Willing to participate in vehicle-to-grid (V2G)? Why not!

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Abstract

The predominant strategy to reduce CO_2 emissions in the transport sector is its renewable based electrification. It implies-mobile storages that could - during long phases of immobility - provide-services for the electricity sector. However, this technical option-called vehicle-to-grid (V2G) requires the vehicle users to temporarily abstain from the usage of their batteries for V2G. A reasonable estimate of the potential of V2G thus considers which individual, technical and economic parameters are decisive for the willingness of vehicle users to participate. To answer these questions a representative sample of vehicle users in Germany has been surveyed - including a discrete choice experiment.

'Range anxiety' and the 'minimum range' proved most important determinants of the willingness of vehicle users to participate in V2G. If these concerns are smoothed out, even without remuneration, high participation rates might be achieved. To increase the participation in the V2G technology, the transition from 'tank control' to 'mobility demand articulation' should be facilitated for vehicle users. Therefore, companies could tailor the V2G design to customers' needs and policy could improve information about V2G. Remuneration, however, cannot be expected to be very supportive.

Keywords

Vehicle-to-grid (V2G), willingness of vehicle users, representative online survey, discrete choice experiment, range anxiety, minimum range.

I Introduction

Electricity supply and the transport sector are currently highly dependent on fossil fuels. They are thus a central source of CO_2 emissions (IPCC 2014) and contribute significantly to climate change. The use of renewable energies for the generation of electricity and an electrified transport sector have the potential to reduce CO_2 emissions significantly and to decrease dependency on fossil fuels (Linssen et al., 2012). Electric mobility offers the possibility to introduce its inherent storage into the electrical system and to improve system efficiency by controlled charging (further classified as uni- or bidirectional charging, Kempton and Tomić, 2005a, b; Parsons et al., 2014; Haidar et al., 2014).

This possibility - vehicle-to-grid (V2G) - consists of integrating the traction batteries of electric vehicles[1] into the electrical system during generally long immobility periods and to participate in energy markets[2]. In praxis, a charging strategy is determined by vehicle users and an “aggregator" in a joint continuous bargain. The aggregator gathers information about the market situation, schedules charging and discharging according to the bargained rules and expected revenues. Revenue estimates vary with respect to the market the storage service is supplied on (arbitrage on the spot market or for reserve services, Kempton and Tomić, 2005a; Parsons et al., 2014)[3] from a few (Vattenfall Europe Innovation GmbH et al., 2011) to several thousand Euros per year and vehicle (Brooks, 2002; Kamboj et al., 2011; Yilmaz and Krein, 2012). Revenues are finally distributed to vehicle users according a predetermined contract.

The technology is ready for the market (Linssen et al., 2012)[4]. It may promote the integration of renewable energy (vgl. dazu auch Kempton and Tomić, 2005b; Mwasilu et al., 2014; Richardson, 2013) and efficiency gains could be used to subsidize electric vehicles. V2G can then contribute to overcoming the battery’s high cost, which is a crucial obstacle to the electrification of the transport sector. This interpretation of V2G as a promoter of electric mobility has become the main research paradigm of V2G (e.g. Parsons et al., 2014)[5].

So far, low figures of registered electric vehicles[6] and insufficiently-dispersed charging infrastructure have limited its immediate large-scale application. But even if these obstacles do not exist anymore the question remains of whether vehicle users will participate in V2G. Up to now, V2G business models have primarily been analysed with a focus on revenues.

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1 In addition to battery-electric vehicles, fuel cell vehicles and plug-in hybrid vehicles are principally suitable for V2G Kempton, W., Tomić, J., 2005a. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. Journal of Power Sources 144, 268-279.

2 Overviews of technoeconomic analyses comprise of Damiano et al. [2014], Tan et al. [2016] and Yilmaz & Krein [2012].

3 In a study of the Californian energy markets ibid., Kempton, W., Tomić, J., 2005b. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280-294. identify the markets for ancillary services and reserves as most profitable.

4 To operate in a V2G configuration, electric vehicles have to feature three elements: ‘a power connection to the electricity grid, a control and/or communication device that allows the grid operators access to the battery and precision metering on board the vehicle to track energy flows Tomić, J., Kempton, W., 2007. Using fleets of electric-drive vehicles for grid support. Ibid. 168, 459-468.. This two-way communication between the electricity grid and the vehicle enables utilities to manage electricity resources better, and it empowers vehicle users to earn money by selling power back to the grid.’Sovacool, B.K., Hirsh, R.F., 2009. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37, 1095-1103. All three components are available on the market.

5 A further technical interpretation is that local load peaks due to uncoordinated charging strategies might be avoided by V2G. From a local perspective (nodal pricing), however, this is economically not different to a scarcity oriented (price) charging strategy.

6 In March 2016, 26730 pure electric vehicles and 130365 hybrid vehicles (including plug-in hybrids) were registered in Germany (https://www.emobilitaetonline.de/news/wirtschaft/2286-der-aktuelle-elektroauto-und-fahrzeugbestand-in-deutschland).

But there are significant (opportunity) costs[7]: 1. the costs of charging infrastructure, 2. the compensation to the vehicle users for the degradation of the battery by additional charging cycles[8] and 3. the substitutive relationship between (potential) mobility and V2G revenues. The reason for the substitutive character is the limited battery capacity and the duration of the charging process. The latter takes 1000 times longer than charging a fossil-fuelled vehicle with the same energy. Spontaneous charges - taking only a few minutes - are therefore insufficient (without high power grid connection) for an 'electric' journey over tens of kilometres. For this reason, electric vehicles require a forward-looking storage management - even without V2G.

If a V2G option is added, it might be valuable to postpone charging or even to reduce the state of charge if electricity prices are high. Therefore, the battery might not be charged sufficiently quickly to meet short-term mobility requirements (Damiano et al., 2014; Tan et al., 2016) and it contributes to range anxiety.

However, the immobility risk can be greatly reduced by the technical design of V2G. This can be achieved by a charging controller (communication device, Kempton & Letendre [1997]). It allows the vehicle user to articulate his or her mobility preferences. Specifically, this is accomplished by specifying an always reserved minimum range and by specifying the timing and duration of the next trip. If these data are considered by the aggregator as a binding restriction, then the immobility risk caused by V2G is entirely excluded and a range anxiety caused by V2G is causeless. Emergency trips to the doctor or holiday trips remain possible, even if the state of charge (SOC) is no longer controlled by the vehicle user.

The willingness to participate in V2G now depends on how inconvenient the effort for the ex-ante operation of the communication device is perceived to be, and how high the revenue of V2G is. The concrete determination of the technical possibilities - among others the minimum range and the option to indicate the following journey - and the remuneration scheme are referred to in the following as technical and economic (V2G-)design.

There are, however, no comprehensive and systematic empirical analyses of the willingness of vehicle users to participate in V2G[9]. Therefore, a prerequisite for profound V2G potential estimates and resulting business models is missing. To close this gap, we ask two research questions: (1) what are the relevant determinants of the willingness of vehicle users[10] to provide the battery for their electric vehicle for V2G? (2) which technical and economic designs of the V2G concept are decisive for the willingness of vehicle users to participate? These questions will be answered based on an empirical analysis. A representative sample of electric vehicle users and users of conventional vehicles who are interested in the purchase of an electric vehicle have been surveyed for the motivational prerequisites to provide the battery for their electric vehicle for V2G. A discrete-choice experiment was embedded in the survey to analyse the impact of the technical and economic V2G design on the V2G participation. Statistical

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7 We assume that the optimal charging strategy is determined by each vehicle user (sovereignty). It is implemented free of charge by the aggregator. Thus, fixed costs of information acquisition and of software implementation of the charging strategy can be shared among V2G participants, which marginalizes its impact.

8 By additional charging and discharging, the degradation of the battery increases (for modelling degradation processes of vehicle batteries in the V2G context, see, for example, Guenther, C., Schott, B., Hennings, W., Waldowski, P., Danzer, M.A., 2013. Model-based investigation of electric vehicle battery aging by means of vehicle-to-grid scenario simulations. Journal of Power Sources 239, 604-610.). However, the charging strategy can also reduce degradation if a high 'state-of-charge' (SOC) is avoided during immobility.

9 In contrast, the technical potential of V2G and business models of electric mobility have been analysed in greater depth by Jonuschat, H., Wölk, M., Handke, V., 2012. Untersuchung zur Akzeptanz von Elektromobilität als Stellglied im Stromnetz. IZT - Institut für Zukunftsstudien und Technologiebewertung, B.A.U.M. Consult GmbH, Berlin, Parsons, G.R., Hidrue, M.K., Kempton, W., Gardner, M.P., 2014. Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms. Energy Economics 42, 313-324.

10 The terms vehicle owners and users will not be distinguished. Both terms shall describe the person that regularly drives the car and has decided upon the purchase of the vehicle. While the judicial ownership is not per se relevant.

methods are explained in section II. In section III the results of the analyses are provided. Conclusions are drawn in section IV.

II Methods

Survey design

Since there are hardly any empirical results on the willingness to participate in V2G it was necessary to collect primary data to investigate the two research questions. Therefore, in 2013, electric vehicle users and users of fossil-fuelled vehicles who could imagine buying an electric vehicle within the next five years were surveyed online[11]. Fossil-fuel vehicle users "only interested in the purchase" had to be considered because only 300 private electric vehicles were registered in Germany in 2011[12] - too few to base a nationwide random sampling on[13].

A representative sample of 611 vehicle users participated in the survey, including 14 users of electric vehicles[14]. Representativeness of the sample was monitored with respect to the demographic characteristics gender, age, education and household size. The sample averages fitted closely to the data of German vehicle users from the comprehensive Consumer Analysis 2012[15](see Appendix B).

The topics of the survey reflect the variables we assume to be relevant for the willingness to participate in V2G. They comprise:

1. The awareness of different types of electric vehicles, because awareness is an important prerequisite for buying and using electric vehicles.
2. Motivational and structural factors which can enhance or limit the willingness to participate in V2G, such as motives for the purchase and use of an electric vehicle, driving and immobility times, charging behaviour and modal choice as well as the assessment of electric mobility objectives.
3. Factors directly connected to the potential participation in V2G, such as the awareness of V2G, the general willingness to participate in V2G and the assessment of V2G objectives, concerns and incentives for the participation in V2G (see Appendix A) and
4. The attitude towards driving, the instrumental, symbolic and affective relevance of driving as well as attitudes towards energy sources and the vulnerability of nature ('myths of nature').

For the latter, the authors considered the same items as Steg [2005] (see Appendix A) for the assessment of attitudes towards driving as well as the instrumental, symbolic, and affective importance of driving.

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11 The questionnaire with the discrete-choice experiment is documented in Appendix A. Both were developed in collaboration with the Technical University of Berlin and the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW). It was performed by Dima Marktforschung GmbH in Mannheim from July 4 to July 10, 2013. The survey is also referred to as a 'NET-INES survey' or 'NET-INES survey 2013'.

12 As per data of the Kraftfahrtbundesamt, only 2307 electric vehicles had been registered in Germany up to January 1 2011. In 2011 two thousand new registrations were expected, so that by the end of 2013 almost 4500 electric vehicles were in operation. More than 90% of these vehicles were registered by traders and industrial customers. Therefore, it was estimated that in 2011 only 101 electric vehicles were bought by private customers. The total number of private users of electric vehicles in the middle of 2013 was therefore estimated at a maximum of 300 by Dima Marktforschung GmbH.

13 A targeted approach of private electric vehicle users was not possible as their addresses were not available for privacy reasons.

14 We used Mann-Whitney U tests to investigate whether the electric vehicle users and conventional vehicle users differ with regard to the variables investigated in the following chapters. Since this was not the case the two groups were neither differentiated nor was it necessary to delete the electric vehicle users from the sample.

15 Klassik III Märkte – Strukturanalyse, one of the largest market-media studies in Europe, has offered, since 1982, a broad and varied insight into attitudes, interests and consumption patterns of the German population. Cf. https://www.verbraucheranalyse.de/home.

The so-called 'myths of nature' (Thompson et al., 1990), which are based on the theoretical assumptions of anthropological cultural sociology, were the conceptual basis for the assessment of attitudes regarding the vulnerability of nature. According to Thompson et al. [1990], four 'myths of nature' can be distinguished: (1) the myth of nature as 'benign', which means that the environment is very adaptable and will recover from any harm caused by people, (2) the myth of nature as 'tolerant', i.e. that with expert management, environmental disasters can be prevented, (3) the myth of nature as 'ephemeral', which means that the environment is very fragile and the slightest human interference will cause a major disaster and (4) the myth of nature as 'capricious', i.e. that it does not matter what we do, the environment will change in unpredictable ways both for the better and the worse.

In contrast to Thompson et al.'s original concept we did not ask the respondents to select one of the four 'myths of nature', but to indicate their agreement or disagreement separately, because we assume that they are not exclusive (cf. Marris et al., 1998). In order to assess the extent to which the 'myths of nature' are reflected in the attitudes of vehicle users, respondents were asked to choose on a scale of 1 (= I do absolutely not agree) to 7 (= I absolutely agree) in response to: (a) the environment is very adaptable and will recover from any damage caused by humans (myth of nature as 'benign'); (b) with good management, we can prevent environmental catastrophes (myth of nature as 'tolerant'); (c) the environment is very vulnerable and even small human interference can cause a disaster (myth of nature as 'ephemeral'); and (d) no matter what we do, the environment will change in unpredictable ways, both for the better and for the worse (myth of 'nature as 'capricious') (see Appendix A).

At first the variables directly connected to V2G participation - the awareness of V2G, the general willingness to participate in V2G, and the assessment of V2G objectives, concerns and incentives for the participation in V2G - were evaluated using descriptive statistics (section III.1)[16]. Subsequently, the determinants of the 'general willingness to participate in V2G' (see section III.2) were identified in an ordinal regression analysis. The following nominal or ordinal variables were included: gender, age, vocational training, current main occupation, housing situation, usage of the vehicle, average daily driving range, instrumental, symbolic and affective intent of driving, attitude towards the vulnerability of nature ('myths of nature'), evaluation of the objectives that can be achieved with V2G, and concerns about V2G and incentives for the vehicle participation in V2G (see Appendix C).

Discrete choice experiment

The impact of the explicit technical and economic design of V2G on the participants was examined in a discrete-choice experiment (III.3). A discrete-choice experiment is a widely applied method to deduce preferences for the design of non- or not yet market goods out of a hypothetical selection among differently designed goods (e.g. Louviere et al. [2010]).

[16] Significance of the differences was proved with non-parametric tests.

Attributes, hypotheses and levels

We apply this method to different technical and economic designs of the V2G concept. The design components (attributes) consist of elements of Kempton's communication device, plugin-time restrictions for the electric vehicle and remuneration schemes as in Parsons et al. [2014]. With V2G it may be valuable to maintain a low state of charge (SOC) or even to reduce the SOC (bidirectional charging) of the vehicle battery at high electricity prices. To limit the risk of immobility for unforeseen trips the communication device includes the option to preserve a dynamically[17] adjustable "minimum range" in kilometres. To estimate the value of this minimum range per kilometre in the experiment the minimum range - as an element of the V2G design - was restricted to constant values (Mr) of 10, 20, 30, 40 or 50 kilometres. This set of ranges was chosen to include a very small guaranteed minimum range up to the average driving range of 38 Km per passenger car in Germany (Kraftfahrtbundesamt), such that most of the vehicle users would not be restricted by V2G at all.

We expect the length of the minimum range to be valuable for vehicle users. Furthermore, the V2G design includes the opportunity to indicate the beginning and the length of the next trip. As it removes mobility restrictions of the V2G technology for foreseeable mobility demand, it should also be valuable for potential V2G participants. It is implemented in the survey with the variable "equipment with an on-board computer" (C{Yes, No}).

We also considered plugin-time restrictions for the electric vehicle. These might improve the predictability of the availability of storage capacities for the aggregator and thus reduce risks. Explicitly the minimum connection time per working day H was restricted to 0, 5, 7, 10 or 14 hours (Parsons et al., 2014) and the minimum number of days per week $T$the vehicles had to be connected to the grid was restricted to 3, 4 or 5 days. These constraints reduce the freedom of the vehicle user and we thus expect a negative impact on the willingness to participate.

As it was illustrated in the introduction V2G users might suffer from handling inconveniences of the communication device and restrictions in freedom caused by connection requirements. To compensate them for these transaction costs and to motivate them to participate, a V2G remuneration was considered, as in Parsons et al. [2014]. The survey participants were not asked directly for their willingness to accept but, a fixed monthly premium $M$of €15, 30, 45 or 60 and a one-time payment $E$of €1000, 3000, 5000 or 7000 were offered. €60 per month equals an annual revenue of €720 per vehicle. The latter is three times the upper bound of the average interval of revenue estimates of $100-300 per vehicle and year (Richardson, 2013). These high values were considered to include a potential increase of the storage value in future, highly renewable energy systems and the impact of the remuneration on a broad scale. The according one-time payment has been calculated as net present values of the monthly income stream of €60 evaluated with an interest rate of 1.5% for 10 years.[18]

Characteristics and hypotheses

As we expect that the vehicle users perceive inconveniences, restrictions and the monetary compensation heterogeneously, we also consider decision makers' characteristics to explain this heterogeneity. To focus the analysis and to avoid collinearity we formulated hypotheses that referred to specific characteristics only. Details of the measurement of the variables are described in table 10 (Appendix F).

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[17] A necessary more detailed specification of the admissible dynamics of both seemed inoperable to communicate within the survey.

[18] The one-time payment was determined as net present value of the monthly payment of e.g. €60 by $\sum_{i=0}^{10\times 12} \frac{60€}{(1+\frac{0.015}{12})^i} \approx €7000$.

A personal characteristic that might affect the valuation of the compensation is the vehicle user's income (€/year). We expect that additional V2G remuneration may be especially valuable for lower income vehicle users and that it increases participation rate.

As the results of analyses of the impact of age [years] and gender (0,1) on fuel preferences is mixed (e.g. Ziegler, 2012 and Hackbarth and Madleiner, 2013), we did not want to exclude these parameters ex ante. In general, "younger, well-educated and environmentally aware car buyers are impartial towards" some alternative fuels (Hackbarth and Madleiner, 2013). We also expect this group to have a higher affinity to V2G and a positive effect on participation rates.

If the planning effort was crucial for the V2G participation, we would expect the driving range [Km] to have a negative impact on the willingness to participate because long or frequent trips imply a frequent costly handling of the communication device. In addition, the opportunity cost of missing a trip due to an increased risk of not being able to drive can be expected to rise with vehicle usage. The impact of the latter was measured in the survey on a scale of 1 to 7 depending on whether they agreed with the statement 'With bidirectional charging, I would fear the battery is not sufficiently charged when I want to start a trip.' The higher this 'range anxiety', the lower we expect the willingness to participate in V2G.

The attitude of vehicle users towards their vehicle was also considered. If the survey participant interprets vehicle usage as 'instrumental' compared to 'symbolic' or 'affective', he or she might attribute importance to its vehicle's availability, which reduces his or her willingness to participate. Alternatively, a less 'instrumental' evaluation of car usage might increase the sensibility towards additional income generated by the car. This would increase the willingness to participate. The authors have no expectation which of the effects will be dominant. The instrumental value was measured by the average level of how much they agree to the given statements Q3.1-5 on a scale from 1 to 7 each (E.g. question 1: 'For me, the car has instrumental functions only').

An important prerequisite to evaluate V2G is the 'awareness of V2G'. A naïve hypothesis about its impact is that with high awareness the knowledge about technology is also high. Therefore, unfounded reservations, e.g. range anxiety might be less pronounced and the participation rate might be high. However, improved knowledge might also result in the awareness that the technology causes inconveniences – in the case of a high driving range. This perception would decrease the willingness to participate. In the experiment the level of awareness was measured as a binary variable, with '1' only in the case that the survey participant had at least 'heard' about V2G.

We also checked the impact of beliefs in myths of nature on the participation by asking the survey participants if they classified nature as 'tolerant or ephemeral'[19]. Both myths have in common the interpretation of nature as an object that can be influenced by human beings. Without consent to one of these concepts, it is questionable whether environmentally friendly behaviour like CO_2 reduction or the application of the V2G technology may have any influence on nature at all.

During the design of the final model the concern that V2G might shorten the battery life (Q11.1_r3) was also considered, but no significant impact could be found.

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[19] The attitudes to the vulnerability of nature have been included as explanatory variables of the willingness to participate in V2G in a very condensed way. The myths of nature as 'tolerant' and 'ephemeral' have been summarized by a logical 'or' and have been termed as 'tolerant or ephemeral nature'. Each of the myths was quantified on a scale from 1 to 7 as the level to agree to Q4.1_2 (Good management, we can prevent environmental catastrophes, myth of tolerant nature) and Q4.1_3 (The environment is very vulnerable and already small human interference can trigger a disaster as a fragile balance). This approach appears to be meaningful since both myths, in contrast to the myths of nature as 'benign" or as 'capricious", are common to interpreting nature as an object which can be influenced by human beings. Without consent to one of these concepts, it can be questionable whether environmental behaviour can have any influence on nature at all.

Design of the experiment

A specific selection of each of the previously described technical and economic design elements (attributes) was combined in a V2G-design (concept). Survey participants had to select their preferred design from three different V2G-designs or the “none of these” option (task). Each of the 611 survey participants was confronted with 8 decisions (tasks) thus 4888 decisions could be recorded. The experiment was designed with the software package Sawtooth. Details are described in Appendix F.

Statistical method – latent class model

The 4888 recorded V2G-designs, decisions and the 611 sets of characteristics were analysed with a latent class model (e.g. Greene and Hensher, 2003). The latent class model is a semiparametric variant of the mixed logit model. It was favoured to the mixed logit model in recent performance comparisons like Junyi Shen (2009) and Hidrue et al. (2011). The impact of characteristics on decisions is modelled by class-specific logit models, which guide the decision probability. The membership of one of the (not observable) latent classes is modelled as a probability depending on the characteristics.

It is assumed that the decisions about a V2G design are based on a class-specific random utility approach. The utility of the within class alternatives is

$$U_i = \beta_{0i} + \beta X_i + \varepsilon_i \text{ with } i = 1, \dots, 3 \quad (1)$$

X_i describes a technical and economic V2G design. An individual weights the design elements with β. When defining the ‘no-V2G participation’ option (optout) by the attributes of the V2G design it has to be considered that the minimum range equals the capacity of the battery, which is assumed to enable a trip of 150 Km length. Therefore, the utility perceived from the ‘opt out’ alternative is

$$U_0 = \beta_m 150 + \varepsilon_0. \quad (2)$$

The error ε_i has a type-1 extreme value distribution with zero mean and standard deviation 1. Optimizing agents act as if their decision to choose alternative i was random influenced by the distribution

$$L(\beta, i) = \frac{exp(\beta_0 + \beta X_i)}{exp(\beta_{MR}150) + \sum_{i'=1}^{3} exp(\beta_{0i'} + \beta X_{i'})}. \quad (3)$$

Class membership is also interpreted as a probability that depends upon decision makers’ characteristics z. The probability of choosing a specific alternative i is thus

$$S(\theta, \beta, i) = \sum_{c=1}^{C} \frac{exp(\theta^c z)}{\sum_{c\prime=1}^{C} exp(\theta^{c\prime} z)} L(\beta^c, i). \quad (4)$$

Here $L(\beta^c, i)$ is the class specific likelihood function and C the number of latent classes. The vector θ^c must be normalised, so that C-1 vectors can be estimated. The parameters β and θ were estimated with NLOGIT5: LCLOGIT; (Greene and Hensher, 2003)).

The classes of the model are defined as the (endogenous) basis for the classification of each individual. Since this basis is endogenous, the evaluation of latent class models always raises the question of how the classes may be interpreted. Two approaches can be observed in practice: 1. It is always possible to define the classes based on their characteristics and to derive the impact of the attributes via classes. Especially if there are many classes this approach makes it difficult to trace the influence of individual attributes on the decision. 2. Therefore, in appropriate cases the classes are interpreted based on 'decisions specific to them'. Hidrue et al. (2011) and Pearson et al. (2014) use this approach without specifying or justifying it[20].

Scenarios

Since this research is focused on the participation and less on the classification, it was considered explicitly whether a behaviour-based interpretation of the classes would lead to sensible results. For this purpose, it was necessary to determine class-specific participation rates without V2G design variants distorting them. Therefore, class-specific participation probabilities were determined applying equation (3) with the estimated parameters $\hat{\beta}^c$ for an average contract (on-board computer, 30 km minimum range, no temporal connection restrictions and a monthly remuneration of €15 per month) in comparison to a non-participation option as 74%, 6% and 73% for classes 1 to 3. With these rates it appeared sensible to consider classes 1 and 3 as participation-promoting and class 2 as participation-inhibiting. Consequently, also the characteristics that raise membership probability of classes 1 and 3 can be interpreted as being participation-promoting and vice versa. This result has led us to follow the interpretation of classes by 'decisions specific to them' without deeper examination of the characteristics of the classes.

To determine the sensitivity of the class-specific participation rates to changes in the remuneration and the minimum range, they were determined (equation 3) for a contract without remuneration and with on-board computer and a high minimum range of 60 km.

III Results

III.1 Descriptive analysis[21]

The awareness of the concept is an important prerequisite for the willingness of vehicle users to participate in V2G. However, the survey shows that, in 2013, V2G was unknown to German vehicle users. 87.7% of the respondents had never heard of V2G, 11.3% had heard about V2G but did not know anything or just a little about it. Only 1% of vehicle users surveyed indicated that they knew quite a bit or a lot about V2G.[22] It was thus necessary to provide the respondents with information on the charging strategies - 'uncontrolled charging', 'unidirectional charging' and 'bidirectional charging' - before asking to what extent they would use them on a scale from 1 (= I would definitely not use it) to 7 (= I would definitely use it) (see the questionnaire in Appendix A). Table 1 shows that the willingness to use bidirectional charging is the lowest, with a mean of 4.7. It is significantly smaller than the willingness to apply uncontrolled or unidirectional charging[23]. In the following the 'general willingness to participate in V2G' is defined as the willingness of the vehicle users to use bidirectional charging.

With the implementation of V2G, different objectives can be achieved (Mwasilu et al., 2014; Sovacool and Hirsh, 2009). In this study, it is assumed that these objectives impact on the willingness of vehicle users to participate. To measure this impact possible objectives of V2G were assessed by the participants on a scale from 1 (= not important at all) to 7 (= very important)[24]. On average (table 2) all objectives were considered as important. The greatest relevance was addressed to 'reducing the costs of

[20] Hidrue et al. call the classes 'EV and GV oriented', which is the decision analysed.

[21] For the descriptive statistical analysis and the ordinal regression analysis we used the software IBM SPSS Statistics (https://ibm.co/2hUZTWp).

[22] The V2G concept is equally unknown across the German population more generally: in a representative survey (IEK-STE, January 2013) 87.5 % of the respondents answered they had never heard of V2G, 10.3 % had heard of it, but did not know nothing or just a bit about it. 2.1 % of the respondents knew quite a bit or a lot about V2G.

[23] The differences in the willingness to use the charging strategies are significant (Appendix C).

[24] cf. Questionnaire in Appendix A

future electricity storage', 'increasing the share of electricity from renewable sources of energy for the use of the electric vehicle' and 'the contribution to the successful implementation of clean energy sources'.

The concerns of the vehicle users regarding V2G were raised by asking the participants to indicate their agreement on a scale from 1 (= I do absolutely not agree) to 7 (= I agree absolutely). The comparison of the means (table 3) shows that the greatest concern of the vehicle users is that the battery life is shortened with controlled bidirectional charging. The second strongest concern is that trips are not sufficiently projectable and it is therefore not possible to dispense with the usage of the electric vehicle for V2G. Further strong concerns are that uncontrolled access to the electric vehicle would be possible due to controlled charging with feedback, as well as the fear that the battery might not be sufficiently charged when the vehicle user wants to start driving.

The relevance of different incentives for the participation of vehicle users in V2G was raised by asking respondents to indicate on a scale from 1 (= I do absolutely not agree) to 7 (= I agree absolutely) how much they agreed with the statements listed in table 4. The most important incentives – indicated by the mean of the answers - are 'cheaper charging', 'price reductions of the electric vehicle' and 'a charging station', as well as 'annual bonus payments' (table 4). The guarantee to load the electric vehicle only with electricity from renewable energies would be a further relevant incentive for participation in V2G. By far less relevant is the provision of special rights to V2G users such as the use of bus lanes or free parking.

III.2 Ordinal regression: determinants of the general willingness to participate in V2G

Determinants of the general willingness of vehicle users to participate in V2G were identified in an ordinal regression analysis. This was performed as a main-effects model, i.e. it contained all direct influences of the independent variables on the dependent variable but no interaction effects between the independent variables. Estimated parameters, standard errors and confidence intervals are reported in the table 'parameter estimators' in Appendix E.[25] The pseudo-R^2 coefficient[26] of Nagelkerke (see Appendix E) of 57.6% indicates a high explanatory power of the ordinal regression model as well as the share of 42% of correctly forecasted answers.

Nominal and ordinal variables were included as binary variables with the values 1 (= yes) and 0 (= no). For example, the answers to the question 'assessment of the objective of V2G: contribution to the successful implementation of the Energiewende' with possible values from 1 (= not important at all) to 7 (= very important) enter the regression model coded as seven binary variables whose impact on the 'general willingness to participate in V2G' were estimated separately. The seven estimated parameters are reported in the table in Appendix D as [Q10.1_r1 = 1] to [Q10.1_r1 = 7]. Thus, parameter [Q10.1_r1 = 1] represents the valuation of the objective as 'not important at all', [Q10.1_r1 = 4] represents a neutral assessment and parameter [Q10.1_r1 = 7] as 'very important'.

Thereby, neither monotonicity nor significance of the estimated parameters are guaranteed. Indeed, frequently only one binary parameter proved significant. To filter intuitive and robust results only nominal or ordinal variables with more than three (seven optional categories) or two (five categories) consecutive significant binary parameters that also had equal signs were considered as relevant for the

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[25] To improve transparency significant parameters are marked in yellow.

[26] The pseudo-R^2-coefficient following Nagelkerke is a measure of the ability of the regression to explain observed data. Values from 0,2 to 0.4 can be considered as highly satisfying Schendera, C., 2014. Regressionsanalyse mit SPSS. De Gruyter Oldenbourg.

general willingness to participate in V2G. These ‘relevant’ variables were ordered according to the number of significant variables and the values of the estimated parameters.

Applying this definition, the parameters that can be identified as ‘relevant’ determinants of the general willingness to participate in V2G are presented in table 5 - sorted in descending order of their relevance. The most relevant determinant on the willingness to participate in V2G is ‘the concern that the battery is not sufficiently charged at the start of a journey when it is used for bidirectional charging’. Five of the seven dummy variables representing the ordinal variable are significantly positive and have the highest impact among all relevant variables on the dependent variable. The (positive) value of the estimators increases, with a decreasing fear the battery might not be sufficiently charged, resulting in an increase of the general willingness to participate in V2G.

The second most relevant determinant is the consent to the myth of nature as “capricious”[27]. Five of the seven dummy variables representing the ordinal variable have a significant negative impact on the dependent variable. Consequently, the willingness to use V2G decreases as nature is considered less ‘capricious’.

The third most relevant parameter is the fear of the vehicle user to feel constrained in his/her freedom and independence by V2G. Four of the seven dummy variables representing this ordinal variable have a significant positive impact on the dependent variable and their values are the second highest. The (positive) estimators increase with a decreasing fear of being restricted in freedom and independence. The general willingness to participate in V2G is thus greater the less that vehicle users fear that this could restrict their freedom and independence.

The objectives ‘support for the decentralization of the electricity storage’ and ‘partial avoidance of an electricity grid expansion’ are also relevant with the three significant binary variables. The estimators are negative and become smaller the less important the objective is. Therefore, the less important the target ‘support for the decentralization of the electricity storage’ or the goal ‘partial avoidance of the electricity grid expansion’ is valued, the lower the willingness to participate in V2G.

Another relevant determinant of the willingness to participate in V2G is the employment status of the vehicle user. Two of the five variables representing the nominal variable parameter categories ‘employment in part-time’ and ‘in education/study’ are significant and have a positive impact on the dependent variable. The estimators have a higher value among the vehicle users in education than among part-time employees. Therefore, vehicle users in education are more willing to use V2G than part-time employees.

III.3 The impact of the technical and economic design of V2G

In this section, the impact of the V2G design on the willingness to participate is analysed. The results of the estimation of the latent class model are summarized in table 6 of Appendix F. The model was estimated for three classes as for more classes the confidence intervals of the estimated parameters proved numerically unstable and for two classes the Akaike information criterion indicated a decline. As the quality of the model estimated, the ratio of the aggregated, correctly predicted decisions to the 4888 overall decisions was 69%. This means that more than two-thirds of all decisions can be reproduced correctly by the model.

The estimated classes have an approximately equal size of 39% (Class 1), 26% (Class 2) and 33% (Class 3). Within each class the parameters (β) ‘minimum range’, ‘on-board computer’, ‘monthly payment’,

[27] The environment will change unpredictably – for the better or for the worse independently of mankind’s action (as per section 3).

and 'one-time payment', which impact latent utility, are highly significant in all classes (table 6). The impact of the 'minimum hours' was only insignificant in class 1, while 'minimum days' was insignificant in any class. Besides the insignificant parameters, all signs were plausible – as expected. Thus, 'minimum range', 'board computer', 'monthly payment' and 'single payment' increase the utility of an alternative, while the minimum grid connection hours reduce it.

Since the signs of the parameters in a multinomial logit model do not have to coincide with the signs of the elasticities of the decision probability, it is necessary to determine the elasticities explicitly. All elasticities are highly significant and the signs of the 'own decision-parameter' elasticities correspond to the sign of the estimated parameters $\hat{\beta}$. The signs of the 'cross-decision parameter' elasticity correspond to the negative sign of the estimation parameters. This means, for example, that the increase in the 'minimum range' in V2G design 1 increases the probability to select design 1; in contrast the probability of design 2, 3 and 'opt out' decreases. All significant elasticities had the same sign across all classes and they were - as expected - positive for 'minimum range', 'board computer', both types of remuneration and negative for the significant elasticities of the connection restrictions. So, all classes evaluate the design elements similarly.

The willingness to pay for one kilometre of minimum range ($\beta_{\mathrm{MR}} /(\mathrm{Mr}\, \beta_{\mathrm{m1}})$) is 6.45, 5.07 and 3.88 €/km for classes 1 to 3 and for the on-board-computer ($\beta_c /\beta_{\mathrm{m1}}$) 11.78, 37.57 and 44.21 €/computer. Therefore, high values - compared to an average monthly remuneration of €30 - would have to be paid to motivate survey participants to dispense with 10km of minimum range or the on-board-computer.

Implicit discount rates (Train, 1985) are very high compared to interest rates: 0.21, 0.20 and 0.11 for classes 1 to 3. Nevertheless, they are in line with findings for alternative fuels in Horne et al., 2005; Mau et al., 2008 and Axsen et al., 2009. Hence, one-time payments are strongly preferred by the survey participants.

The impact of characteristics on V2G participation rates can be deduced via a twostep procedure from the classes membership model. As described in section II, first, the participation rates are determined for each class with the estimated parameters $\hat{\beta}$ for an average V2G design - consisting of an on-board computer, 30km minimum range, no temporal connection restrictions and a monthly remuneration of 15 euros per month - resulting from a comparison with a non-participation option. The participation rates are 74% and 73% respectively for classes 1 and 3 and only 6% in class 2 (table 7). Therefore, a high membership probability of classes 1 and 3 leads to a high V2G participation rate; a high probability of class 2 membership to a low participation rate. This procedure ensures that differences in the participation rates only stem from characteristics and the class specific valuation of the V2G design, but not from differences in the V2G design.

Second, based on this class-decision correlation it is possible to deduce the impact of the characteristics on the participation rates. For this purpose, an evaluation of the sign of the estimation parameter $\hat{\theta}$ is insufficient as in the multinomial logit model. Instead elasticities have been calculated. They are presented in table 7 with the significance levels of the estimated parameters $\hat{\theta}$ (table 6). E.g. An increase in the characteristic 'mileage' raises the membership probability of class 2, while it falls for classes 1 and 3. In this sense, the driving range reduces participation rates.

This result is consistent with the hypothesis that a high 'mileage' requires a frequent operation of the communication device, which is perceived as particularly unpleasant, lowering participation rates. Likewise, 'range anxiety' is significant in class 2 and has a positive effect on class 2 membership probability and a negative effect on class 1 and 3 memberships. Thus 'range anxiety' reduces V2G participation rate. This result is also plausible and confirms the expectation.

Contrary to our expectations, the income did not show a significantly positive parameter value $\hat{\theta}$ in any class. In addition, the "support for renewables" and the estimation of the nature as "ephemeral" was not significant at all.

Age, the gender (male) and the interpretation of the vehicle as "instrumental" proved to be significant but qualitatively ambivalent. All three parameters increased class 1 but also class 2 membership probabilities, while they had a negative impact on class 3 membership.

The ambivalence results from the complex interaction effects covered by the latent class modelling. For example, the "instrumental meaning of the vehicle" (estimated parameter is significant for class 1 and 2) adds a positive impact on the V2G participation rate via class 1 and a negative impact via class 2 and 3. The impact interacts with other characteristics. In class 2, which is characterized by "range anxiety", a high "mileage", higher "age" and a high share of male participants, the "instrumental meaning" has a negative effect, which could be caused by a high aspiration level of availability. In contrast with lower levels of "range anxiety" and lower "mileage" in class 1, the impact on participation rates inverts.

The awareness of V2G (parameter significant for class 2) has a positive effect on participation over class 2 and class 3. In class 1 the parameter is insignificant. The information about V2G is therefore eligible for the participation rate. This suggests that targeted information policy can increase participation rates affecting class 2 and 3.

To compare the impact of remuneration and the design parameter 'minimum range' on the participation rates, they were determined with the class specific V2G design parameters $\hat{\beta}$ in a decision between a V2G design - with 60 km minimum range, an on-board computer, without remuneration and no further connection restrictions - and the non-participating option. The simulated participation rates rose to 86%, 40% and 77% in classes 1- 3. That shows that even without remuneration, high participation rates can be achieved. In this sense, the design parameter 'minimum range' dominates the remuneration.

IV Conclusion

The V2G technology has the technical potential to link electric mobility and storage services in the electrical system. Under which conditions vehicle users might be willing to abstain temporarily from the use of their vehicle battery and how they could be motivated to do so is largely unknown because the V2G concept is even further from everyday experience than electric vehicles.

To close this gap, individual, technical and economic determinants for the willingness to participate in V2G are examined in this research. This creates a qualified basis for the assessment of welfare effects, the potential of V2G and the design of business models. The low level of everyday experience made it necessary to conduct a survey combined with a choice experiment. The responses were analysed with an ordinal regression and the choice experiment with a latent class approach. With these statistical methods, the most relevant determinants of the general willingness to participate in V2G were identified.

Due to the high number of determinants included in the survey, not all of them could be analysed with both methods. Among the parameters that were investigated, 'range anxiety' proved to be an especially important parameter for participation in V2G in both approaches. This parameter is therefore robust with respect to the statistical method. Among the V2G design parameters the 'minimum range' was most relevant, more relevant than remuneration.

The integration of the batteries of electric vehicles into the electrical system (V2G) is a promising modern technology. It is technically mature, but low penetration rates of electric vehicles and an insufficiently developed charging infrastructure are currently hindering widespread application. This requires vehicle users partially to abstain from the permanent access to their batteries. The V2G technology - technically implemented with a communication device - replaces the control of the tank level by the expression of the vehicle user's mobility demand. Our analysis shows that this transition is not equal for all vehicle users. Long-time and frequent vehicle users for example have a special motivation that differs fundamentally from short-distance drivers and makes the transition less attractive for them. This can hardly be influenced by income generated from the batteries or subsidies.

For users with low mileage, the transition is tedious and takes time to get used to. Even though this is largely unfamiliar, it can be expected that the transition will be less problematic in the longer term. This also means that there is a large virtual storage available without additional cost of capital and with minor inconvenience to the V2G users.

To increase the participation in the V2G technology, the transition for the vehicle users should be facilitated. For this purpose, the aggregator (a private company) should tailor the V2G design to customer's needs. Furthermore, policy could contribute by credible commitment and through an information campaign. Remuneration, however, cannot be expected to be very supportive. But our analysis shows, that it is not required for significant participation rates if the V2G design is sensible with sufficient freedom for unforeseeable and foreseeable mobility demand.

This work has not resulted in a clear estimate of the impact of V2G caused degradation of the vehicle battery on the willingness to participate; possibly because the participants of the survey could not be informed sufficiently as there are only a few empirical technical analyses available. Therefore, it would be desirable to include quantified degradation effects in future analyses of the willingness to participate to foster the results.

It would also be interesting for future research to specify the timing of the 'next trip' and the 'minimum range' input more accurately. A low frequency of change on the user side and a long lead time would increase the predictability and could result in a more efficient battery management by the aggregator. Predictable behaviour could then be rewarded by special remuneration. However, the question arises of whether this remuneration scheme would have an influence on the willingness to participate in V2G. This is highly likely as monetary motivation would this time be closely linked to the V2G design elements that are particularly important for participation rates.

In this article, the V2G (battery) supply was empirically analysed. For the design of business models, it would be important to combine this supply with a short-term demand for storage services on electricity markets. It was then possible to derive the optimized business model. This work required the integration of storage supply into an energy system model.

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Tables

Charging strategy	Mean[1]	Standard deviation
Uncontrolled charging	5.5	1.6
Unidirectional charging	5.4	1.7
Bidirectional charging	4.7	1.9

Table 1: Willingness to apply charging strategies; [1] Scale from 1 (= I would definitely not use it) to 7 (= I would definitely use it). The higher the mean, the higher the willingness to use the charging strategy.

Bidirectional charging of electric vehicles battery (Vehicle to grid)…	Mean[1]	Standard deviation
can reduce costs for necessary future electricity storage.	5.6	1.4
can increase the share of renewable energy used for the electric vehicle.	5.6	1.3
can contribute to the successful implementation of the 'Energiewende'.	5.5	1.4
can absorb or offset fluctuations of renewable energy.	5.3	1.4
can generate revenue by charging the battery at a low price and discharging at a high price.	5.3	1.6
can provide an emergency power supply to own household.	5.3	1.5
can support a decentralization of electricity storage.	5.0	1.4
can make reserve power plants obsolete, which compensate for fluctuations in demand.	4.9	1.5
can help to avoid grid expansion.	4.6	1.6

Table 2: Assessment of objectives achievable with V2G; [1] Scale from 1 (= not important at all) to 7 (= very important). The higher the mean, the higher the relevance that was ascribed to the objective.

Concerns	Mean[1]	Standard deviation
With bidirectional charging, I would be afraid that the battery life would be shortened by the frequent charging and discharging, and I had to buy a new battery earlier.	4.9	1.8
My trips are not sufficiently projectable to dispense with my vehicle for V2G.	4.7	1.8
With bidirectional charging there will be access to my electric vehicle which I cannot control.	4.6	1.8
With bidirectional charging, I would fear the battery is not sufficiently charged when I want to start a trip.	4.6	1.8
With bidirectional charging, I would feel restricted in my freedom and independence.	4.2	1.8
With bidirectional charging, I would fear that my data would be used to create motion profiles.	4.1	1.9
The input of charging and discharging data into the on-board computer would make driving too complicated for me.	3.7	1.8

Table 3: V2G concerns; [1] Scale from 1 (= I do absolutely disagree) to 7 (= I do absolutely agree). The higher the mean, the bigger the V2G concerns.

I would provide my electric vehicle for bidirectional charging if ...	**Mean [1]**	**Standard deviation**
charging my electric vehicle would be cheaper than with uncontrolled charging.	5.8	1.4
I would receive a discount on the purchase of an electric vehicle.	5.7	1.4
I would receive a price reduction for the purchase of a charging station for my electric vehicle.	5.5	1.5
I would receive an annual bonus.	5.4	1.6
there was a guarantee that my electric vehicle would be loaded exclusively with electricity from renewable energy.	5.0	1.7
I would receive special rights, e.g. to use a bus lane or public parking for free.	3.6	2.1

Table 4: Incentives for the participation in V2G; [1] Scale from 1 (= I do absolutely not agree) to 7 (= I absolutely agree). The higher the mean, the higher the consent to the incentive for participating in V2G.

	Relevant determinants of the general willingness to participate in V2G	**Number of significant parameters**
1	Concerns that the battery is not sufficiently charged,	5 out of 6
2	Consent to the myth of nature as “capricious”	5 out of 6
3	Concerns to feel constrained by V2G in freedom and independence,	4 out of 6
4	Evaluation of the objective of V2G ‘Support the decentralization of electricity storage’,	3 out of 6
5	Evaluation of the objective of V2G ‘partial avoidance of an electricity grid expansion’ and	3 out of 6
6	Current main occupation	2 out of 4

Table 5: ‘Relevant’ determinants of the general willingness to participate in V2G

		Multinomial Logit		**Latent Class Logit Model**					
Parameters				Class 1		Class 2		Class 3	
		Value	Z	Value	z	Value	Z	Value	Z
Constant 1	β_1	0.99056 ***	7.65	3.00902 ***	8.15	2.35441 ***	4.67	1.25867 ***	3.66
Constant 2	β_2	1.14137 ***	8.83	3.19869 ***	8.22	2.50081 ***	4.86	1.39088 ***	3.81
Constant 3	β_3	1.08720 ***	8.40	3.03734 ***	8.14	2.53795 ***	5.05	1.38826 ***	4.01
Minimum range	β_m	1.17190 ***	28.19	1.52671 ***	11	3.65508 ***	12.35	0.60411 ***	4.71
Computer	β_c	0.34507 ***	9.10	0.20628 **	2.51	0.59241 ***	4.61	0.52784 ***	5.89
Days	β_t	0.02277	1.01	-0.00538	-0.12	0.00237	0.03	0.06938	1.47
Hours	β_h	-0.05343 ***	-12.74	-0.00032	-0.03	-0.07455 ***	-5.53	-0.11932 ***	-10.31
Monthly payment	β_m	0.01338 ***	14.29	0.01751 ***	8.55	0.01577 ***	5.44	0.01194 ***	5.73
Single payment	β_e	0.00020 ***	25.72	0.00031 ***	13.92	0.00026 ***	10.11	0.00011 ***	5.12
In class probability model									
Constant	θ_0			-5.10559 ***	-3.37	-5.58569 ***	-4.02		
Age	$\theta_{Age,c}$			0.05274 ***	3.47	0.05557 ***	4.11		
Gender	θ_{Sexc}			2.42512 **	2.5	2.71012 ***	3.09		
Age x Gender	θ_{AgeSe}			-0.03962 **	-2.02	-0.0497 ***	-2.75		
Income	θ_{Ek}			0.00001	0.1	0.00002	0.2		
Mileage	$\theta_{Fahr,c}$			0.00148	0.61	0.00454 **	2.07	Restricted	
Instrumental car use	θ_{Ins}			0.18297 *	1.76	0.20748 *	1.96		
Nature ephemeral	θ_{Aut}			0.13078	0.35	0.28624	0.73		
Awareness of V2G	θ_{Bek}			-0.47246	-1.11	-0.78919 *	-1.8		
Renewable support	θ_{Gre}			0.21693	1.27	0.04081	0.25		
Range anxiety	θ_{Ler}			0.08101	1.03	0.23287 ***	2.92		
Average. Class membership probability				0.40		0.27		0.34	

Table 6: Estimation Results; Note: ***, **, * == > Significance at 1%, 5%, 10% level.

Class interpretation	Class1		Class 2		Class 3
Estimated share of the classes [%]	40		27		34
Simulated participation rate with mean design [a] [%]	74		6		73
Participation rate	High		Low		High
Characteristics θ	Elasticity of class membership probability due to a change in characteristics [b]				
Age	0.75	***	0.88	***	-1.67
Gender (male = 1)	0.35	**	0.49	***	-0.84
Age x Gender	-0.24	**	-0.48	***	0.70
Income	0.00		0.03		-0.02
Mileage	-0.02		0.14	**	-0.10
Instrumental motives for car use	0.23	*	0.34	*	-0.58
Nature ephemeral	0.00		0.13		-0.11
Awareness of V2G	-0.01		-0.05	*	0.05
Support for renewables	0.71		-0.36		-0.61
Range anxiety	-0.06		0.63	***	-0.44

Table 7: classes, behaviour and characteristics. [a] Participation rates simulated with estimated class parameters $\hat{\theta}$ and $\hat{\beta}$, average charcteristics and a mean V2G design. The mean design is defined as an equipment with board computer, a minimum range of 30 Km and a remuneration of 15 €/month, without connection restrictions and single payment. The option was to accept this design or to opt out. [b] Significance level of the according parameter $\hat{\theta}$. ***, **, * ==> Significance at 1%, 5%, 10% level. Appendix F.

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Appendix F – Discrete Choice Experiment

Design

After defining the attributes and the values admissible per attribute, concepts were created. A concept consists of the connection of one level with each attribute. The participants in the choice experiment were then presented several concepts to choose from (task). The number of the concepts shown (number of tasks) is as much part of the design of the choice experiment as the definition of the concepts themselves and their number per task.

When determining the number of concepts and tasks, on the one hand a high number per participant is desirable in order to achieve a high measurement accuracy, on the other hand the precision of the results decreases with the burden on the participants. In our design, the number of concepts was kept low. Instead the number of tasks was chosen higher. Reducing the number of alternatives to be compared made it easier for the participants to choose (the concept). Therefore, we decided to create 8 tasks with 3 + 1 concepts each (CBC design or block). The 'none' or 'optout' alternative was explicitly taken into account as the fourth concept in order to record the non-participation in V2G. By means of this design, the questionnaire processing time was expected to be 14 - 18 minutes and for the choice experiment another 2 - 2.5 minutes.

The concepts were designed with the Sawtooth software package (Sawtooth, 2009). In the first step 300 different CBC designs were sampled from a subset of the full-choice design for each respondent. The balance and near-orthogonality (Johnson et al., 2011) was ensured within each respondent's profile (balanced-overlap method). This procedure allows more overlaps than the complete enumeration method but fewer than the random method. It was intended that respondents evaluate all levels of the attributes at least 3 times to make the results more stable. Each participant was then presented a randomly chosen CBC design, so that each design had been seen by at least two of the 611 participants.

Discrete choice experiment: willingness to buy an electric vehicle which can be utilized for vehicle-to-grid

Please imagine, you would be offered three different V2G contracts when buying your electric vehicle. **Please compare the different elements and then decide for a contract.**

If you can not make a decision, you can choose "none of these contracts". In the following you will be faced eight times with this decision.

Provided that all other contract elements would be the same. Which contract would you choose?

20 km **minimum range**	**30 km** **minimum range**	**50 km** **minimum range**	None of the three contracts
Without board computer	**With board computer**	**With board computer**	
5 days per week controlled charging/discharging	**3 days per week** controlled charging/discharging	**4 days per week** controlled charging/discharging	
At least **5 hours per day** connection to a loading station	At least **7 hours per day** connection to a loading station	More than **5 hours per day** conneted to a loading station	
30 € monthly remuneration	**45 €** monthly remuneration	**No** monthly remuneration	
7000 € premia for buying a car	**No** premia for buying a car	**No** premia for buying a car	
❍	❍	❍	❍

Explanations:

Guaranteed minmum range: regardless of how often the battery is charged and discharged by the V2G partner, the electric vehicle achieves a minimum range of 10 to 50 kilometers depending on the contract.

Board computer: the electric vehicle has a board computer with which the point in time and the length of the next trip can be programmed. This guarantees that the charge of the battery is sufficient for performing the next trip. With this it is also guaranteed that trips can be done which are longer than the guaranteed minimum range. The minimum range is still guaranteed indepently from the time of the trip.

Number of days per week for bidirectional charging: bidirectional charging is only possible if the car is standing and plugged to a charging station. It is assumed that a private charging station exists as well as a charging station at the working place. The owner ensures that the car will be available for bidirectional charging every week at least on the specified number of days (depending on the contract between 3 and 5 working days). Otherwise he will receive a lower remuneration from the V2G contract partner.

Number of hours during which the electric vehicle has to be plugged to a charging station: on the before specified number of days the owner ensures that the car will be plugged to a charging station at least during the specified number of hours. The possible minimum number of hours is between 0 and 14 hours per day depending on the contract. Otherwise the owner will receive a lower remuneration from the V2G contract partner.

Monthly reimbursement between 10 and 60 € per month

Price reduction for the purchase of the electric vehicle: the price reduction can amount to between 0 and 7000 Euro.

Estimation Results

The parameters used for the classification are summarized in Table 10. Additionally conditioning procedures of the answers and descriptive statistics of the data are listed.

The mean of dichotomous variables in the feature expression {0,1} corresponds to the number of responses with the expression "1". The average mileage is 53 km with standard deviation of more than 100%. In order to limit the number of regressors, the answers to the question for the "instrumental motives for case use" and the "range anxiety" were determined as mean values of questions indicated in Table 10.

In the discrete-choice experiment, it must be considered that the "optout" alternative does not impose any restrictions on usage - the minimum range is therefore fully available and can not be parameterized with 0. Thus, the minimum range in the optout case was assumed to be 150 km.

10% of the replies did not fill the income categories. In order not to completely dispense the presumably important information for the adoption of a V2G contract, in these cases the the income was estimated from the sociodemographic data with a linear regression.

Variables	Based on answers to the questions:	Domain, computation	Mean	Std.Dev.	Min	Max
Age	Q14.1.2	[Years]	46.35	15.85	19	86
Gender	Q14.1.1	{1(f),2(m)} 2->1, 1->0	0.49	0.50	0	1
Dummy age x gender	Own calculations	$[Gender \times Age]$				
Income	Q14.6.1	$[Euros]$	2509.13	1250.71	500	7000
Mileage	Q2.3a_1, Q2.3a_2, Q2.3b	[Km]	53.22	65.89	0	500
Instrumental motives for car use	Q3.1_1, Q3.1_2, Q3.1_3, Q3.1_4, Q3.1_5	per 1-7, average	4.45	1.36	1	7
„tolerant or ephemeral nature“	logical ‘or’ combination of the answers to questions Q4.1_2, Q4.1_3	1-7	0.83	0.37	0	1
Awareness of V2G	Q7.1	Answers „2“ and „3“ projected to 1; answer „1“ to 0 $\in \{0,1\}$	0.12	0.33	0	1
Support for renewables	Q5.1_1, Q5.1_2, Q5.1_3, Q5.1_4	Average 1-7	6.10	0.85	2.5	7
Range anxiety	Q11.1_r2	1-7	4.59	1.82	1	7

Table 10: Descriptive statistics of the regressors

<table>
<tr><td colspan="4">Discrete choice (multinomial logit) model</td><td colspan="4">Latent Class Logit Model</td></tr>
<tr><td colspan="4">Estimation based on N = 4888, K = 8
Inf.Cr.AIC = 11524 AIC/N = 2.385
Model estimated: Jul 28, 2015, 15:17:17
Chi-squared[6] = 2009.18330
Prob[chi squared > value] = .00000
Response data are given as ind. choices
Number of obs.= 4888, skipped 0 obs</td><td colspan="4">Restricted log likelihood -6776.20684
Chi squared [49 d.f.] 3428.32047
Significance level .00000
Estimation based on N = 4888, K = 49
Inf.Cr.AIC = 10222.1 AIC/N = 2.091
Model estimated: Jul 28, 2015, 15:17:17</td></tr>
<tr><td></td><td>Log-L fncn</td><td>R2=1-LogL/LogL*</td><td>R2Adj</td><td></td><td>Log-L fncn</td><td>R2=1-LogL/LogL*</td><td>R2Adj</td></tr>
<tr><td>Constants only</td><td>-6757.64</td><td>.1382</td><td>.1355</td><td>No coeffi-cients</td><td>-6776.2068</td><td>0.2530</td><td>0.2505</td></tr>
<tr><td>Full Model</td><td>-5823.55989</td><td></td><td></td><td>Constants only</td><td>-6757.6433</td><td>0.2509</td><td>0.2484</td></tr>
<tr><td></td><td></td><td></td><td></td><td>At start va-lues</td><td>-5754.3525</td><td>0.1203</td><td>0.1174</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Full Model</td><td>-5062.04660</td><td></td><td>McFadden Pseudo R-squared 0.2529675</td></tr>
</table>

Table 5: General informationen of the latent class model estimation

Parameters		Multinomial Logit Value	Z	Latent Class Logit Model Class 1 Value	z	Class 2 Value	Z	Class 3 Value	Z
Constant 1	β_1	0.99056 ***	7.65	3.00902 ***	8.15	2.35441 ***	4.67	1.25867 ***	3.66
Constant 2	β_2	1.14137 ***	8.83	3.19869 ***	8.22	2.50081 ***	4.86	1.39088 ***	3.81
Constant 3	β_3	1.08720 ***	8.40	3.03734 ***	8.14	2.53795 ***	5.05	1.38826 ***	4.01
Minimum range[a)]	β_m	1.17190 ***	28.19	1.52671 ***	11	3.65508 ***	12.35	0.60411 ***	4.71
Computer	β_c	0.34507 ***	9.10	0.20628 **	2.51	0.59241 ***	4.61	0.52784 ***	5.89
Days	β_t	0.02277	1.01	-0.00538	-0.12	0.00237	0.03	0.06938	1.47
Hours	β_h	-0.05343 ***	-12.74	-0.00032	-0.03	-0.07455 ***	-5.53	-0.11932 ***	-10.31
Monthly payment	β_m	0.01338 ***	14.29	0.01751 ***	8.55	0.01577 ***	5.44	0.01194 ***	5.73
Single payment	β_e	0.00020 ***	25.72	0.00031 ***	13.92	0.00026 ***	10.11	0.00011 ***	5.12
In class probability model									
Constant	θ_0			-5.10559 ***	-3.37	-5.58569 ***	-4.02		
Age	$\theta_{Age,c}$			0.05274 ***	3.47	0.05557 ***	4.11		
Gender	θ_{Sexc}			2.42512 **	2.5	2.71012 ***	3.09		
Age x Gender	θ_{AgeSe}			-0.03962 **	-2.02	-0.0497 ***	-2.75		
Income	θ_{Ek}			0.00001	0.1	0.00002	0.2		
Mileage	$\theta_{Fahr,c}$			0.00148	0.61	0.00454 **	2.07	Restricted	
Instrumental car use	θ_{Ins}			0.18297 *	1.76	0.20748 *	1.96		
Nature ephemeral	θ_{Aut}			0.13078	0.35	0.28624	0.73		
Awareness of V2G	θ_{Bek}			-0.47246	-1.11	-0.78919 *	-1.8		
Renewable support	θ_{Gre}			0.21693	1.27	0.04081	0.25		
Range anxiety	θ_{Ler}			0.08101	1.03	0.23287 ***	2.92		
Average. Class membership probability				0.40		0.27		0.34	

Table 12 Estimation Result, Note: ***, **, * == > Significance at 1%, 5%, 10% level. [a)] The logarithm of the minimum range was used, as it improved convergence and results of the estimation.

Crosstables

In the cross tables, the success of the estimation is shown. The size of the ratio of the diagonal elements of the matrices to the non-diagonal elements describes a measure of the correct decisions predicted by the model. Table 12 shows cross tables of the standard logit model and table 13 of the latent class model.

Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i):							Predicted total is N(k,j,i)=Sum(i=1,...,N) Y(k,j,i). Predicted y(ij)=1 is the j with largest probability					
	C1	C2	C3	C4	Total			C1	C2	C3	C4	Total
C1	467	262	241	252	1222		C1	690	242	214	76	1222
C2	260	536	266	282	1345		C2	222	816	214	93	1345
C3	238	266	495	266	1265		C3	187	233	751	94	1265
C4	257	281	263	256	1056		C4	289	339	277	151	1056
Total	1222	1345	1265	1056	4888		Total	1388	1630	1456	414	4888
Share correctly predicted: 36%							Share correctly predicted: 49%					

Tabelle 6: Crosstable of observed (rows) and by the standard Logit Modell predicted decisions (columns)

The predicitve success increases by the consideration of the three classes from 49 to 63% correctly relates answers.

Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i):							Predicted total is N(k,j,i)=Sum(i=1,...,N) Y(k,j,i). Predicted y(ij)=1 is the j with largest probability					
	C1	C2	C3	C4	Total			C1	C2	C3	C4	Total
C1	603	269	245	104	1222		C1	816	221	185	0	1222
C2	267	694	270	113	1345		C2	206	943	196	0	1345
C3	243	272	637	113	1265		C3	173	199	893	0	1265
C4	161	162	164	569	1056		C4	108	109	98	741	1056
Total	1275	1398	1316	899	4888		Total	1303	1472	1372	741	4888
Share correctly predicted: 51%							Share correctly predicted: 69%					

Tabelle 7: Crosstable of observed (rows) and by the standard Logit Modell predicted decisions (columns)