average electricity consumption of 17 kWh per 100 km for BEVs, these amounts are equivalent to about 13 €-cents and 29 €-cents per kWh that individuals would additionally spend for fast-charging stations that enable to fully refill the battery in 1 hour or 5 minutes, respectively. In other words, car buyers would accept an increase in operating costs of 55% and 123%, respectively, if the recharging process would be sped up in exchange. As before, the economic potential of these monetary values, and their translation into business models is beyond the scope of this research.

However, the results indicate that German car buyers are not unwilling to pay considerable amounts for a spatially fully extended network of fast-charging stations for their PHEVs and/or BEVs. To be precise, individuals in class 6 would additionally forfeit 8.63 €-cents/km or 51 €-cents/kWh for such an infrastructure for BEVs alone, and thus would not only accept more than a tripling of current operating costs of BEVs, but also much higher operating costs than comparable CFVs. This result suggests, that a financially attractive provision of electric mobility might be achievable for investors, e.g. electric utilities.[7] For instance, a potential business model to simultaneously provide a fully developed network of fast-charging stations and to reach as many consumers as possible could be the selling of a mobility service (either independently or jointly with the car manufacturers, e.g. as a package deal in conjunction with the vehicle purchase) with many different volume (kWh/month) or flat-rate options, comparable to contracts in the telecommunication industry.

7 Summary and Conclusion

In the light of steadily tightened clean air legislations on the European level, the corresponding need of car manufacturers to either diminish the fuel consumption of their conventionally fueled vehicle fleet or to increase the sales figures of AFVs, and the ambitious aim of the German administration of one million registered electrically propelled vehicles by the year 2020, it is useful to investigate German car buyers' preferences for AFVs – in particular against the background of the latter currently not being very popular among

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[7] Although very simplified, the following sample calculation might help to convey a sense of the economic potential of providing a nation-wide fast-charging infrastructure for PHEVs and BEVs, for which car buyers in segment 6 would be willing to pay an extra amount of €11.32/100 km. Conservatively assuming 1) total investment costs of 625 million euros (12,500 fast-charging stations for €50,000 each); 2) a less than average annual mileage of 12,000 km; 3) a usage of the fast-charging infrastructure for 50% of the kWh needed for the annually driven distance, while the other half is recharged at home; and 4) an accepted payback period of the investment of 5 years, ignoring interest rates for the time being, about 184,000 PHEVs or BEVs would suffice for an economic operation of the comprehensive fast-charging network, i.e. less than ⅕ of the 2020 German electric mobility target.

consumers. Our study is based on stated preferences discrete choice data, gathered in a nation-wide survey among 711 respondents conducted in the summer of 2011.

We extended previous studies focusing on the German market, by taking non-linear impacts of vehicle attributes on the choice decision into account, by incorporating the heterogeneity in the population through an LCM specification, and by calculating not only consumers' WTP for the improvement of the most important vehicle characteristics, but also their CV values, which reflect their willingness to forfeit money for attribute upgrades more realistically, as they take the currently low choice probabilities of AFVs into account.

Two model specifications were used, a standard MNL and an LCM. The MNL results suggest that, on average, except for refueling time, all experimentally varied vehicle attributes are highly statistically significant and affect vehicle choice in the predicted way, i.e. positively (driving range, fuel availability, and governmental monetary and non-monetary incentives) or negatively (purchase price, fuel costs, CO_2 emissions, and recharging time). Furthermore, the MNL results indicate that, on average, German car buyers currently dislike all AFVs (except PHEVs), especially BEVs and FCEVs. However, the findings of the LCM, which significantly improves the MNL statistically, show that the population of German car buyers is not as homogeneous as assumed by the MNL, but can be described best by 6 distinct consumer groups that vary in taste concerning vehicle characteristics and fuel types. For instance, the results of the LCM reveal that currently not all German car buyers reject AFVs, but that two consumer segments exist that are open-minded towards at least some of the AFVs. More precisely, 20.6% of the respondents prefer PHEVs (segment 4) over all other propulsion technologies, while 15% of the car buyers like PHEVs, BEVs, BVs, and FCEVs more than vehicles that mainly rely on fossil fuels (segment 6). In other words, especially younger, less educated, and highly environmentally aware consumers with a high annual mileage are more likely to choose new vehicle technologies in general, while particularly PHEVs find enthusiasts also among the elderly and technophile buyers of larger cars. Hence, specifically tailored marketing strategies should aim at these two consumer groups, in order to effectively increase the adoption rates of those AFVs that are mainly or exclusively propelled by non-fossil fuels.

Moreover, we find that German car buyers are willing to pay considerable amounts for the improvement of all kinds of vehicle attributes, although this appreciation varies depending on the consumer segment. For example, individuals are willing to dispense up to about €2530 for a fuel cost reduction of €1/100 km (class 2), about €17,710 and €13,410 for a vehicle tax exemption and the permission to use bus lanes and park free of charge, respectively (class 6), about €5200 for the abatement of the last percent of vehicle's CO_2 emissions (class 6), almost €350 for an increase in driving range from 100 km to 101 km (class 1), about €960 for increasing the fuel availability by one percent to 21% (class 1), and almost €375 for a one minute foreshortening of the battery recharging process to a duration of 9 minutes (class 1). Expressed in additional fuel costs per 100 km that consumers would be willing to disburse for these improvements, we find slight differences to the results mentioned above regarding the consumer segment with the highest WTP. Individuals would accept an increase in fuel costs of up to about €3.90/100 km for a purchase price reduction of €1000 (class 5), about €21.80 and €17.82 for the monetary and the non-monetary governmental incentives, respectively (class 3), about €6 for the CO_2 emissions mitigation (class 6), €0.31 for the one kilometer driving range expansion to 101 km (class 1), almost €0.90 for increasing the fuel station density from 20% to 21% (class 1), and almost €0.40 for a reduction of the recharging time from 10 minutes to 9 minutes (class 6). Furthermore, the curved shape of the WTP for the four logarithmically transformed vehicle attributes (CO_2 emissions, driving range, fuel availability, and recharging time) reflects the diminishing marginal returns of their improvement, and indicates that minimum requirements and relatively narrow thresholds exist beyond which attributes rapidly gain in consumer's valuation. For instance, CO_2 emissions mitigation measures start to be appreciated, when they cut vehicle emissions down to about 15% of current average cars. Moreover, considerable recharging time reductions to a duration of only 30 minutes are almost worthless, while further increases in fuel availability beyond about 40% and in driving range beyond circa 400 km, respectively, rapidly decrease in car buyer's appreciation. These findings are particularly interesting for vehicle manufacturers, private investors and policy makers, and should be taken into account in their financial efforts and strategic decisions: They suggest that consumers do not accept to be charged for small reductions in recharging time and vehicle emissions, whereas they are willing to forfeit the highest amounts for initial improvements of driving range and fuel availability, so that it is unclear whether improvements of vehicle attributes could be provided entirely privately and maybe even cost-effectively, or whether they might need governmental subsidies (e.g. for basic research or in terms of a purchase price subsidy) to take the hurdle beyond which they are valued sufficiently high to be adopted by German car buyers.

Additionally, we have also shown that fuel-specific CV values are more useful than the partially pronounced fuel-unspecific WTP values, as they account for the currently low choice probabilities of AFVs in the majority of the consumer segments. Consequently, car buyers' maximum CV of attribute improvements depends on the propulsion technology for which the measure is implemented. For instance, consumers are willing to forfeit up to almost €790 for a reduction in fuel costs to €6.5/100 km (BVs, class 2), more than €2750 for a vehicle tax exemption (PHEVs, class 6), more than €3750 for the permission to use bus lanes and park free of charge (BEVs, class 6), about €513 to reduce vehicle's CO_2 emissions to 50% of a current average car (CFVs, class 4), almost €3600 to increase the driving range of BEVs to 750 km (class 6), almost €4890 to increase the fuel availability to 100% (PHEVs, class 4), and almost €4280 to shorten the battery recharging process to 5 minutes (BEVs, class 6). Expressed in additional fuel costs per 100 km that consumers would be willing to disburse for these improvements, we find that individuals in class 6 consistently exhibit the highest total CV values, although not necessarily for every single vehicle alternative. Thus, members of this consumer group would accept an increase in fuel costs of up to €4.90/100 km for a purchase price reduction of €15,000 (BEVs), about €3.18 and €4.34 for the monetary (PHEVs) and the non-monetary (BEVs) governmental incentives, respectively, about €0.48 for the halving of vehicle's CO_2 emissions (CFVs), €4.16 for the expansion of BEVs' driving range to 750 km, about €5.14 for increasing the fuel station density to 100% (FCEVs), and about €4.95 for reducing the time to fully recharge a battery to 5 minutes (BEVs). Thus, in contrast to the WTP calculations, where individuals in segment 6 had the highest WTP for incentives and CO_2 emissions only, the CV calculations show that car buyers in segment 6 actually have the highest willingness to forfeit money for the improvement of most of the vehicle attributes. This applies except fuel cost reductions, purchase price cuts, and fuel availability expansions, where individuals in segment 2, segment 5, and segments 1 and 4, respectively, exhibit the highest values, when expressed in additional acquisition costs. This can be explained by their marked probability to choose an AFV, e.g. about 30% BEVs, even when they suffer from several disadvantages as today (*status quo*), thus, the results again suggest that decision-makers should particularly focus on consumers in this group.

Regarding the single vehicle attributes, our results show differences in their potential to increase the acceptance of AFVs and the possibility to be provided in a cost-effective way. For instance, our findings suggest that especially the non-monetary governmental incentives could increase AFVs' choice probability very cost-effectively, at least in segment 6. Vehicle tax exemptions and fuel cost reductions, on the other hand, are not valued high enough on the consumer side to be made available cost-effectively, even though they could be able to also push the demand for AFVs. By making conventional fuels more expensive, however, changes in the tax system could still be a possible way to accelerate the diffusion of AFVs. Even though they could not be provided in a cost-efficient way, governmental purchase price subsidies also have the potential to strongly increase the choice probability of AFVs, as car buyers seem to behave slightly myopic and thus perceive upfront costs more negatively than operational expenses. Again, the costs of such a governmental incentive program could partly be regained by a price rise of fossil fuels. This, however, assuredly would lead to problems in political enforceability.

CO_2 mitigation measures for all vehicles that mainly run on fossil fuels are also not appreciated much *per se*. However, as CO_2 emissions of carbon-based fuels are directly related to a vehicle's fuel consumption, a possibility to increase consumers' WTP for such abatement action could be to point out this dependency more prominently and thus to focus on vehicles' fuel efficiency and its corresponding potential for savings in marketing activities. Maybe this should be done anyhow, since, as mentioned before, car buyers undervalue fuel efficiency and seem to need more information on this topic, e.g. through brochures or commercials with instructive sample calculations.

The limited driving range of BEVs is one of the major barriers for electric mobility, and consequently its extension is identified as the silver bullet to increase consumer acceptance. As our results show, it is problematic in this respect is, that German car buyers are not willing to pay sufficient amounts of money for the increase in battery capacity necessary to that end. Hence, either battery research is vigorously intensified (e.g. through governmental financial support) to achieve a major break-through enabling battery prices of €50/kWh, which corresponds to about 20% of today's costs, or the concerted efforts should be focused on the installation of a comprehensive fast-charging infrastructure and the enhancement of its ease of handling (e.g. by use of battery swapping stations or inductive charging, to alleviate the shortcoming of BEVs' limited cruising radius). Such an increase in recharging station density could potentially be accomplished cost-effectively by private investors, since our results suggest that individuals would accept considerable markups on the electricity price for an area-wide fast-charging infrastructure. The same point can be made in the case of all other

AFVs, especially BVs and FCEVs. However, due to the very high up-front costs of such an investment, governmental guarantees could be necessary to that end. Accordingly, future research has to develop and evaluate business models for a cost-effective deployment of refueling and recharging infrastructure in Germany. A joint project of the German automotive industry, electric utilities and research institutions, funded by the Federal Ministry of Economics and Technology, has exactly that exact focus, and is scheduled to start in April 2014.

To conclude, the acceleration of the diffusion of AFVs in general and BEVs in particular could be fostered cost-effectively through monetary and non-monetary governmental incentives, and the extension of the fuel availability (or the fast-charging infrastructure, as in the case of electrified vehicles), which could help car buyers to condone especially the limited driving range of BEVs. This still is one of the major barriers, even when individuals are generally open-minded towards these new propulsion technologies (segment 6). These measures would in turn help to increase acceptance of AFVs, and especially BEVs, also in consumer groups, that currently are very reluctant towards the adoption of AFVs, but actually have the highest WTP for e.g. driving range or fuel availability (segment 1), which in turn opens up new possibilities for their improvement and cost-effective provision. These measures should be accompanied by marketing and information campaigns, which should be tailored to the distinct consumer groups. Regarding the attainment of the ambitious German electric vehicle goal, 5.5% of the annual car sales need to be BEVs or PHEVs until 2020. This target could be reached by solely focusing on the 'AFV aficionados' in segment 6 (15% of the population with a joint choice probability of BEVs and PHEVs of 40%), which should be done in a first step to achieve a rapid and major leap forward, which in turn could lead to the afore-mentioned bandwagon effects and sustained diffusion of AFVs.

However, since our study is based on a DCE, the results suffer from the major drawbacks of this methodological approach: The choices are made in a hypothetical setting, and the number of vehicle attributes is limited, so that no statements can be made about omitted variables. Furthermore, we asked the respondents to assume that all propulsion technologies are the same regarding their bandwidth of available segments, makes, and models, which currently is very unrealistic. Nevertheless, this study and our results establish a good starting point for political decision-makers and car manufacturers to review their strategic decisions on how the acceptance of and the demand for AFVs could be raised most cost-effectively, which areas most urgently need governmental subsidies to support actions from car manufacturers, and which ones could be provided by the private sector alone. Without such a concerted action from policy-makers, vehicle manufacturers, and private investors in refueling and recharging infrastructure, AFV adoption rates might remain marginal, and the policy goal in particular for PHEVs and BEVs will not be reached.

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