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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 regulations, 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 and compensating variation (CV) for improvements in vehicle attributes, also taking taste differences in the population into account by applying a latent class model with 6 distinct consumer segments. Our results indicate that about 1/3 of the consumers are oriented towards at least one AFV option, with almost half of them being AFV-affine, showing a high probability of choosing AFVs despite their current shortcomings. Our results suggest that German car buyers' willingness-to-pay for improvements of the various vehicle attributes varies considerably across consumer groups and that the vehicle features have to meet some minimum requirements for considering AFVs. 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. It also shows that some vehicle attribute improvements could increase the demand for AFVs cost-effectively, and that consumers would accept surcharges for some vehicle attributes at a level which could enable their private provision and economic operation (e.g. fast-charging infrastructure). Improvement of other attributes will need governmental subsidies to compensate for insufficient consumer valuation (e.g. battery capacity).

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 European Union, and other countries.[1] This can be explained by its strong dependence on carbon-based fuels, and, consequentially both its significant contribution to climate change and local air pollution and its vulnerability to fluctuations in crude oil prices. Hence, general environmental considerations and increased energy security concerns led to attempts of policy-makers to tackle the oil dependency of road transport and to bring alternative fuel vehicles (AFVs)[2]

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[1] A comprehensive overview of the evolution of worldwide fuel economy and GHG emissions regulations over the years is given in, e.g., An and Sauer (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).

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into the market, e.g. by the introduction or tightening of clean-air legislation and incentive programs. For instance, the European Union has defined legally binding CO_2 emission abatement targets for newly registered vehicles (EC, 2014). Furthermore, the German government stipulated the very ambitious electric mobility goal of 1 million registered vehicles by the year 2020 (Federal Government, 2009), which has been accompanied by governmental purchase incentives and funding of technology research.

Despite of these efforts on the part of policy-makers and, as a consequence, also vehicle manufacturers, the reluctance of car buyers towards all kinds of AFVs, especially BEVs, remains very high. Consumer demand thus has to increase drastically in the upcoming years to reach the diffusion targets and to meet the requirements of the European clean-air legislation.[3] 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 concerning the importance of specific vehicle attributes, 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, in order to accelerate the adoption of AFVs in the future by specifically customizing their products or incentive schemes subject to the differences in preferences between consumer segments.

The aim of this paper is to study the heterogeneity of car buyers' preferences, i.e. to determine the amount that different groups of vehicle buyers are willing to forfeit for improving important vehicle characteristics and how and why the sum differs between the groups. For this reason, two welfare measures are calculated: The willingness-to-pay (WTP) and the compensating variation (CV), which explicitly takes 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 to assess the potential of a cost-effective provision or the need for governmental action. Finally, the characteristics of the potential car buyers that are open for all kinds of AFVs are determined.

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. To take the preference heterogeneity in the population into account, we apply a latent class model (LCM), which allows for taste differences between consumer groups, in addition to a standard multinomial logit model (MNL).

Our research builds on a comprehensive body of stated preferences DCE literature on the demand for AFVs (see Table A1 in the appendix for on overview of selected studies). Especially the works of Abdoolakhan (2010), Hidrue et al. (2011), Beck et al. (2013), and Parsons et al. (2014), which to the best of our knowledge are the only ones so far applying an LCM approach, are closely related to our work. Furthermore, our study is linked to the research of Daziano (2013) who calculated the WTP and CV of Californian car buyers for driving range improvements of BEVs. Finally, the studies by Eggers and Eggers (2011), Achtnicht (2012), Achtnicht et al. (2012), Ziegler (2012), Daziano and Achtnicht (2013), and Hackbarth and Madlener (2013) ought to be mentioned as they also focus on the case of Germany, covering the following topics: (1) the differences in the WTP for CO_2 emission mitigation between groups of potential car buyers (Achtnicht, 2012; Hackbarth and Madlener, 2013); (2) the influence of fuel availability, especially for BEVs and FCEVs, on vehicles' market shares (Achtnicht et al., 2012; Daziano and Achtnicht, 2013; Hackbarth and Madlener, 2013); (3) the impact of car buyers' socio-demographic characteristics on their potential demand for AFVs (Achtnicht et al., 2012; Ziegler, 2012; Hackbarth and Madlener, 2013); and (4) the prediction of the adoption and diffusion of AFVs under various monetary and non-monetary attribute improvement scenarios in a dynamic (Eggers and Eggers, 2011) and static analysis (Hackbarth and Madlener, 2013).

Our research, however, differs to these studies also focusing on Germany at least in three 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, a specification of the size of these consumer groups, and their detailed description by socio-demographic characteristics and attitudes. Secondly, 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 and applied by several authors (see Table A1), we consider the effect of decreasing marginal utilities of attribute improvements, which is a more realistic representation of human behavior, and assess this non-linear consumer valuation for driving range, fuel availability, recharging time, and CO_2 emissions.[4]

The remainder of this paper is organized as follows: Section 2 describes the survey generation and the data gathered. In Section 3, the methodological approach is introduced. Empirical results are reported in Section 4 and discussed in Section 5. Section 6 concludes.

2. 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 the probability-based online panel of the Dialego AG, and comprise persons who provided their intention to purchase a new car within the next year or such that made an actual vehicle purchase in the last 12 months. 711 respondents completed the web-based survey.

[3] For instance, today, only a small fraction of the postulated electric mobility goal is accomplished – 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 very modest market penetration.

[4] Eggers and Eggers (2011) and Achtnicht et al. (2012) also accounted for the non-linear impact of driving range and fuel station density, respectively.

A comparison of our sample with the German population statistics depicted in Table 1 shows many similarities, but also some minor differences.

For instance, our sample slightly over-represents younger and higher educated individuals with high income, who live in multi-person households, own a car, reside 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 remembered when interpreting the results.[5]

The stated preferences DCE included seven different vehicle types, six AFVs (NGVs, HEVs, PHEVs, BEVs, BVs, and FCEVs) and conventional fuel vehicles (CFVs), to cover all currently or 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 (see Table 2).

In order to increase the 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; (2) a single fuel cost unit (€/100 km) was used for the different vehicle alternatives to increase their commensurability; (3) a fixed car segment-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 PHEVs; (7) currently available governmental incentives were taken into account, i.e. a motor vehicle tax exemption for BEVs, the permission for bus lane usage, and special parking areas for BEVs and PHEVs (BMF, 2012; Federal Government, 2014); and (8) respondents had to choose from only four out of the seven different vehicle alternatives in every choice task.[6]

In the final, completely randomized fractional factorial design, which was generated using the *Sawtooth* software, each respondent had to complete 15 separate choice tasks (Table A2 in the appendix gives an example of a choice card), 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.

3. Methodological approach and model specification

Our empirical analysis of the stated preference DCE data is based on two model specifications: A standard MNL and an LCM, the latter of which remedies the known shortcomings of the former, as it is able to account for preference heterogeneity of decision-makers by assuming that the population is composed of a finite number of different segments or classes in the population, to partly overcome the restrictive independence of irrelevant alternatives assumption, and to handle correlations of repeated choices of a single respondent (Swait, 2007). Furthermore, recent studies have concluded that LCMs also seem to be advantageous over mixed logit models (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).

3.1. Latent class model

Drawing directly from Swait (1994, 2007), Boxall and Adamowicz (2002), Greene and Hensher (2003), Bujosa et al. (2010), and Hess et al. (2011), the main assumption in the LCM framework is the existence of S segments or classes in the population, where the individuals within each group are characterized by homogeneous utility functions, while the preferences can differ between classes. The utility functions of the respondents are only partially known to the researcher, while their true class membership is even unobservable. 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 class and (2) a class membership model which allocates the decision-makers to the S classes, e.g. based on their socio-demographic or attitudinal characteristics.

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) that yields the highest level of utility in choice situation t. The utility function U_{njt} is then assumed to be given by

$$U_{njt} = V_{njt} + \varepsilon_{njt}, \quad (1)$$

[5] In the fuel type choice literature, younger (e.g. Ewing and Sarigöllü, 1998; Potoglou and Kanaroglou, 2007; Hidrue et al., 2011; Achtnicht et al., 2012; Ziegler, 2012; Li et al., 2013; Hackbarth and Madlener, 2013; Shin et al., 2015) and better educated individuals (e.g. Potoglou and Kanaroglou, 2007; Hidrue et al., 2011; Hackbarth and Madlener, 2013; Li et al., 2013) with higher income (e.g. Potoglou and Kanaroglou, 2007; Caulfield et al., 2010; Musti and Kockelman, 2011; Link et al., 2012), living in larger households (e.g. Knockaert, 2010; Musti and Kockelman, 2011), and owning a smaller number of vehicles (e.g. Ewing and Sarigöllü, 1998; Batley et al., 2004; Musti and Kockelman, 2011), are found to be more likely to choose AFVs instead of conventional vehicles. Thus, compared to the entire German population (which is used for comparison since detailed official data on buyers of new vehicles is unavailable) our sample presumably slightly overestimates the share of potential buyers of alternatively fueled vehicles.

[6] Note that, similarly to the studies summarized in Table A1, the goal of our study is to analyze the choice of the newest household vehicle and not to model the choice and composition of the entire household vehicle fleet (i.e. consecutive choices of the first, second, third, etc. household vehicle under consideration of the respective budget constraint). An example for the application of the latter approach can be found in Ahn et al. (2008).

Table 1
Household and vehicle characteristics of the sample vs. the German population. *Source:* Own calculations; German population shares computed on the basis of Infas/DLR (2010), BBSR (2012), DAT (2012), KBA (2012), and Destatis (2012a, 2012b).

Variable	Value	Sample (%)	Population (%)
Household characteristics			
Gender	Female	50.4	50.9
	Male	49.6	49.1
Age	18–44 years	57.8	41.1
	45–64 years	38.0	34.3
	65 years 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 €2000	17.9	49.5
	€2000–5999	60.4	40.3
	€6000 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 or more	21.4	12.9
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 or more	6.7	5.0
Vehicle characteristics			
Vehicle purchase	Vehicle purchase in past 12 months	47.3	–
	Vehicle purchase planned within next 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
	€20,000–40,000	35.7	51.0
	€40,000 or more	9.0	15.0
Vehicle segment	Mini and small cars	23.3	26.5
	Medium and large cars	48.6	45.5
	Executive and luxury cars	8.0	6.0
	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
	10,000–20,000 km	41.9	41.4
	20,000 km or more	27.3	21.9

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

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, and β_s', a class-specific vector of parameters – and ε_{njt} is the unobserved, random portion of utility. Assuming, firstly, a distribution of the error terms which leads to the standard MNL, secondly, class membership of each decision-maker as being given, and thirdly, independence of the t consecutive choice situations decision-makers are facing,[7] we can express the joint probability of the observed sequence of choices of decision-maker n belonging to class s as

$$P_{nj|s} = \prod_{t=1}^{T} \frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})}. \tag{2}$$

Turning to the class membership model, and assuming that it is also specified as a standard MNL, the probability that decision-maker n belongs to class s is

$$H_{ns} = \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)}, \tag{3}$$

with observable characteristics of the decision-maker Z_n, and the class-specific parameter vector θ_s'.

The unconditional probability or likelihood that a randomly chosen decision-maker n selects a sequence of alternatives $j = (j_1, \ldots, j_T)$ is then obtained by multiplying Eqs. (2) and (3), which yields

$$P_{nj} = \sum_{s=1}^{S} H_{ns} P_{nj|s} = \sum_{s=1}^{S} \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)} \prod_{t=1}^{T} \frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})}. \tag{4}$$

The true number of consumer segments is also unknown and has to be specified by the analyst *a priori.* 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).[8]

Our analysis further comprises the calculation of two welfare measures, which monetize car buyers' appreciation for improvements of the different vehicle attributes, enabling us to make profound policy recommendations: the WTP and the CV.

3.2. Willingness-to-pay

Following Louviere et al. (2000), Train (2003), and Daziano (2013), the WTP indicates the monetary amount that an individual is willing to disburse to acquire benefits or prevent costs from specific (policy) actions leaving the level of utility unchanged. In our linear model specification, the WTP is derived from the ratio of a vehicle attribute's (class-specific) coefficient 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 (weighted by class membership H_{ns}[9]):

$$WTP_n = \sum_{s=1}^{S} H_{ns} \left(-\frac{\beta_X}{\beta_C} \right). \tag{5}$$

The WTP of the logarithmically transformed attributes has to consider their non-linear influence on utility, and thus has to take into account the base level x of the attribute, from which the action starts out, i.e.

$$WTP_n = \sum_{s=1}^{S} H_{ns} \left(-\frac{\beta_{\ln(X)}}{\beta_C} \frac{1}{x} \right). \tag{6}$$

However, although the WTP measures the economic welfare and reveals the accepted maximum additional cost for technical progress, it also suffers from drawbacks. WTP values are calculated under the *ceteris paribus* assumption and do not account for the choice probabilities of the different alternatives before and after the improvement. Therefore, more revealing for policy-makers and car manufacturers is the CV, 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 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.

[7] See Hess et al. (2011, p. 3): "In the case of multiple choices for each respondent, the assumption is generally made that the tastes vary across respondents but not across choices for the same respondent (cf. Revelt and Train, 1998 and see Hess and Rose, 2009 for a recent discussion of this issue), and the probability of the observed sequence of choices is used in the maximisation of the log-likelihood."

[8] 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, although also non-statistical reasons (e.g. behavioral interpretability) should guide the decision.

[9] The probability of individual n's membership in class s, H_{ns}, equals unity if the individual is assigned to a specific class with certainty.

3.3. Compensating variation

Drawing directly from Small and Rosen (1981), Louviere et al. (2000), Boxall and Adamowicz (2002), Train (2003), Lancsar and Savage (2004), and de Jong et al. (2007), the CV, also known as expected change in consumer surplus, indicates the change in a monetary measure needed to compensate changes in utility after the change in an attribute's level occurred, leaving individuals equally well off. Hence, for an improvement of vehicle attributes the CV is the monetary amount (i.e. purchase price surcharge or increase in fuel costs) car buyers are willing to forfeit to retain the improvement. In a logit model with linear-in-utility and constant monetary attributes, the CV for a representative individual *n* facing *J* choice alternatives 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 (β_C), and weighted by class membership probabilities (H_{ns}) if class assignment is uncertain:

$$CV_n = \sum_{s=1}^{S} H_{ns}\left(-\frac{1}{\beta_C}\left[ln\left(\sum_{j=1}^{J}\exp(V_{nj}^1)\right) - ln\left(\sum_{j=1}^{J}\exp(V_{nj}^0)\right)\right]\right). \tag{7}$$

4. Empirical results

4.1. Discrete choice models

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. Vehicles' CO_2 emissions, driving range, fuel availability, and recharging time were logarithmically transformed to account for their non-linear impact on utility.[10]

Vehicle segments were primarily ordered by purchase price and secondarily by size, leading to the following ascending order: Mini/small cars, medium cars, large cars, multi-purpose cars/SUVs, executive cars, luxury cars, and sports cars. Technophilia was measured with respondents' level of agreement (5-level Likert scale) to the following statement: 'I like to engage myself with the way new technologies function'. Environmental awareness was determined with a scale developed by Preisendörfer (1999), which assesses environmental consciousness by adding up the degree of agreement (5-level Likert scale) to 9 questions. 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 instead of a replacement.

The LCM was estimated over 2–7 classes. 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 in favor of the LCM with 6 classes as the best model to portray population heterogeneity, since the LCM with 7 classes led to a very small segment with a selection probability of below 1%, and thus did not add to the explanatory power of the model.

The 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. Furthermore, it can be seen that all ASCs are negative, i.e. CFVs are highly preferred to all AFVs *ceteris paribus*.

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.[11] As can be seen in Table 5, some of the coefficients vary considerably between the 6 different groups, as do the number and structure of attributes that significantly influence vehicle choice. 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 classes.

To ensure model identification, the coefficients of one class have to be normalized to zero – in our case class 6 – and the class-assignment parameters of all other consumer segments have to be interpreted in relation to that base group.

The base group consists of car buyers having 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, and 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

[10] 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. A likelihood ratio test illustrated that the stepwise specification (part-worth utilities) of the vehicle attributes is not a statistically significant improvement over their logarithmic specification ($-2(LL_{Pw} - LL_{Log}) = 49.36 < \chi^2_{\alpha=0.95}(36) = 50.99$), whereas the latter is advantageous regarding model parsimony. Moreover, besides the ultimately selected logarithmic transformation, also other functional forms were tested, e.g. quadratic, square root, and inverse functions. However, compared to the logarithmic transformation they did not only perform poorer statistically regarding log likelihood but also visually in reproducing the distribution of the significant part-worths.

[11] McFadden's ρ^2 and the LL values reported in Table 4 indicate that in general the 6-class LCM greatly and statistically significantly outperforms the MNL specification.

Table 3
Variables used in the model.

Variable	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 and bus lane access) is granted, 0 otherwise
Vehicle segment	Respondents' favorite vehicle segment ordered by purchase price and size (7 categories)
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	Respondents' age in years
Daily mileage	Respondents' daily mileage (5 categories)
Educational level	Respondents' educational level (6 categories)
Additional vehicle	1 if vehicle is an additional one, 0 otherwise

Table 4
Class selection criteria.

	No. of classes						
	1 (MNL)	2	3	4	5	6	7
LL	−12,874.3	−12,322.9	−11,879.0	−11,579.1	−11,344.1	−11,190.6	−11,121.4
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
ρ^2 (0)	0.380	0.406	0.428	0.442	0.453	0.461	0.464
ρ^2 (c)	0.091	0.130	0.162	0.183	0.199	0.210	0.215
No. of parameters	15	38	61	84	107	130	153

process of this consumer group, although they enter the utility function significantly. Thus, individuals in class 6 can be labeled 'AFV aficionados'.

In class 1, in contrast, 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. Purchase price, fuel cost, and the two governmental incentives only have a medium influence on vehicle choice, compared to other consumer segments, while refueling time and most ASCs (except NGV, BV) are found to be insignificant. Compared to the base group, individuals in this class are more likely to be older, less environmentally aware, and higher educated buyers of larger/more expensive cars with less technical interest. Their high daily mileage, a feature that is comparable to the base group, seems to mainly drive the vehicle choice decisions and the pronounced valuation of the three mobility attributes, so that this group can be labeled 'car dependents'.

Consumers in class 2 appraise fuel costs as more important than members of any other group. Purchase price and CO_2 emissions, driving range, and the non-monetary governmental incentive exert a great influence on vehicle choice, too. In contrast, refueling and charging time, as well as all ASCs, do not seem to have much impact on the decision process. Compared to the base group, the members of this class are more likely to be older, less environmentally aware, but technically more interested buyers of larger/more expensive cars with lower daily mileage. Thus, although individuals in this group drive less than the base group, their purchase decisions are strongly influenced by mobility attributes, especially fuel costs, so that they could be best described as 'fuel cost savers'. A possible explanation for this finding could be that vehicle purchase decisions of members of this group are subject to budget constraints, which are not captured by our model.

In class 3, decisions are mainly based on the availability of both governmental incentives and the large and negatively signed ASCs, 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 class 3 are the only ones who consider refueling time in their vehicle choice decisions. Since they are more likely to be older and less environmentally aware buyers of larger/more expensive cars who have a smaller daily mileage than members of the base group, the strong reluctance towards all kinds of AFVs in this group is reasonable, and their members can be dubbed 'CFV buyers'.

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: Incentive 1 = no vehicle tax; incentive 2 = free parking and bus lane access.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Car buyers in class 4 show the largest or second-largest negative parameter values for almost all ASCs, except for HEVs and PHEVs. The latter are *ceteris paribus* even more preferred than CFVs by individuals in this group. Vehicle emissions and fuel availability are also quite 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 and recharging and refueling time do not enter the utility function significantly. Thus, although individuals in this group are comparable to members of the remaining non-base classes in being older and planning to buy a larger/more expensive car, they are the only ones besides car buyers of the base group who at least rate one AFV positively. However, they are also equally environmentally aware and, even more important, more technophile than the reference group, which could be an explanation for being such ‘PHEV enthusiasts’.

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. Individuals in this consumer segment are more likely to be older, less environmentally aware, and higher educated drivers with lower daily mileage than the base group, but, on the other hand, planning to buy an additional and larger/more expensive car for their household, which would explain why mobility cost attributes, such as the vehicles’ purchase price, dominate their vehicle choice decision. Thus, this consumer segment could be termed ‘purchase price sensitives’.

To summarize, we find that individuals who at a first glance share many socio-demographic characteristics do behave quite differently: (1) attributes that are important in one class are irrelevant in another class, e.g. purchase price and fuel cost are relatively unimportant for those individuals who prefer AFVs (class 6), while two of the groups consist of individuals for whom monetary attributes are the most decisive factors in vehicle choice (classes 2 and 5), and some consumers even leave most attributes aside (class 3); (2) incentives have a large impact on vehicle choice; (3) on average, AFVs are disliked in the population (as can be seen in the MNL), but two market segments exist who favor at least some AFVs (PHEVs, BEVs, BVs, and FCEVs in class 6; PHEVs in class 4), all else equal; and (4) ‘AFV aficionados’ are more likely to be composed of younger, more environmentally aware, and slightly less educated buyers of smaller/cheaper cars, having a high daily mileage and a moderate technical interest.

4.2. Willingness-to-pay

Based on the estimation results depicted in Table 4, consumers' marginal WTP expressed as the increased purchase price individuals are willing to spend for improvements of the most important vehicle characteristics is calculated using Eqs. (5) and (6), and shown in Table 6 (the WTP for marginal changes in the attribute levels expressed as additional fuel cost per 100 km is shown in Table A3 in the appendix).

As can easily be seen from the LCM results, the WTP values conditional on class membership (columns 3–8) differ significantly across consumer segments and vehicle attributes. This finding is supported, firstly, by the marked variation (standard deviation) around the unconditional mean WTP of the sample, which in turn is gained by weighting the class-specific WTP values by the class membership probabilities for each individual.[12] Secondly, it is supported by the specific class and respective class membership probability of the decile of individuals with the highest WTP (last column). The latter confirms the particularly pronounced importance of vehicles' fuel costs in class 2, tax incentives, and vehicles' CO_2 emissions in class 6, non-monetary incentives in class 3, and flexibility of vehicle utilization enhancing attributes in class 1. Furthermore, the WTP values calculated with MNL coefficients are lower than the probability-weighted average WTP values of the LCM. For the non-monetary incentive the WTP 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 driving range, service station density, and battery recharging time not only differs between consumer groups but, due to its logarithmic shape, also depending on the value set as a base for the improvement, reflecting a different valuation of e.g. the last percent of CO_2 mitigations (resulting in a zero emission vehicle) and the first percent of emission reduction measures in the *status quo*. Finally, it can be observed that for the improvement of vehicles' driving range and fuel availability car buyers in class 1 are even willing to spend a larger extra amount for the further improvement of vehicles' long driving ranges and the last percent of fuel availability than respondents in other consumer segments for extensions of short ranges (class 5) and the first percent of additional fuel availability (classes 2 and 5), respectively.

On average, individuals are willing to spend €1056 for a fuel cost reduction of €1/100 km, €7175 and €5925 for a vehicle tax exemption and the permission to use bus lanes and park free of charge, respectively, between €14 and €1432 for the abatement of one percent of vehicles' CO_2 emissions,[13] €12–125 for an additional kilometer of driving range, €60–296 for increasing fuel availability by one percent, and between €5 and €194 for a one minute foreshortening of the battery recharging process.

Although our WTP estimates are apparently at the top end for some vehicle attributes, they are broadly in line with the wide bandwidth of results reported in previous studies, which are selectively summarized in the following. For instance, Jensen et al. (2013), Batley et al. (2004), and Hackbarth and Madlener (2013) report a WTP[14] of €79–200, €538, and €530–1070, respectively, for fuel cost savings of €1/100 km. Hoen and Koetse (2014), Potoglou and Kanaroglou (2007), and Hackbarth and Madlener (2013) reveal a WTP of €1670, €1600–3790, and €2330–4700, respectively, for all kinds of vehicle tax exemptions. Hoen and Koetse (2014), Horne et al. (2005), Daziano and Bolduc (2013), and Hess et al. (2012) find a WTP of €553, €1350, €1436, and €515–2233 for express/bus lane access, while Hoen and Koetse (2014) and Hess et al. (2012) report a WTP of €377 and €394–1415, respectively, for the possibility to park free of charge. Tanaka et al. (2014) and Hackbarth and Madlener (2013) state a WTP of €5–65 and €20–90, respectively, for the abatement of 1% of vehicle CO_2 emissions, while Mabit and Fosgerau (2011) report a WTP of €4230–5700 for halving the vehicle pollution, and Hidrue et al. (2011) find a WTP of €3310 for a pollution reduction of 95%. Concerning a kilometer of additional driving range, Hoen and Koetse (2014), Parsons et al. (2014), Hackbarth and Madlener (2013), and Jensen et al. (2013) state a WTP of €8–33, €16–34, €19–52, and €3–134, respectively, while Hess et al. (2012) and Daziano (2013) find a WTP of €12–43 (at 215 km) and €20 (at 400 km) to €105 (at 80 km), respectively. Regarding a 1% expansion of the refueling infrastructure, Tanaka et al. (2014), Hackbarth and Madlener (2013), Daziano and Bolduc (2013), and Achtnicht et al. (2012) state a WTP of €10–21, €45–92, €126, and €70–820, respectively. Hackbarth and Madlener (2013) and Hoen and Koetse (2014) find a WTP of €5–18 and €24–182, respectively, for every saved minute in battery recharging time of BEVs, while Hidrue et al. (2011) and Ito et al. (2013) report a WTP of €1630 (10 h to 5 h) to €6510 (10 h to 5 min) and €6110 (8 h to 5 min), respectively.

The decreasing marginal utilities of non-linear attribute improvements are additionally illustrated in Fig. 1 for the statistically significant WTP values expressed as purchase price surcharge (Fig. A1 in the appendix shows these changes expressed as additional fuel cost per 100 km). As can be seen, consumers do have some minimum requirements, which have to be met so that they are willing to pay money for improvements of vehicle attributes.

For example, the WTP for a reduction of vehicles' CO_2 emissions by 1% starts to accelerate when they are about to drop below 10–15% of a current average car's emissions. Comparably, the WTP for shortening the charging process increases

[12] In our model, the individual probabilities of belonging to a specific class range from 0 to 1. Each respondent can be allocated to a specific class with a probability of at a minimum 0.45, with 68.8% of the individuals being assigned to a specific class with a probability of at least 0.9, and 44.3% of our sample belonging to a specific class with a probability of at a minimum 0.99.

[13] The WTP values for improvements of vehicles' CO_2 emissions 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, small attribute levels automatically lead to very high WTP values, approaching infinity when moving the attribute levels infinitesimally close towards zero.

[14] Currency conversions are based on the following exchange rates: £1 = €1.23, $1 = €0.76 (for Canadian and US dollars), and ¥1 = €0.009. The conversion factor of miles to kilometers is 1.609344.

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

	MNL	LCM						Mean	Std. dev.	$Prob_{WTP>0.9}$
		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	1055.74	686.80	0.9938 (Class 2)
Incentive 1 (No vehicle tax)	4058.70	6749.78	3171.83	17,309.00	105.63†	1046.17	17,712.21	7175.20	6414.98	0.9972 (Class 6)
Incentive 2 (Free parking and bus lane access)	2811.24	4432.38	2815.96	14,147.83	7074.97†	283.44†	13,410.50	5924.88	4963.02	0.8797 (Class 3)
CO_2 emissions abatement by 1%										0.9982 (Class 6)
At 100%	9.43	15.24	8.14	−6.61†	32.51	1.67	51.98	14.32	17.66	
At 50%	18.86	30.49	16.28	−13.22†	65.02	3.33	103.96	28.64	35.31	
At 1%	942.95	1524.39	814.06	−660.93†	3250.84	166.53	5197.90	1432.20	1765.50	
Driving range increase by 1 km										0.9757 (Class 1)
At 100 km	95.25	346.13	94.04	150.28	97.39†	18.18	88.59	124.77	98.22	
At 500 km	19.05	69.23	18.81	30.06	19.48†	3.64	17.72	24.95	19.64	
At 1000 km	9.53	34.61	9.40	15.03	9.74†	1.82	8.86	12.48	9.82	
Fuel availability increase by 1%										0.9651 (Class 1)
At 20%	212.48	960.60	85.97	75.79†	646.60	35.12	249.26	296.09	308.81	
At 60%	70.83	320.20	28.66	25.26†	215.53	11.71	83.09	98.70	102.94	
At 99%	42.93	194.06	17.37	15.31†	130.63	7.09	50.36	59.82	62.39	
Battery recharging time reduction by 1 min										0.9615 (Class 1)
At 6 h	3.49	10.40	1.83†	8.34†	3.55†	1.27	9.21	5.39	3.50	
At 1 h	20.93	62.40	11.01†	50.05†	21.30†	7.64	55.26	32.31	21.01	
At 10 min	125.60	374.39	66.06†	300.29†	127.80†	45.81	331.54	193.85	126.04	

† Indicates WTP values based on insignificant attribute coefficients.

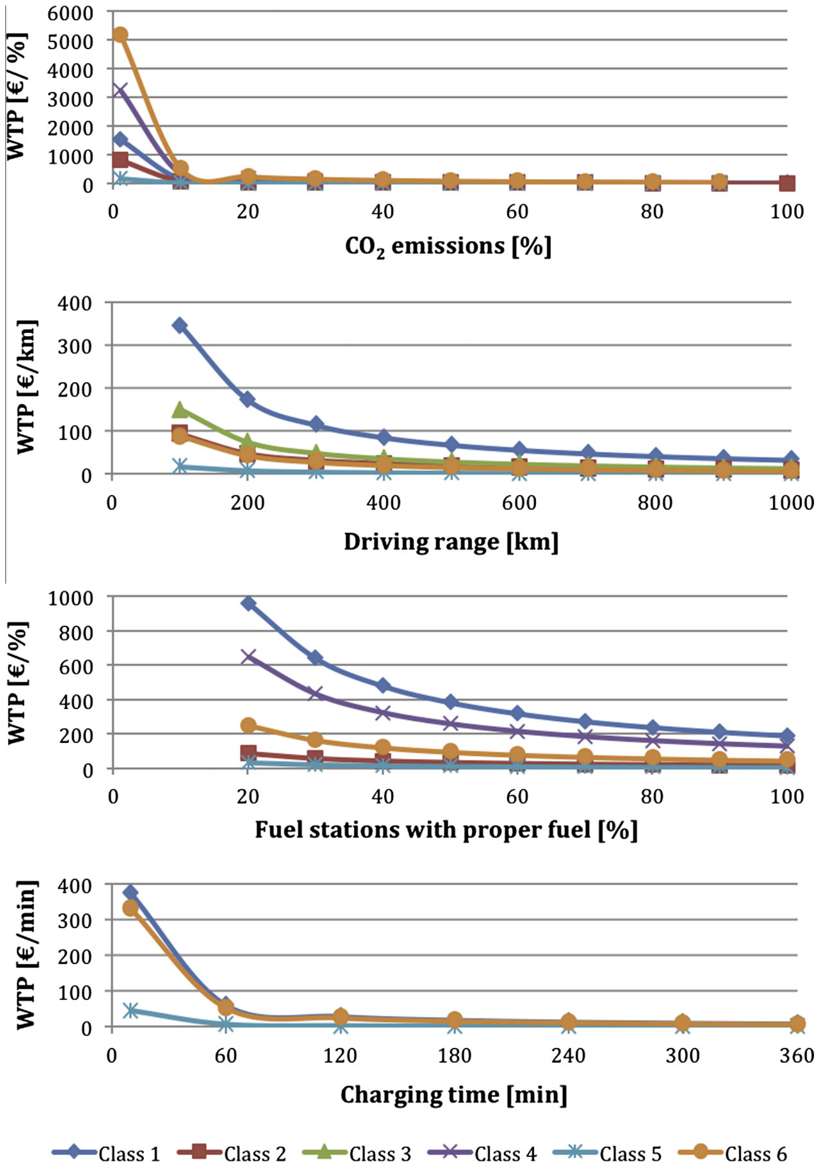

Fig. 1. Marginal WTP for changes in vehicle attributes (in € of purchase price surcharge).

sharply when the charging time undercuts the 30 min 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 in some cases marked differences in the WTP across consumer groups are also eye-catching, e.g. the high importance of vehicle attributes that enable and simplify long trips (driving range, fuel station density, and recharging time) in class 1, or the high valuation of substantial emission mitigation measures and fast-charging in class 6.

Summarizing the results obtained so far, we find that on average 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 exists about which particular vehicle option is chosen, which usually is not the case in DCEs, or if, all else being equal, every vehicle alternative undergoes the exactly same attribute improvement, which is very unrealistic in the case of highly heterogeneous vehicle alternatives (Louviere et al., 2000; Train, 2003). 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 (i.e. a BEV). This, however, would currently almost never happen (choice probability of 0.5%). The second interpretation of the WTP values is problematic, too, as we deal with very dissimilar choice alternatives regarding their current attribute levels, which can also be seen in the German *status quo* figures (Table 8). Furthermore, car buyers are usually not willing to pay for an attribute improvement of a vehicle 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 she willing to forfeit money for them.

4.3. Compensating variation

In the following, the expected CV for several non-marginal attribute improvement scenarios is calculated for the specific vehicle alternatives, taking the considerable choice probability differences in the six distinct consumer groups into account. This measure is thus explicitly useful for policy-makers and car manufacturers to assess the economic viability of different potential actions. Individuals' class-specific, i.e. conditional on their assignment to a particular consumer segment, and unconditional, i.e. sample mean and standard deviation, CV is computed for manifold fuel-specific policy scenarios, based on the estimation results in Table 4 and the *status quo* on the German vehicle market. The respective policy scenarios comprise non-marginal improvements of the individual vehicle attributes and further include four multi-attribute enhancement programs, such as a governmental incentive package or the availability of area-wide fast-charging. The underlying base scenario depicted in Table 7 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 shows that the conditional and unconditional choice probabilities of the different vehicle alternatives vary considerably between consumer segments in the base scenario.

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 likely chosen option on average and in classes 1, 3 and 5, it is NGVs in class 2, PHEVs in class 4, and BEVs in class 6. However, despite this particular appreciation of BEVs in class 6, it can be stated that BEVs, BVs, and especially FCEVs, are the vehicle alternatives disliked most in the population. Interestingly, in class 4 NGVs are as much rejected as these three alternatives, as are PHEVs in classes 1, 3, and 5. However, they can gain a market share of more than 10% in the other three classes, with a maximum of 42.6% in class 4, and on average are the third-most preferred AFV (after HEVs and NGVs).

As already observed for the WTP, the results in Tables 9 and 10 show that also the conditional and unconditional CV values significantly vary across the consumer segments and attributes, but now are additionally dependent on the vehicle alternative for which the attribute improvement is established (i.e. generally a very large standard deviation of the mean CV for attribute improvements, especially in the case of BEVs, can be observed). Again, the values calculated from MNL coefficients are lower than the probability-weighted average CV values of the LCM, although not consistently. Furthermore, comparable to the WTP results, the class membership of those individuals with the greatest CV varies depending on the respective policy scenario, thus indicating the existing heterogeneity in the population regarding the importance of the different vehicle attributes.

Starting with the CV expressed as a purchase price surcharge car buyers would have to pay extra to secure their gain in utility, it can be seen in Table 9 that fuel cost reductions for biofuels and hydrogen, e.g. due to governmental tax reliefs,

Table 7
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

Notes: Incentive 1 = no vehicle tax; incentive 2 = free parking and bus lane access.

Table 8
Choice probabilities in the base scenario by vehicle type.

	MNL	LCM						Mean	Std. dev.
		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	0.354	0.100
NGV	0.213	0.170	0.282	0.250	0.034	0.265	0.123	0.173	0.043
HEV	0.198	0.336	0.201	0.111	0.234	0.111	0.123	0.283	0.078
PHEV	0.118	0.069	0.134	0.018	0.426	0.034	0.137	0.092	0.063
BEV	0.043	0.005	0.032	0.013	0.029	0.002	0.258	0.038	0.076
BV	0.080	0.013	0.099	0.059	0.038	0.122	0.133	0.039	0.041
FCEV	0.033	0.002	0.040	0.050	0.015	0.004	0.114	0.020	0.034

Table 9
CV for changes in vehicle attributes (in € of purchase price surcharge).

	MNL	LCM						Mean	Std. dev.	$Prob_{CV>0.9}$
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6			
Fuel cost reduction scenario										
BV (€9/100 km → €6.5/100 km)	197.03	37.29	787.81	120.08	149.26	83.85	290.95	235.20	237.55	0.9947 (Class 2)
FCEV (€7.5/100 km → €6.5/100 km)	31.22	2.06	112.34	40.51	23.21	1.08	99.25	42.25	41.79	0.9938 (Class 2)
Incentive 1 (No vehicle tax) scenario										
PHEV	524.66	532.38	473.04	402.06	45.01†	40.49	2751.67	674.31	848.05	0.9986 (Class 6)
BV	360.06	97.64	352.61	1291.02	4.02†	144.00	2665.59	710.49	859.86	0.9986 (Class 6)
FCEV	148.13	13.96	144.49	1108.94	1.60†	4.94	2301.12	539.39	780.28	0.9986 (Class 6)
Incentive 2 (Free parking and bus lane access) scenario										
PHEV	353.08	334.56	414.86	313.66	3131.18†	9.92†	2020.11	735.13	890.09	0.6975 (Class 4)
BEV	129.90	21.98	99.53	232.00	219.39†	0.72†	3752.55	656.36	1246.57	0.9986 (Class 6)
BV	241.97	61.16	309.06	1009.92	287.20†	35.65†	1956.54	538.85	634.82	0.9986 (Class 6)
FCEV	99.37	8.74	126.52	867.00	114.21†	1.21†	1687.68	414.23	571.38	0.9986 (Class 6)
CO_2 emissions abatement scenario										
CFV (100% → 50%)	208.38	433.79	121.45	−227.09†	512.84	53.86	416.54	187.34	215.93	0.6858 (Class 4)
NGV (84% → 50%)	105.03	136.04	120.67	−85.52†	58.85	23.06	338.17	96.79	114.99	0.9986 (Class 6)
HEV (77% → 50%)	81.35	223.31	71.47	−31.70†	331.72	8.02	280.55	119.61	117.38	0.6540 (Class 4)
Driving range increase scenario										
BEV (175 km → 350 km)	336.14	181.70	267.11	161.72	208.68†	3.64	1644.37	373.58	515.83	0.9986 (Class 6)
BEV (175 km → 750 km)	854.49	723.54	756.48	402.63	470.45†	9.34	3596.26	912.29	1102.56	0.9986 (Class 6)
Fuel availability increase scenario										
PHEV (43.3% → 50%)	73.00	202.18	33.38	3.96†	800.45	3.45	98.68	121.23	192.35	0.8118 (Class 4)
BEV (14.1% → 50%)	265.38	185.56	75.03	26.38†	555.12	2.44	1691.64	357.92	553.74	0.9982 (Class 6)
BV (2.3% → 50%)	1450.51	2864.34	635.62	292.70†	2224.73	340.01	2271.03	1283.92	945.58	0.9624 (Class 1)
FCEV (0.2% → 50%)	1452.15	2888.04	556.90	473.34†	2261.34	27.72	3846.49	1460.47	1331.73	0.9982 (Class 6)
NGV (50.9% → 100%)	646.76	2730.67	338.72	259.01†	325.59	131.49	424.23	709.71	827.52	0.9772 (Class 1)
PHEV (43.3% → 100%)	454.51	1518.95	202.25	23.40†	4887.15	21.41	588.41	788.66	1195.64	0.7940 (Class 4)
BEV (14.1% → 100%)	443.24	393.36	121.67	41.44†	938.28	4.04	2673.31	588.84	871.72	0.9982 (Class 6)
BV (2.3% → 100%)	1912.98	4876.05	813.26	363.71†	2984.72	441.42	2852.53	1862.42	1512.14	0.9687 (Class 1)
FCEV (0.2% → 100%)	1777.37	4756.35	658.27	540.54†	2815.68	33.66	4442.26	1959.18	1791.92	0.9610 (Class 1)
Battery recharging time reduction scenario										
PHEV (4 h → 1 h)	213.37	397.42	126.40†	79.95†	761.88†	23.28	650.07	270.89	243.73	0.6114 (Class 4)
BEV (8 h → 1 h)	120.09	41.38	45.90†	91.29†	79.04†	2.64	1854.65	324.47	615.30	0.9986 (Class 6)
PHEV (4 h → 5 min)	640.37	1327.25	373.41†	248.41†	2164.66†	75.73	1925.37	825.38	718.72	0.5977 (Class 4)
BEV (8 h → 5 min)	285.41	110.86	107.41†	223.30†	178.77†	6.81	4278.42	753.19	1417.55	0.9986 (Class 6)
Area-wide fast-charging scenario: fuel availability 100%, battery recharging time 5 min										
PHEV	1204.49	3843.82	613.20	280.66	7307.43	109.34	2628.80	1841.52	1947.02	0.7622 (Class 4)
BEV	871.12	879.21	260.15	283.91	1223.68	13.85	7460.98	1505.77	2418.08	0.9986 (Class 6)
Governmental incentive scenario: purchase price subsidy €5000 (PHEV, BEV, FCEV), fuel costs €6.5/100 km (BV, FCEV), incentives 1 and 2										
PHEV	1840.56	1531.56	2144.07	1135.75	5538.94	519.66	6404.80	2367.89	2001.19	0.9966 (Class 6)
BEV	410.35	51.89	337.71	338.29	392.79	28.10	5308.38	980.50	1743.19	0.9986 (Class 6)
BV	924.24	235.16	1909.66	3133.80	462.12	302.46	5606.05	1786.61	1772.14	0.9986 (Class 6)
FCEV	588.68	44.86	936.55	3181.49	235.87	72.79	5546.47	1504.93	1864.14	0.9986 (Class 6)
NGV support scenario: purchase price €21,800, CO_2 emissions 50%, fuel availability 100%										
NGV	1296.65	3501.36	1152.43	716.78	483.92	906.23	1065.09	1377.84	877.01	0.9786 (Class 1)
Massive multi-measure support scenario: purchase price €21,800, fuel costs €6.5/100 km (BV, FCEV), driving range 750 km, fuel availability 100%, battery recharging time 5 min, incentives 1 and 2										
PHEV	4826.88	9211.86	4584.80	2136.84	15,695.25	2231.70	11,590.46	6375.55	4130.78	0.6929 (Class 4)
BEV	6737.93	12,498.10	5912.24	2629.47	3858.17	2048.96	24,995.24	8372.09	7347.25	0.9986 (Class 6)
BV	4062.02	8472.71	4051.56	4160.44	4215.03	1359.96	10,338.20	5091.18	2921.49	0.9984 (Class 6)
FCEV	5476.77	11,043.88	4537.90	5836.47	4490.50	1484.79	14,885.15	6629.36	4300.03	0.9984 (Class 6)

† Indicates CV value based on insignificant attribute coefficient.

leading to competitiveness regarding operating costs with currently already fuel tax-advantaged NGVs, are not valued highly (up to €790 for a reduction in fuel costs to €6.5/100 km for BVs, class 2).

In contrast, governmental granting of monetary and non-monetary incentives is much more appreciated by German car buyers, i.e. especially consumers in class 6 are willing to forfeit more than €2750 for a vehicle tax exemption (PHEVs), and more than €3750 for the permission to use bus lanes and to park free of charge (BEVs). 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 is highest for CFVs in class 4, amounting to around €513.

Table 10
CV for changes in vehicle attributes (in €/100 km of fuel cost increase).

	MNL	LCM						Mean	Std. dev.	$Prob_{CV>0.9}$
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6			
Purchase price reduction scenario										
BEV (€36,800 → €30,000)	0.376	0.032	0.111	0.126	0.139	0.182	2.114	0.438	0.689	0.9987 (Class 6)
FCEV (€33,800 → €30,000)	0.149	0.007	0.070	0.254	0.039	0.105	0.515	0.160	0.160	0.9987 (Class 6)
NGV (€23,900 → €21,800)	0.503	0.330	0.249	0.677	0.048	2.657	0.303	0.838	0.861	0.9908 (Class 5)
HEV (€26,700 → €21,800)	1.160	1.573	0.454	0.732	0.783	3.824	0.722	1.513	1.131	0.9906 (Class 5)
PHEV (€30,200 → €21,800)	1.296	0.612	0.593	0.216	2.469	3.654	1.412	1.503	1.136	0.9889 (Class 5)
BEV (€36,800 → €21,800)	1.029	0.083	0.347	0.314	0.331	1.795	4.900	1.336	1.568	0.9987 (Class 6)
BV (€22,900 → €21,800)	0.098	0.013	0.045	0.083	0.028	0.596	0.170	0.182	0.198	0.9884 (Class 5)
FCEV (€33,800 → €21,800)	0.583	0.025	0.309	0.899	0.134	1.347	1.728	0.774	0.583	0.9985 (Class 6)
Incentive 1 (No vehicle tax) scenario										
PHEV	0.566	0.476	0.187	0.506	0.030†	0.158	3.182	0.750	1.004	0.9987 (Class 6)
BV	0.389	0.087	0.139	1.626	0.003†	0.563	3.082	0.889	1.011	0.9987 (Class 6)
FCEV	0.160	0.012	0.057	1.397	0.001†	0.019	2.661	0.709	0.832	0.9983 (Class 6)
Incentive 2 (Free parking and bus lane access) scenario										
PHEV	0.381	0.299	0.164	0.395	2.064†	0.039†	2.336	0.709	0.832	0.9983 (Class 6)
BEV	0.140	0.020	0.039	0.292	0.145†	0.003†	4.339	0.764	1.468	0.9987 (Class 6)
BV	0.261	0.055	0.122	1.272	0.189†	0.139†	2.262	0.623	0.763	0.9987 (Class 6)
FCEV	0.107	0.008	0.050	1.092	0.075†	0.005†	1.952	0.485	0.686	0.9987 (Class 6)
CO_2 emissions abatement scenario										
CFV (100% → 50%)	0.225	0.388	0.048	−0.286†	0.338	0.211	0.482	0.198	0.221	0.9986 (Class 6)
NGV (84% → 50%)	0.113	0.122	0.048	−0.108†	0.039	0.090	0.391	0.104	0.133	0.9988 (Class 6)
HEV (77% → 50%)	0.088	0.200	0.028	−0.040†	0.219	0.031	0.324	0.117	0.116	0.9987 (Class 6)
Driving range increase scenario										
BEV (175 km → 350 km)	0.363	0.163	0.106	0.204	0.138†	0.014	1.901	0.402	0.616	0.9987 (Class 6)
BEV (175 km → 750 km)	0.922	0.648	0.299	0.507	0.310†	0.037	4.159	0.961	1.320	0.9987 (Class 6)
Fuel availability increase scenario										
PHEV (43.3% → 50%)	0.079	0.181	0.013	0.005†	0.528	0.014	0.114	0.106	0.134	0.8118 (Class 4)
BEV (14.1% → 50%)	0.286	0.166	0.030	0.033†	0.366	0.010	1.956	0.391	0.649	0.9987 (Class 6)
BV (2.3% → 50%)	1.565	2.564	0.251	0.369†	1.467	1.330	2.626	1.438	0.868	0.9986 (Class 6)
FCEV (0.2% → 50%)	1.567	2.585	0.220	0.596†	1.491	0.108	4.448	1.498	1.450	0.9987 (Class 6)
NGV (50.9% → 100%)	0.698	2.444	0.134	0.326†	0.215	0.514	0.491	0.757	0.739	0.9809 (Class 1)
PHEV (43.3% → 100%)	0.490	1.359	0.080	0.029†	3.222	0.084	0.680	0.692	0.845	0.8102 (Class 4)
BEV (14.1% → 100%)	0.478	0.352	0.048	0.052†	0.619	0.016	3.091	0.640	1.020	0.9987 (Class 6)
BV (2.3% → 100%)	2.064	4.364	0.322	0.458†	1.968	1.726	3.299	2.053	1.344	0.9752 (Class 1)
FCEV (0.2% → 100%)	1.918	4.257	0.260	0.681†	1.856	0.132	5.137	1.991	1.851	0.9986 (Class 6)
Battery recharging time reduction scenario										
PHEV (4 h → 1 h)	0.230	0.356	0.050†	0.101†	0.502†	0.091	0.752	0.277	0.236	0.9987 (Class 6)
BEV (8 h → 1 h)	0.130	0.037	0.018†	0.115†	0.052†	0.010	2.145	0.379	0.724	0.9987 (Class 6)
PHEV (4 h → 5 min)	0.691	1.188	0.148†	0.313†	1.427†	0.296	2.226	0.850	0.697	0.9987 (Class 6)
BEV (8 h → 5 min)	0.308	0.099	0.042†	0.281†	0.118†	0.027	4.947	0.879	1.668	0.9987 (Class 6)
Area-wide fast-charging scenario: fuel availability 100%, battery recharging time 5 min										
PHEV	1.300	3.440	0.243	0.353	4.818	0.428	3.040	1.766	1.514	0.7653 (Class 4)
BEV	0.940	0.787	0.103	0.358	0.807	0.054	8.627	1.693	2.854	0.9987 (Class 6)
Governmental incentive scenario: purchase price subsidy €5000 (PHEV, BEV, FCEV), fuel costs €6.5/100 km (BV, FCEV), incentives 1 and 2										
PHEV	1.986	1.371	0.848	1.430	3.652	2.032	7.406	2.585	2.103	0.9986 (Class 6)
BEV	0.443	0.046	0.134	0.426	0.259	0.110	6.138	1.129	2.055	0.9987 (Class 6)
BV	0.997	0.210	0.755	3.947	0.305	1.183	6.483	2.067	2.094	0.9987 (Class 6)
FCEV	0.635	0.040	0.370	4.007	0.156	0.285	6.414	1.746	2.245	0.9987 (Class 6)
NGV support scenario: purchase price €21,800, CO_2 emissions 50%, fuel availability 100%										
NGV	1.399	3.134	0.456	0.903	0.319	3.544	1.232	1.821	1.168	0.9878 (Class 5)
Massive multi-measure support scenario: purchase price €21,800, fuel costs €6.5/100 km (BV, FCEV), driving range 750 km, fuel availability 100%, battery recharging time 5 min, incentives 1 and 2										
PHEV	5.209	8.245	1.813	2.691	10.348	8.728	13.403	7.290	3.766	0.9987 (Class 6)
BEV	7.271	11.186	2.338	3.312	2.544	8.013	28.903	9.716	8.373	0.9988 (Class 6)
BV	4.384	7.583	1.602	5.240	2.779	5.318	11.955	5.844	3.085	0.9986 (Class 6)
FCEV	5.910	9.884	1.795	7.351	2.961	5.807	17.212	7.590	4.650	0.9986 (Class 6)

† Indicates CV value based on insignificant attribute coefficient.

Although not showing the lowest valuation for such improvements, individuals in class 1, which had the highest WTP for driving range extensions, have a much lower CV than individuals in class 6, who value them most (almost €3600 to increase the driving range of BEVs to 750 km).[15]

Car buyers in class 1 have the highest appreciation for an improvement of the fuel availability of all non-electrified AFVs. Concerning BEVs and FCEVs, car buyers in classes 6 and 1 have the highest CV, while individuals in class 4 show the highest valuation of an increased station density for PHEVs (amounting up to €4890 to increase the fuel availability to 100%). The acceleration of the battery recharging process, e.g. through the installation of fast-charging or battery swapping stations, assessed separately for PHEVs and BEVs, is valued higher for the latter vehicle alternative, where the CV is almost €4280 to shorten the battery recharging process to 5 min (class 6).

Turning to the multi-attribute scenarios, the CV for the installation of a large-scale fast-charging infrastructure is highest in class 4 for PHEVs and class 6 for BEVs, amounting up to €7460 for the latter. It is worth mentioning that the CV for such a multi-attribute measure is larger than the sum of the CV values for equivalent individual attribute improvements, which arises from the impact that changes in attribute levels exert on the choice probabilities of the respective vehicle alternatives. The governmental incentive scenario, which includes a purchase price subsidy of €5000 for PHEVs, BEVs, and FCEVs (comparable to support programs in other European countries, see e.g. ACEA, 2013), tax reliefs resulting in fuel costs of €6.5/100 km for BVs and FCEVs, as well as a vehicle tax exemption and non-monetary incentives, is most appreciated in class 6 for all vehicle alternatives considered, and sums up to about €6400 for PHEVs.

The CV for increasing the attractiveness of NGVs by reducing their purchase price and increasing the fuel availability to the level of CFVs, as well as cutting their CO_2 emissions to 50% of a current average car is highest in class 1 and amounts up to €3500. Finally, a substantial governmental and corporate multi-measure support program, leading to identical purchase prices of all vehicle alternatives and a huge increase in driving range of BEVs, induced, for example, by subsidies or technical progress and economies of scale in the AFV production, and including further governmental monetary and non-monetary incentives, fuel costs of €6.5/100 km for BVs and FCEVs, and the provision of a large-scale fast-charging infrastructure, is greatly valued in classes 4 (PHEVs) and 6, and the CV runs up to almost €25,000 for BEVs.

Looking at the CV values expressed in additional fuel costs per 100 km that consumers would be willing to disburse in Table 10 and beginning with purchase price reductions which lower the up-front expenditure for AFVs, we can observe the highest appreciation of such a measure in classes 5 and 6, and a maximum CV of €4.90/100 km for a purchase price reduction of €15,000 (BEVs, class 6).

Individuals in class 6 also show the highest appreciation for vehicle tax exemptions, free parking and the allowance for bus lane usage for all AFVs considered, which aggregate to €3.18 and €4.34 for the monetary (PHEVs) and the non-monetary (BEVs) governmental incentives, respectively. The base group also exhibits the highest valuation regarding CO_2 emission reductions (maximally about €0.48 for halving CFV's emissions), and extensions of the cruising radius of BEVs (up to €4.16 for the expansion of BEVs' driving range to 750 km).

Concerning the valuation of a refueling network extension, for the most part the highest CV values can be found in class 1 for NGVs and BVs, in class 4 for PHEVs, and in class 6 for BEVs and FCEVs, regardless of the size of the fuel network expansion, maximally adding up to about €5.14 for increasing the fuel station density of FCEVs to 100%. The appreciation for reducing the time to fully recharge a battery is highest in class 6 and reaches the total of €4.95 to fast-charge a BEV in 5 min.

The CV for the provision of an area-wide fast-charging network is highest in class 4 for PHEVs and class 6 for BEVs, totaling up to €8.63 for the latter. For all vehicle alternatives considered, individuals in class 6 also have the highest appreciation for the governmental monetary and non-monetary incentive program, which sums up to €7.41 for PHEVs. Regarding the valuation of an NGV support package, the highest CV can now be found in class 5, maximally adding up to €3.54, while a massive AFV support program on the part of the government and the industry is greatest in class 6 and aggregates up to €28.90 for BEVs.

Summing up the results, we find that German car buyers on average are willing to forfeit significant amounts of money for the improvement of vehicle attributes, and that the distinct consumer groups attach different importance to these attributes, leading to partially huge differences in their CV. Car buyers in classes 4 and 6 consistently show the highest appreciation for all attribute improvements (except for fuel cost reductions and the NGV support package), although not necessarily for every single vehicle alternative, while the lowest CV values are almost always found in classes 1, 2, or 5. This finding can be explained by the marked probability to choose (at least some of the) AFVs in classes 4 and 6. Interestingly, this is in sharp contrast to the WTP calculations, where individuals in classes 4 and 6 had the highest WTP for incentives and CO_2 emissions only. A further distinction between the CV and WTP results stems from the differences in their calculation formula, so that the CV values for all attribute improvements are consistently lower than the WTP values for identical non-marginal changes in attribute levels. For instance, the maximum CV for increasing the driving range of BEVs to 750 km is about €3600, while the maximum WTP for such an extension is about €50,400, and thus 14 times larger. This finding shows that a calculation of realistic (and not potentially misleading) monetary measures of consumers' appreciation for vehicle attribute improvements should take the current market situation and the choice probability of the respective vehicle technology into account.

5. Discussion

In the following discussion, we focus on the implications of the more informative results of the CV calculations, and assess the potential of the various attribute improvement measures to increase AFV demand, and to be realized cost-effectively.

[15] Note that 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.

Fuel tax reductions for BVs and FCEVs are not highly valued on the consumer side, and at most equivalent to a required payback period of slightly more than two years, assuming the annual mileage of an average German car driver of 14,210 km (DAT, 2014). This result suggests that car buyers in our sample undervalue fuel cost savings of individual AFVs and thus seem to act slightly myopically.[16] Hence, fuel price cuts do not seem to be able to significantly increase AFV demand, and the losses in fuel tax revenues would probably exceed the monetized environmental benefits, especially as the biofuel and hydrogen production goes along with undesired (environmental) side effects. 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 whether such a measure would be politically enforceable. Comparably to this, a compensation of purchase price subsidies through higher mobility costs (which are accepted in class 6 up to the point where fuel or electricity costs are about €9/100 km, i.e. comparable to those of CFVs) does not seem to be a revenue-neutral option to increase the demand for AFVs: 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, and as seen in Norway for example, such a measure could nevertheless be useful for increasing AFV diffusion.

Vehicle tax exemptions are highly appreciated in class 6 (and to a somewhat lesser extent in class 3), where the willingness to pay for such an incentive exceeds the forgone tax revenue over the entire vehicle lifetime, while in other consumer segments they are not. Non-monetary governmental incentives are again only appreciated by individuals in class 6, and to a lesser extent in class 3, but could increase the demand especially for BEVs in these consumer segments in a quite cost-effective way, as the CV amounts by far exceed the losses in parking fees. Taken together, German car buyers in class 6 value these two governmental incentives with an amount that is comparable to the purchase subsidies other European countries grant for electric cars, while their provision is less costly for the German government.[17]

The CV for a CO_2 emissions mitigation measure of (mainly) fossil-fueled vehicles is quite low. One possible explanation for this finding is that individuals who value emission reduction actions high are unlikely to choose fossil-fueled vehicles, while individuals having a high choice probability for fossil-fueled cars do not care that much about CO_2 emissions, and thus are unwilling to spend money for their improvement. Consequently, it could be more expedient to promote more environmentally friendly fossil-fueled vehicles by emphasizing their fuel efficiency instead of their 'greenness'.

The CV for an extension of the driving range of BEVs lies between maximally €55.3/kW h and €36.8/kW h (class 6), assuming a consumption of 17 kW h/100 km. This is far less than the current battery prices of about €250/kW h. Put differently, even BEV-affine consumers are far away from being willing to spend high extra amounts for a driving range expansion up-front or through higher operating costs (around €0.001–0.004/100 km for an additional kW h of battery capacity).

Regarding a refueling infrastructure expansion and a charging time reduction, the CV displayed in operating costs gives a better insight into the potential of business models, since vehicle manufacturers are usually not the same as the providers of the respective fuel or mobility service. German car buyers are currently willing to forfeit up to €0.35/l and €0.53/l extra for NGVs and BVs (class1), and €0.18/kW h and €5.14/kg for BEVs and FCEVs (class 6) for 100% fuel availability.[18] Concerning FCEVs and BEVs, this is equivalent to an accepted increase in fuel or electricity price by more than 2/3 and 3/4, respectively, compared to the *status quo*. Furthermore, individuals in class 6 would additionally spend about €0.29/kW h for fast-charging stations that enable to fully recharge the battery of BEVs in 5 min. Hence, car buyers would accept an increase in operating costs of 123%, if the recharging process is sped up in turn. These results suggest that the potential for private investors exists to provide, in a cost-effective manner, either an area-wide refueling and recharging infrastructure or selected fast-charging stations.

This impression is reinforced by the monetary values that German car buyers are willing to pay for a spatially fully extended network of fast-charging stations for their PHEVs or BEVs. More specifically, individuals in class 6 would additionally forfeit up to €0.51/kW h for such an infrastructure for BEVs alone, and thus would accept more than a tripling of current operating costs of BEVs and much higher operating costs than comparable CFVs.[19]

Finally, we look at the three scenarios that combine policy actions, which seem to be economically viable, with measures that do not seem to be realized cost-effectively, as our analysis of the CV for the individual attribute improvements has

[16] However, this myopic behavior cannot be observed when we look at the mean WTP for a fuel-unspecific operating cost reduction of €1/100 km (see Table 6), which can be translated into an accepted payback period of 7.5 years. 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 a review paper, 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 mileage, or commensurate interest rates for credit-financed vehicle purchases (e.g. Helfand and Wolverton, 2011; Allcott and Wozny, 2012; Busse et al., 2013; Allcott, 2013; Gillingham and Palmer, 2014).

[17] Hackbarth and Madlener (2013) exemplarily calculated the savings from a vehicle circulation tax exemption and the possibility of free parking over the entire vehicle lifetime of 10 years. They find that, compared to an average CFV, the vehicle tax savings would amount to between €920 and €2120 and, compared to a regularly taxed BEV, to €450, while the savings in parking costs would sum up to at least €300.

[18] The calculation is based on the following assumptions regarding vehicles' energy consumption: 6.9 l/100 km for NGVs, 8.3 l/100 km for BVs, 17 kW h/100 km for BEVs, and 1 kg/100 km for FCEVs.

[19] The following simple calculation might help to convey a sense of the economic potential of providing a nationwide fast-charging infrastructure for PHEVs and BEVs, for which car buyers in class 6 would be willing to pay €11.32/100 km extra in total. Conservatively assuming (1) total investment costs of €625 million (12,500 fast-charging stations at €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; (4) a payback period of the investment of 5 years; and (5) interest rates and running costs set to zero, about 184,000 PHEVs or BEVs would suffice for a profitable operation of the comprehensive fast-charging network, i.e. less than 1/5 of the 2020 German electric mobility target.

shown, to assess if such multi-attribute improvement schemes become cost-effectively in total, since the willingness to spend money for multi-measure packages is higher than the sum of individual actions.

Our CV results for a governmental incentive scheme, which are at the most €1600 higher than a support package without €5000 purchase support (PHEVs, class 6), suggest that the more is not always the merrier, since car buyers seem to heavily discount such buyer's premia for AFVs. Thus, from a cost-effectiveness viewpoint, the approach of the German government of not implementing purchase subsidies seems to be reasonable. Regarding the NGV support package and the multi-measure attribute improvement program the same marked discounting of up-front monetary purchase premia can be observed for all kinds of AFVs, which reduces the economic viability of these multi-measure support packages in general.

Furthermore, our results suggest that although the CV for combined attribute improvements is higher on average and within classes, compared to the sum of CV values for individual attribute enhancements, it can be lower than the sum of the maximum CV across classes, as the consumer groups who appreciate attribute improvements most can differ by attribute (e.g. in the NGV support scenario the maximum valuation for CO_2 emissions can be found in class 6 and for fuel availability in class 1, while individuals in class 1 have the highest CV for the combination of measures). Moreover, in the multi-measure support scenario, which massively reduces the main disadvantages of all AFVs, but especially those of BEVs, car buyers in classes 4 and 6, who did stand out due to their high AFV choice probability even in the base scenario, show an even stronger appreciation for AFVs, which amounts to a choice probability of almost 58% for PHEVs (class 4), 51% for BEVs (class 6), and 36% for FCEVs (class 1). The latter is particularly interesting since it shows that also individuals that are not highly AFV-affine would consider the purchase of at least some AFV options, if the current disadvantages are (massively) reduced, and that they would accept substantial additional purchase price charges for competitive BEVs and FCEVs, as indicated by the relatively pronounced CV values.

Finally, note that the conclusions from such a cost-effectiveness assessment of individual or simultaneous attribute improvements will look totally different if they are based on the average CV values, since the sample mean is often considerably lower than the CV of the consumer segment willing to pay most (which in most cases is class 6, i.e. most if not all AFV support measures would be uneconomical).[20] However, the class-specific CV results show that the costs for providing attribute improvements do not have to decrease first, e.g. through technical progress, to be implemented cost-effectively, since consumer groups exist already today that value such measures sufficiently, while the average CV values indicate the cost targets which should be reached in an AFV mass market.

6. Summary and conclusion

We investigate German car buyers' preferences for AFVs, based on stated preferences discrete choice data and by applying two model specifications, a standard MNL and an LCM. The findings of the LCM show that the population of German car buyers is not as homogeneous as assumed by the MNL, but can be best described by six distinct consumer groups that vary in taste concerning vehicle characteristics and fuel types: 'car dependents' (class 1), 'fuel cost savers' (class 2), 'CFV buyers' (class 3), 'PHEV enthusiasts' (class 4), 'purchase price sensitives' (class 5), and 'AFV aficionados' (class 6). The results reveal that currently two consumer segments exist which, everything else equal, might choose at least some of the AFVs: Especially younger, less educated, and highly environmentally aware consumers with a high daily 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. That is, over all other propulsion technologies 20.6% of the respondents prefer PHEVs (class 4) and 15% favor PHEVs, BEVs, BVs, and FCEVs (class 6), although especially the size of the latter segment is likely to be smaller in the entire German population (see Footnote 5), so that these results need to be interpreted with some caution.

Moreover, we find that German car buyers are willing to pay considerable amounts for the improvement of all vehicle attributes and that this appreciation varies depending on the consumer group, and is characterized by diminishing marginal returns of improvements of vehicles' CO_2 emissions, driving range, fuel availability, and recharging time, i.e. minimum requirements exist beyond which attributes rapidly gain in consumer's valuation.

We additionally calculated fuel-specific CV values, which are more useful than the fuel-unspecific WTP values, as they account for the currently low choice probabilities of AFVs in the majority of the consumer segments. Our results suggest that in contrast to the WTP values car buyers in class 6 have the highest willingness to forfeit money for the improvement of most of the vehicle attributes. Regarding the single vehicle attributes, our results show differences in their potential to increase the acceptance of AFVs, and also the possibility to be provided in a cost-effective way. For instance, our findings suggest that governmental purchase price subsidies and fuel cost reductions are not valued high enough on the consumer side to be made available cost-effectively, even though they could be able to strongly push the demand for AFVs. On the other hand, especially vehicle tax exemptions and non-monetary governmental incentives could increase the probability to choose AFVs very cost-effectively, at least in class 6.

The limited driving range of BEVs is one of the major barriers for electric mobility. Consequently, its extension is identified as the silver bullet to increase consumer acceptance. Problematic in this respect is that German car buyers are not willing to pay the necessary amounts of money for the increase in battery capacity, even if they generally seem to like BEVs (class 6). Hence, either battery research is vigorously intensified (e.g. through governmental financial support) to achieve

[20] Please note further that due to the presumable slight overrepresentation of AFV-friendly individuals in our sample (see Footnote 5), the average CVs of the overall population are probably even somewhat lower.

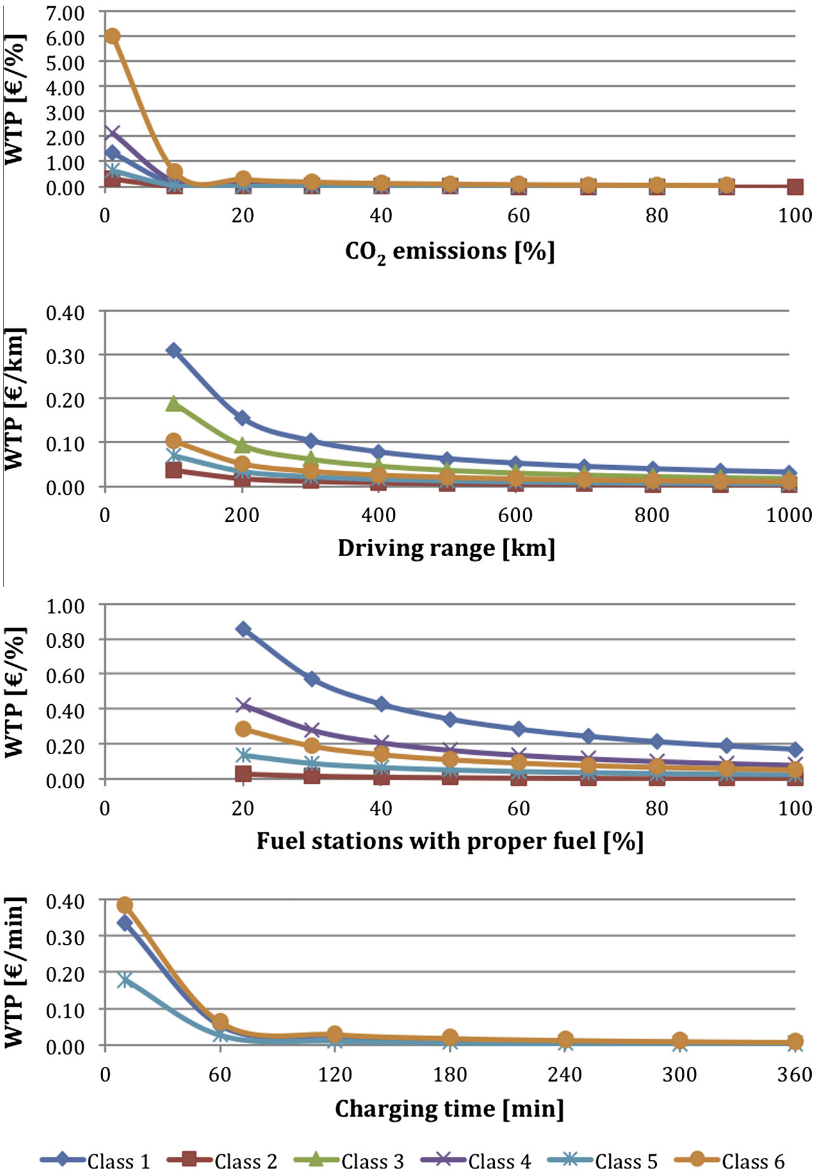

Fig. A1. Marginal WTP for changes in vehicle attributes (in €/100 km of fuel cost increase).

a major technological break-through, enabling battery prices of €50/kW h (corresponding 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 use (e.g. by offering 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 a large-scale fast-charging infrastructure. However, due to the very high up-front costs of such an investment, governmental support could be necessary to that end.

Finally, such a comprehensive fast-charging network, especially when its installation is accompanied by other attribute improvements (e.g. like in the multi-measure scenarios) would in turn help to increase the acceptance of AFVs in general, and especially BEVs, in consumer groups that currently are very reluctant towards the adoption of AFVs, but actually have the highest WTP, e.g. for driving range or fuel availability improvements (class 1). This increase in potential consumers would in turn open up new possibilities for the cost-effective provision of attribute enhancements.

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: (1) consumers do not accept

Table A1
Literature overview.

Study	Location	Model	Fuel types	Attributes (non-linear functional form)	Main results[1]
Abdoolakhan (2010)	Australia	NL, LCM	CFV, NGV, HEV, BV	Purchase price, fuel costs, performance, fuel efficiency, vehicle type (d), number of doors (d)	Complementary preference for AFVs (especially NGVs) in 2 consumer groups; choice of AFVs influenced by female (+), age (−); demand with respect to purchase price and fuel costs is very inelastic; scenario analysis: major demand shift from CFVs to NGVs/BVs in the future, although CFVs will further dominate the market
Achtnicht (2012)	Germany	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; WTP for emissions reduction varies with female (+), education (+), budget (+), age (−)
Achtnicht et al. (2012)	Germany	MNL	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability (q), performance	CFVs preferred over AFVs; choice of AFVs influenced by desired driving range (−), environmental awareness (+), age * BEV/NGV (−), annual mileage * HEV/FCEV (−); WTP for increase in fuel availability varies with fuel type (BEV > CFV), budget (+), current fuel availability (−)
Axsen et al. (2013)	UK	MNL	CFV, BEV	Purchase price, driving range (ln), refueling time (ln), performance	Liminal lifestyle influences choice of BEVs (+); consumer perceptions of BEVs change through social influence (diffusion, translation, reflexivity); methodological finding: advantages of multi-method approach (reflexive layers of social influence framework and discrete choice experiment) due to ability to model dynamic consumer preferences
Batley et al. (2004)	UK	MNL, ML	CFV, AFV	Purchase price, fuel costs, emissions, driving range, fuel availability, refueling location (d), performance	AFVs preferred over CFVs; WTP for CFVs varies with age (−), environmental awareness (−), car ownership (+), children (+); scenario analysis: demand for AFVs is elastic and more sensitive to purchase price than demand for CFVs, while fuel costs, driving range and fuel availability are inelastic; AFVs need substantial support (technical, legislative, fiscal) to achieve significant market shares
Beck et al. (2013)	Australia	LCM	CFV, HEV	Purchase price, fuel costs, performance, vehicle type (d), registration and emissions charges, fuel efficiency, number of seats, country of origin (d)	Choice of AFVs and valuation of vehicle attributes influenced by age, children, environmental awareness; mainly differences in consumer 'greenness' cause variation in preferences for an emission charge; methodological finding: advantages of model with attitudinal information (more detailed segmentation of the population)
Daziano (2013)	USA	MNL, ML	CFV, HEV, BEV	Purchase price, fuel costs, driving range (ln), performance (d), vehicle type (d)	HEVs preferred over CFVs/BEVs; 4 different welfare measures for driving range improvements show that BEVs need substantial financial support (WTP, CV lower than current battery production costs); methodological finding: advantages of models with nonparametric heterogeneity distributions
Daziano and Achtnicht (2013)	Germany	MNP	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; scenario analysis: increasing fuel availability of BEVs/FCEVs to 100% more than triples their market shares; methodological finding: advantages of models with Bayes estimator
Eggers and Eggers (2011)	Germany	ML	CFV, HEV, BEV, PHEV	Purchase price (d), driving range (d)	AFVs without driving range limitation preferred over CFVs; scenario analysis: HEVs will dominate the market (even with significant price increase), PHEVs and BEVs are purchased much less often; BEVs have to meet minimum requirements (driving range, recharging infrastructure, purchase price) to be adopted
Ewing and Sarigöllü (2000)	Canada	MNL	CFV, BEV, AFV	Purchase price, emissions (d), driving range (d), refueling time (d), performance (d), commuting time and costs, maintenance costs	AFVs preferred over CFVs; choice of AFVs influenced by environmental awareness (+); scenario analysis: price subsidies, fast-charging and driving range improvements significantly increase market share of AFVs (especially BEVs), exceeding those of CFVs
Hackbarth and Madlener (2013)	Germany	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV, PHEV	Purchase price, fuel costs, emissions, driving range, fuel availability, refueling time, incentives (d)	CFVs preferred over AFVs; choice of AFVs influenced by environmental awareness (+), age * BEV (−), share of city trips * BEV (+), plug−in possibility * PHEV/BEV (+), education * PHEV/BEV (+), small car * BEV (+); heterogeneity (e.g. budget (+)) in WTP for vehicle attributes; scenario analysis: even with massive attribute improvements CFVs will dominate the market and demand for BEVs/FCEVs will remain small

(continued on next page)

Table A1 (*continued*)

Study	Location	Model	Fuel types	Attributes (non-linear functional form)	Main results[1]
Hess et al. (2012)	USA	MNL, NL, ML, CNL	CFV, NGV, HEV, BEV, BV, PHEV	Purchase price, fuel costs, emissions, driving range (ln), fuel availability (d), incentives (d), vehicle type (d), fuel efficiency, vehicle age (d), maintenance costs	PHEVs/BVs preferred over CFVs/other AFVs; WTP for vehicle attributes varies with income (+); scenario analysis: demand increase for specific fuel-vehicle-type combinations draws market shares from other vehicle types with same fuel and from vehicles of same type but with different fuel; methodological finding: advantages of CNL in analysis of multi-dimensional choices (simultaneous vehicle-fuel-type choice)
Hidrue et al. (2011)	USA	MNL, LCM	CFV, BEV	Purchase price, fuel costs, emissions (d), driving range (d), refueling time (d), performance (d)	Complementary preferences for BEVs in 2 consumer groups; choice of BEVs influenced by age (−), education (+), environmental awareness (+), plug-in possibility (+), small car (+), number of long drives (−), expected fuel price increase (+), etc.; heterogeneity in WTP for vehicle attributes; scenario analysis: driving range, charging time, emissions, and acceleration have to drastically improve before BEVs conquer the mass market
Hoen and Koetse (2014)	Netherlands	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV, PHEV	Purchase price, fuel costs, driving range, refueling time incentives (d), additional detour time, number of models	CFVs preferred over AFVs; choice of AFVs and valuation of vehicle attributes influenced by annual mileage (−), commute frequency (−), current fuel diesel/LPG (−), plug-in possibility * BEV (+), incentives * urban (+), driving range * annual mileage (+), purchase price/monthly costs * budget (+), etc.; heterogeneity in WTP for vehicle attributes; scenario analysis: even for massively improved AFVs considerable negative preferences remain
Ito et al. (2013)	Japan	MNL, NL	CFV, HEV, BEV, FCEV	Purchase price, fuel costs, emissions (d), driving range (q), fuel availability (d), refueling time (d), vehicle type (d), manufacturer (d)	HEVs preferred over CFVs and BEVs/FCEVs; complementary WTP for increase in fuel availability and driving range for FCEVs and BEVs; scenario analysis: battery-exchange stations can be efficient with low BEV market shares, high subsidies needed to reach governmental BEV diffusion targets
Link et al. (2012)	Austria	MNL	CFV, HEV, BEV	Purchase price (sqr), fuel costs (ln), emissions, driving range (ln), refueling time (q), performance (sqr)	CFVs preferred over AFVs; (antagonistic to CFVs/HEVs) choice of BEVs influenced by age (−), income (−), male (−), main car (−), vehicle age (−), part-time employed (−), garage (+), willingness to buy BEV (+), accepted charging time (+), reasons for decision environmental/operating costs (+), etc.; scenario analysis: moderate technological development and fuel price increase can lead to considerable market shares of HEVs/BEVs
Parsons et al. (2014)	USA	MNL, LCM	CFV, BEV	Purchase price, fuel costs, emissions (d), driving range (d), refueling time (d), performance (d), annual cash back payment	See Hidrue et al. (2011); additional comparison of BEVs with/without V2G-contracts; WTP for improvement of V2G contract attributes varies with consumer group; scenario analysis: consumers require higher compensation for V2G-BEVs than can be generated with V2G services, i.e. V2G does not seem to be able to increase BEV demand
Potoglou and Kanaroglou (2007)	Canada	NL	CFV, HEV, AFV	Purchase price, fuel costs, emissions (d), fuel availability (d), incentives (d), performance (d), vehicle type (d), maintenance costs	Choice of AFVs and valuation of vehicle attributes influenced by age * AFV (−), education * HEV (+), performance * male/single household (+), fuel availability * long distance commuters (+); WTP for vehicle attributes varies with income (+)
Ziegler (2012)	Germany	MNP	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; choice of AFVs influenced by age (−), environmental awareness (+), male * NGV/FCEV (+), annual mileage * BEV (+), desired driving range * BEV/FCEV (+), desired horsepower * FCEV (+), car used for commute * NGV (+), company car * BV (+), small vehicle * FCEV (+), multiple vehicle household * BV (+), etc.; methodological finding: advantages of models with taste persistency effects

Notes: CFV = conventional fuel vehicle; AFV = alternative fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; MNL = multinomial logit model; NL = nested logit model, ML = mixed logit model; MNP = multinomial probit model; LCM = latent class model; CNL = cross-nested logit model; d = dummy; ln = logarithmic; q = quadratic; and sqr = square root; (+) = positive effect; (−) = negative effect.

[1] Almost all studies find that the main vehicle attributes significantly impact vehicle choice in the expected direction, i.e. negative influence of purchase price, fuel costs, maintenance costs and other vehicle charges, emissions, refueling/recharging time, and positive influence of driving range, fuel availability, fuel efficiency, performance, number of doors/seats, and governmental incentives.

Table A2
Sample choice card.

Fuel type	Plug-in hybrid	Hybrid	Electric	Gasoline or diesel
Purchase price	€31,250	€25,000	€18,750	€25,000
Fuel cost per 100 km	€5	€25	€15	€25
CO_2 emissions (% of today's average car)	0	75	100	50
Driving range	1000 km	700 km	100 km	400 km
Fuel availability (% of stations)	60	60	20	100
Refueling time	10 min	10 min		5 min
Battery recharging time	6 h		10 min	
Policy incentives			No vehicle tax	

Table A3
Marginal WTP for changes in vehicle attributes (in €/100 km of fuel cost increase).

	MNL	LCM						Mean	Std. dev.	$Prob_{WTP>0.9}$
		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	1.52	1.144	0.9896 (Class 5)
Incentive 1 (No vehicle tax)	4.380	6.041	1.254	21.800	0.070†	4.091	20.481	8.643	7.752	0.9349 (Class 3)
Incentive 2 (Free parking and bus lane access)	3.034	3.967	1.114	17.819	4.665†	1.108†	15.507	6.61	6.181	0.9735 (Class 3)
CO_2 emissions abatement by 1%										0.9987 (Class 6)
At 100%	0.010	0.014	0.003	−0.008†	0.021	0.007	0.060	0.015	0.020	
At 50%	0.020	0.027	0.006	−0.017†	0.043	0.013	0.120	0.030	0.040	
At 1%	1.018	1.364	0.322	−0.832†	2.143	0.651	6.011	1.509	1.987	
Driving range increase by 1 km										0.9760 (Class 1)
At 100 km	0.103	0.310	0.037	0.189	0.064†	0.071	0.102	0.131	0.089	
At 500 km	0.021	0.062	0.007	0.038	0.013†	0.014	0.020	0.026	0.018	
At 1000 km	0.010	0.031	0.004	0.019	0.006†	0.007	0.010	0.013	0.009	
Fuel availability increase by 1%										0.9789 (Class 1)
At 20%	0.229	0.860	0.034	0.095†	0.426	0.137	0.288	0.300	0.263	
At 60%	0.076	0.287	0.011	0.032†	0.142	0.046	0.096	0.100	0.088	
At 99%	0.046	0.174	0.007	0.019†	0.086	0.028	0.058	0.061	0.053	
Battery recharging time reduction by 1 min										0.9973 (Class 6)
At 6 h	0.004	0.009	0.001†	0.011†	0.002†	0.005	0.011	0.006	0.004	
At 1 h	0.023	0.056	0.004†	0.063†	0.014†	0.030	0.064	0.038	0.022	
At 10 min	0.136	0.335	0.026†	0.378†	0.084†	0.179	0.383	0.231	0.130	

† Indicates WTP values based on insignificant attribute coefficients.

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; (2) improvements of some vehicle attributes could be provided entirely privately and maybe even cost-effectively, while others might need governmental support (e.g. for basic research or in terms of a purchase price subsidy) to take the hurdle beyond which they are valued sufficiently high by German car buyers; (3) specific actions should be accompanied by marketing and information campaigns tailored to those distinct consumer groups which appreciate these improvements most; (4) in order to effectively increase the adoption rates of AFVs, car manufacturers and government policies should aim at consumers in classes 4 and 6, i.e. 'PHEV enthusiasts' and 'AFV aficionados', since they show the highest CV values for all kinds of attribute improvements and for all kinds of vehicle alternatives; and (5) the attainment of the ambitious German electric vehicle goal could not be reached by solely focusing on these two consumer groups[21], which, however, in a first step should nevertheless be done for obtaining a rapid and major adoption, which in turn could lead to the afore-mentioned bandwagon effects and sustained diffusion of AFVs.

[21] In the base case scenario the aggregated weighted choice probability for PHEVs and BEVs in classes 4 and 6 is 15.3%. Since, for example, in 2014 private households purchased only 1.1 million new vehicles (KBA, 2015), the German electric mobility target cannot be reached until 2020 by 'PHEV enthusiasts' and 'AFV aficionados' alone.

Finally, 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. Nevertheless, this study and our results establish a good starting point for political decision-makers and car manufacturers alike 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. Accordingly, future research will have to develop and evaluate business models for a cost-effective deployment of refueling and recharging infrastructure in Germany.

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Appendix A

See Fig. A1 and Tables A1–A3.

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