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Research Article

Are electric vehicle drivers willing to participate in vehicle-to-grid contracts? A context-dependent stated choice experiment

Bing Huang [a,*], Aart Gerard Meijssen [a,b], Jan Anne Annema [a], Zofia Lukszo [a]

[a] Department of Engineer System and Services, Delft University of Technology, 2628, BX, Delft, the Netherlands
[b] Pon Holdings B.V., 1076, CM, Amsterdam, the Netherlands

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ABSTRACT

Vehicle-to-grid (V2G) technology could turn electric vehicles (EVs) into a potentially valuable solution to the problem of increased load demand caused by large-scale EV integration. Successful market penetration of V2G relies not only on developing the technology itself, but also on EV drivers' willingness to participate in this technology. This paper aims to explore Dutch EV drivers' preferences for participating in V2G contracts. In particular, we conduct a context-dependent stated choice experiment to examine the impact of EV recharging technology on the V2G contract preferences. Two contexts have been designed: the current EV recharging time and fast recharging. Our results show that in the context of current recharging time, Dutch EV drivers in general prefer not to participate in V2G contracts, while the opposite is true in the context of fast recharging. With regard to specific V2G contract attributes, Dutch EV drivers are most concerned about 'discharging cycles'. Also important to them is 'the guaranteed minimum battery level', but its importance drops significantly in the fast charging context. In addition, 'monthly remuneration' and 'plug-in time' also influence people's preferences for adopting V2G. From these findings, we draw the implications for the aggregator and policy makers.

1. Introduction

Decarbonisation of the transport sector is increasingly seen as an important step towards achieving mid-term and long-term climate goals. A potential solution to transport decarbonisation is the widespread introduction of electric vehicles (EVs) around the world. For example, the European Commission strives to have at least 30 million EVs on European roads by 2030 to tackle carbon emissions from the transport sector (Abnett, 2020). However, the large-scale adoption of EVs will bring new challenges to power systems and electric utilities (Alshahrani et al., 2019; Das et al., 2020; Habib et al., 2018; Li and Lenzen, 2020; Mullan et al., 2011). A major issue is the concurrent and unmanaged recharging of EVs, which could lead to a surge in electricity demand, thereby resulting in congestion problems for power distribution and transmission networks.

Recent years have seen an increasing interest in intelligently integrating grid operations with EVs. Given that EVs have electricity stored in their batteries, the electricity can be used by feeding it back to the grid whenever the vehicle is parked. This idea is called "vehicle-to-grid" (V2G) (Gage et al., 2003; Guille and Gross, 2009; Kempton and Letendre, 1997; Kempton and Tomić, 2005). V2G gives personal EVs the potential to become a source of reserve power that can provide services to the grid during the peak demand. This means V2G could turn EVs into a potentially valuable solution to the increased power demand caused by the large-scale adoption of EVs. Moreover, the implementation of V2G technology is also expected to improve grid efficiency, smooth the integration of renewable energy, and bring economic benefits to EV owners (Denholm and Hand, 2011; Noel et al., 2017, 2019; Parsons et al., 2014).

V2G is technically ready for the market (Kempton and Tomić, 2005; Zecchino et al., 2019). However, successful V2G market penetration depends not only on the development of the technology, but also on the willingness of EV drivers to use this technology. In general, there are two ways to investigate people's preferences for a particular product or technology. One way, called the revealed preference (RP) study, is to collect actual choice data about the market. RP data has high validity, but it is subject to current market constraints. At present, only a few energy companies, such as Octopus Powerloop and OVO Energy, are conducting V2G trials. The collection of actual V2G choice data is therefore constrained by the current small-scale market and limited

* Corresponding author.
E-mail address: b.huang-1@tudelft.nl (B. Huang).

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variation in the settings of V2G trials. Another way is to collect people's behavioural intention in hypothetical choice sets by conducting stated choice experiments, called the stated preference (SP) study. Compared to RP data, SP data is more flexible and less expensive, and more importantly, it does not have to be constrained by the current market scale and conditions. Over the last few decades, a large number of studies have explored people's preferences for adopting EVs using SP data (e.g. Hidrue et al., 2011; Hoen and Koetse, 2014; Horne et al., 2005). However, when compared with the wealth of literature on preferences for EV adoption, only a handful of studies have been conducted to investigate people's intention for V2G adoption (Geske and Schumann, 2018; Kubli et al., 2018; Noel et al., 2019; Parsons et al., 2014). Sovacool et al. (2018) highlighted the lack of literature on social aspects of V2G adoption. They did a systematic literature review on V2G and found that most of the literature focused on technical aspects, but largely neglected the social elements of V2G, especially people's preferences and social acceptance. Therefore, more empirical studies on people's preferences for V2G adoption are highly needed to enrich the V2G literature.

Previous V2G preference studies have mainly focused on exploring the influence of different V2G contract attributes on the willingness to participate in the V2G contract (Geske and Schumann, 2018; Kubli et al., 2018; Parsons et al., 2014; Zonneveld, 2019). The V2G contract is a contractual agreement between EV owners and an actor called the aggregator. The role of the aggregator is to coordinate V2G and participate in the market on behalf of EV owners (Lee et al., 2018). A V2G contract consists of several contract attributes which specify the extent to which the aggregator is allowed to manage the EV's battery. EV drivers who sign V2G contracts have an obligation to have their vehicles plugged in for a specified number of hours per day or month. This provides the aggregator with the certainty of power capacity but causes inconvenience to EV owners. Thus, V2G contracts often include the amount of remuneration paid to compensate for the inconvenience. Common V2G contract attributes include a cash back payment, required plug-in time, the guaranteed minimum driving range, contract duration, etc. In the next section, there will be a detailed discussion of V2G contract attributes commonly used in existing literature.

In addition to contract attributes, the technical performance of EVs is also expected to influence people's willingness to participate in the V2G contract. Many studies have shown that the current technical restrictions of EVs, such as long recharging time, are the barriers to the widespread adoption of EVs (e.g. Coffman et al., 2017; Hidrue et al., 2011). Such restrictions can be also seen as potential barriers to the adoption of V2G. However, little research has been done to examine the impact of these technical restrictions on V2G adoption. Parsons et al. (2014) expressed a need to examine the interaction between EV recharging time and the guaranteed minimum driving range (one V2G contract attribute specified in their experiment). For example, it is expected that if EV drivers have a fast recharging time, their "range anxiety" will be greatly alleviated. At present, both EV technology and V2G technology are being further developed. It would be interesting and valuable to consider the ongoing development of EV technology, in particular EV battery technology, in the study of the adoption of V2G programmes.

The goal of this paper is to (1) contribute to the literature on the adoption of V2G by exploring Dutch EV drivers' preferences for participating in V2G contracts in terms of different contract attributes and (2) assess the impact of future battery technology (i.e. fast recharging) on the preferences for V2G contracts. For the first goal, we have conducted a stated choice experiment in which EV drivers were provided with various V2G contract schemes. To achieve the second goal, the experiment was designed as a context-dependent experiment. More specifically, the choice sets of the experiment were presented in two different contexts concerning EV recharging time: the current recharging time and fast recharging. Through this context-dependent experiment, we aim to explore the impact of EV recharging time on the general preference for V2G contracts and the interaction effect between EV recharging time and the guaranteed minimum battery level of the EV.

The remainder of this paper is structured as follows: Section 2 first introduces V2G contract attributes and a context variable used in this study, and then presents a conceptual framework. Section 3 introduces data collection and the estimated model. Model estimation results are elaborated in Section 4. Section 5 presents conclusions and policy implications. Limitations and recommendations for future research are given in Section 6.

2. V2G contract attributes and a context variable

This section first reviews V2G contract attributes used in current literature and also discusses how these attributes will be applied in this study. It then introduces a context variable, EV recharging time, which is used in the context-dependent experiment. Finally, this section presents a conceptual framework which shows how the preference for adopting V2G programmes is measured in this study.

2.1. V2G contract attributes

2.1.1. Remuneration

Remuneration is always considered in V2G contracts to reward EV drivers for supplying electricity to the grid as well as to compensate for the inconvenience brought about by connection requirements. In previous studies, remuneration was often set as a fixed cash payment. For example, Parsons et al. (2014) designed six levels for annual cash back in their experiment, ranging from $500 to $5000. Geske and Schumann (2018) designed two types of remuneration in V2G contracts: a fixed monthly payment ranging from €15 to €60 per month, and a one-time payment ranging from €1000 to €7000. Both studies found that remuneration has a positive impact on the willingness to participate in V2G contract schemes. In addition to fixed remuneration, there is another type of payment called "pay-as-you-go". Fixed remuneration is often related to a pre-specified plug-in time in contracts, whereas "pay-as-you-go" does not restrict the plug-in time and EV drivers get paid depending on the capacity they provide. Although "pay-as-you-go" provides flexibility for EV drivers, it cannot guarantee the certainty of storage capacity for the aggregator. This type of payment is thus not preferable for V2G contracts. In this study, we consider two types of remuneration. One is *fixed monthly remuneration* rewarded to EV drivers for a certain required plug-in time. Another type is *extra remuneration* rewarded for every extra hour outside the plug-in time obligation. We expect these two types of remuneration to have a positive effect on the willingness to participate in V2G contracts.

2.1.2. Plug-in time

Most previous studies have considered plug-in time restrictions in the V2G contract. Plug-in time restrictions can provide the certainty of power capacity and ensure the reliability of the system. Parsons et al. (2014) defined the plug-in time as the average daily plug-in time over the month. This gives some flexibility to EV drivers as they can arrange the plug-in time (more or fewer hours on a certain day) based on their own schedules. In Parson et al.'s study, they found a negative effect for this attribute, and the effect was non-linear, implying that EV drivers dislike long plug-in times and the degree of the dislike increases with the extension of the plug-in time. Geske and Schumann (2018) tested two types of plug-in time restrictions. One was minimum plug-in time per working day and the other was the minimum number of days per week that EVs have to be connected to the grid. Only the former was found to have a significant impact on the willingness to participate. In this study, we adopt Parsons et al. (2014)'s *average daily plug-in time* as a V2G contract attribute. Plug-in time restrictions inconvenience EV drivers, thus we expect a negative impact.

2.1.3. Guaranteed minimum battery level

Parsons et al. (2014) and Geske and Schumann (2018) included the guaranteed minimum driving range in the V2G contract. Both studies found a positive effect on the willingness to participate in V2G contracts. Kubli et al. (2018) considered the guaranteed charging level in their study, expressed in percentages. Given that different types of EVs have different practical driving ranges, it is relatively difficult for the aggregator to manage the number of ranges available for different EVs. Therefore, in this study we adopt the guaranteed charging level in our V2G contract schemes. Specifically, we define this attribute as the *guaranteed minimum battery level*, expressed in percentages. Take an EV with a driving range of 300 km as an example. A minimum battery level of 50% corresponds to a minimum driving range of 150 km. It is found that EV drivers are highly concerned about driving ranges. As higher battery levels correspond to longer driving ranges, we expect this attribute to have a positive impact.

2.1.4. Discharging cycles

Battery degradation has been widely discussed in the V2G literature. Although it is argued that V2G has the potential to improve battery lifetime (Uddin et al., 2018), mainstream V2G literature holds the view that V2G may shorten battery life expectancy due to the increased number of battery charge cycles (Marongiu et al., 2015; Parsons et al., 2014; Wang et al., 2016). Geske and Schumann (2018) considered the concern that V2G might shorten battery life in their model, but no significant effect was found. Zonneveld (2019) included battery degradation in the design of V2G contracts. Three attribute levels were set: one, four, and seven discharging cycles per session, which represents a minimum, moderate, and large impact on battery lifetime. He found that limiting the number of discharging cycles in the contract can increase the participation rates of V2G programmes. In this study, we also consider battery degradation in the design of V2G contracts. As in Zonneveld (2019), this attribute is defined as *the number of discharging cycles* per *session*. We expect the number of discharging cycles to have a negative impact on the willingness to participate in V2G contracts.

2.1.5. Contract duration

Contract duration was included as a V2G contract attribute in Kubli et al. (2018) and Zonneveld (2019). It is defined as the length of the contract between an aggregator and an EV owner. Kubli et al. (2018) varied the contract duration from zero to 48 months. Zonneveld (2019) based the contract duration on contracts for phone subscriptions, i.e., one month, one year or two years. Interestingly, contradicting results were found in these two studies: Kubli et al. (2018) found that people preferred a shorter contract duration, while Zonneveld (2019) obtained an opposite result. In this study, we also consider contract duration in the V2G contract. Long contract duration may reduce the flexibility of contracts, so we expect this attribute to have a negative impact.

2.2. Context variable

Currently, many EV companies and development departments are trying to develop batteries with a faster recharging speed, some claiming they will be able to charge an EV to 80% or 100% within 5 min in the near future (Schmidt, 2019; Slav, 2020). As discussed in Section 1, ongoing developments in EV technology, especially in EV battery technology, would also influence people's willingness to participate in V2G programmes. In this study, we include recharging time as a context variable, with the aim of examining the interaction between recharging time and the guaranteed minimum battery level, as well as exploring the influence of recharging time on people's preferences for V2G contracts. This context variable is set to two levels. The first level is the respondent's current recharging time. The second level is a hypothetical future scenario where respondents can recharge their cars within 5 min. Although recharging EVs within 5 min will probably not be the case in the very near future, the impact of battery technology developments on "future" V2G adoption can be measured using such a context-dependent experiment.

Fig. 1 presents a conceptual framework based on the above-mentioned V2G contract attributes and EV recharging time as the context variable. The preference for adopting V2G is measured essentially through observing choices from a given set of V2G contracts. In particular, we apply the random utility maximization (RUM) decision rule (McFadden, 1973) which assumes that people choose the V2G contract which can bring them the maximum utility.

3. Data collection and the estimation model

3.1. Survey, data collection and sample

The survey consisted of four main sections. The first section started with two simple questions. As our target respondents were full EV drivers, the first question was to investigate whether a respondent currently owns a full EV, a plug-in hybrid EV, or another type of vehicles. Only the respondents who owned a full EV would continue with the remaining part of the survey.[1] The second question was to determine the share of respondents who had heard of the concept of V2G. The second section provided respondents with general information concerning V2G and explanations about the survey. Specifically, a short video clip was embedded in the online survey; it explained the concept of V2G and introduced contract attributes used in the survey. In the paper-pencil version, full explanations and instructions were provided in writing. The third section presented choice sets which were described using the contract attributes introduced in Section 2.1. For each choice set, respondents were requested to first choose their preferred option from two hypothetical V2G contract options and an opt-out alternative 'no V2G'; then respondents were requested to choose only between two hypothetical V2G contract options. In the final section, respondents were asked to fill in some questions regarding socio-demographics.

Data collection was conducted during late May to early July 2019 in

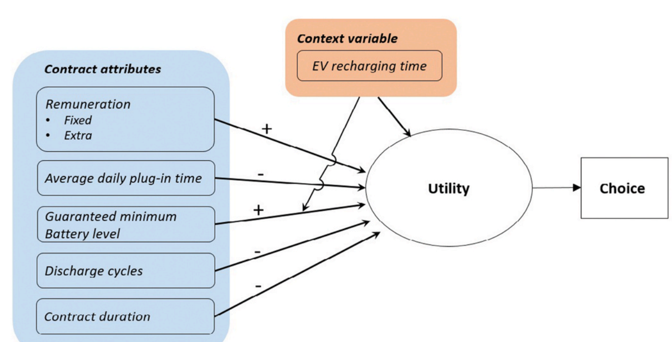

Fig. 1. Conceptual framework for EV drivers' V2G preference.

[1] Note that fuel cell vehicles and plug-in hybrid vehicles can also be compliable with V2G, but this paper only focuses on battery electric vehicles.

Table 1
Statistics of the first section and sample characteristics.

Items		Value	Share
Statistics of the first section ($N = 157$)	Car type	Full EV	99%
		Plug-in hybrid EV	1%
		another type of vehicles	0%
	Knowledge about the "vehicle-to-grid" concept	Heard of and know the concept	48%
		Heard of but do not know	18%
		Never heard of it	34%
Socio-demographics ($N = 148$)	Gender	Male	86%
		Female	14%
	Age	18–24	7%
		25–34	19%
		35–44	26%
		45–54	18%
		55–64	26%
		65+	4%
	Education level	No high-level education	39%
		High-level education[a]	59%
		Unknown	2%

[a] High-level education represents higher vocational or university education.

the Netherlands, specifically within the cities of Amstelveen, Badhoevedorp (Schiphol) and Zwolle. Respondents were approached at random at EV charging points with an invitation to fill out a paper-pencil survey or a flyer containing a link of the online version. The final sample contains 148 respondents who completed the survey either using the paper-pencil ($N = 42$) or the online ($N = 106$) version. The statistics of the first section and the socio-demographic characteristics of the final sample are given in Table 1.

From Table 1, we can see that almost half of the respondents have heard of and also know the V2G concept, while only one third expressed that they had never heard of this concept. After inspecting the socio-demographics of the sample ($N = 148$), we notice that the majority of the respondents were male (86%) and about 60% of the respondents were highly educated. Although socio-demographic statistics of the Dutch EV driver population are not available, a recent survey (Hoekstra and Refa, 2017) among Dutch EV drivers shows that the majority of the population are male (around 90%), and more than half of the respondents are highly educated. Therefore, our sample is sufficiently representative of Dutch EV drivers.

Table 2
Contract attributes used in the stated choice experiment.

Attributes	Attribute levels
Fixed monthly remuneration [€]	€ 20.00 per month
	€ 60.00 per month
	€ 100.00 per month
Extra remuneration [€]	No variable extra remuneration
	€ 0.15 per extra hour plugged-in outside of contract per day
	€ 0.30 per extra hour plugged-in outside of contract per day
Guaranteed minimum battery level [%]	10%
	30%
	50%
Average daily plug-in time [hours/day]	5 h per day
	10 h per day
	15 h per day
Discharging cycles [#/session]	1 time per session
	4 times per session
	7 times per session
Contract duration [months]	6 months
	12 months
	24 months

3.2. Stated choice experiment design

In the stated choice experiment, hypothetical V2G contracts were described using six contract attributes, which have been amply discussed in Section 2.1. Each attribute has three levels, as shown in Table 2. The levels of the six attributes were set in accordance with previous studies and the current situation in the Netherlands. More specifically, fixed remuneration was set at €20, €60, or €100 per month, and extra remuneration was €0, €0.15, or €0.30 per extra hour. In terms of average daily plug-in time, Parsons et al. (2014) set the level at 5–20 h per day, and Geske and Schumann (2018) set it at 0–14 h per day. In this study, considering that there are three levels, this attribute was restricted to 5, 10, or 15 h. The setting of guaranteed minimum battery level is related to the typical EV driving range and the average car driving range. Currently, the driving range of some popular EV options has already reached about 250–350 km (e.g. Nissan Leaf), while the average car driving range is only 36 km per day in the Netherlands (StatisticsNetherlands, 2018). The guaranteed minimum battery level of 10%, 30%, or 50% was chosen to cover the average daily driving range, as well as to ensure the certainty of power capacity to the aggregator. As for discharging cycles, we adopt the level of 1, 4, or 7 times per session as described in Zonneveld (2019). The contract duration level was set at 6, 12, or 24 months, representing a short, moderate, and long duration contract respectively.

Each respondent was presented with nine choice sets generated using a so-called D-efficient design (Rose and Bliemer, 2009). To conduct such a design, prior expectations for all attributes are needed to increase the efficiency of the design. The priors used here were obtained from a small pilot study ($N = 31$). The software, Ngene, was used to generate an efficient design with nine choice sets. As 148 respondents completed the survey, we eventually obtained 1332 choice observations. For each choice set, the respondents had to first select from two V2G contract options or the "no V2G" option, and thereafter select only one of the two V2G contract options.

As elaborated in Section 2.2, recharging time was added as a context variable at two levels: the current recharging time and fast recharging within 5 min. These two contexts were randomly presented to the respondents within the nine choice sets. This means, in one survey, each choice set was shown either in the context of current recharging time or in the context of fast recharging, the chance was fifty-fifty. Eventually, the context of current charging time was presented 674 times, and fast charging was presented 658 times. Fig. 2 gives the examples of the same choice set under two different contexts.

3.3. The estimation model

The theoretical foundation for the analysis of our data is based on the RUM framework (McFadden, 1973). The RUM model assumes that when making choices from a choice set, the decision maker chooses an alternative which brings him/her the maximum utility. The chosen alternative's utility is composed of a systematic utility and a random part. The total utility of alternative i chosen by a respondent is expressed by

$$U_i = V_i + \varepsilon_i, \tag{1}$$

where V_i denotes the systematic utility, and ε_i denotes the random component. More specifically, the collected data were estimated using the Multinomial Logit (MNL) model (McFadden, 1973; Train, 2009) in which three alternatives (two V2G contract options and the opt-out alternative) are modelled. The alternative-specific constant is added to the model to capture the general preference for V2G options compared to "no V2G". The systematic utility function for two V2G alternatives (i = V2G contract A or B) is defined as follow:

$$V_i = \delta + \delta' RT + \beta_{REM} REM_i + \beta_{EREM} EREM_i + \beta_{GBL} GBL_i + \beta_{PLUG} PLUG_i + \beta_{DIS} DIS_i + \beta_{CD} CD_i + \beta_{PLUG^2} PLUG_i^2 + \beta_{GBL_{RT}} RT \cdot GBL_i, \tag{2}$$

If your recharging time is the same as it is now, which option would you choose?

Contract attributes	V2G contract A	V2G contract B	
Remuneration	**€20** per month + **€0.30** per extra hour outside of the contract	**€100** per month + **€0.00** per extra hour outside of the contract	**No V2G**
Guaranteed minimum battery	**10%**	**30%**	
Average daily plug-in time	**5** hour per day	**10** hour per day	
Discharging cycles	**7** times per session	**1** time per session	
Contract duration	**24** month	**6** month	
Your most preferred option	○	○	○
Your preferred V2G contract	○	○	

(a) The context of current recharging time

If you can recharge your car within 5 minutes, which option would you choose?

Contract attributes	V2G contract A	V2G contract B	
Remuneration	**€20** per month + **€0.30** per extra hour outside of the contract	**€100** per month + **€0.00** per extra hour outside of the contract	**No V2G**
Guaranteed minimum battery	**10%**	**30%**	
Average daily plug-in time	**5** hour per day	**10** hour per day	
Discharging cycles	**7** times per session	**1** time per session	
Contract duration	**24** month	**6** month	
Your most preferred option	○	○	○
Your preferred V2G contract	○	○	

(b) The context of fast recharging

Fig. 2. Examples of one choice set under different contexts (Translated from Dutch).

where δ is the constant associated with V2G alternatives[2] (the constant for "no V2G" is normalized to zero in its utility function), and β_{REM}, β_{EREM}, β_{GBL}, β_{PLUG}, β_{DIS}, β_{CD} are the coefficients associated with fixed monthly remuneration (REM), extra remuneration (EREM), guaranteed minimum battery level (GBL), average daily plug-in time (PLUG), discharge cycles (DIS), and contract duration (CD). Apart from linear-additive forms, the quadratic component is also included in the utility function. Specifically, parameter β_{PLUG^2} is the coefficient associated with the quadratic component of plug-in time ($PLUG^2$). In addition, recharging time (RT) is included in this utility function as a context variable. When estimating the model, we encoded this variable as either zero or one: $RT = 0$ when the context is the current recharging time; $RT = 1$ when the context is fast recharging. The two additional parameters δ' and $\beta_{GBL_{RT}}$ are both related to the variable RT. The parameter δ' captures the change in the constant under different contexts. In the context of the current recharging time, the constant for V2G is captured only by δ, while in the context of fast recharging, the constant for V2G is $(\delta + \delta')$. The parameter $\beta_{GBL_{RT}}$ captures the interaction effect between the attribute GBL and the variable RT; it indicates how the coefficient of attribute GBL changes with the recharging time. Specifically, when the context is the current recharging time, the coefficient of attribute GBL is β_{GBL}; when the context changes to fast recharging, the coefficient associated with GBL is $(\beta_{GBL} + \beta_{GBL_{RT}})$.

In the MNL model, the random component ε_{in} is assumed to follow an i.i.d Extreme Value Type I distribution, which leads to a closed form for

[2] The constant for the "no V2G" alternative is normalized to zero. Thus, in this study, the systematic utility for "no V2G" is zero in the model: $V_{no\ V2G} = 0$.

the choice probability. The probability of choosing alternative i over alternative j is $P_i = \frac{e^{V_i}}{\sum_{j \neq i} e^{V_j}}$.

4. Results

This section first presents statistics on choosing the "no V2G″ option under two contexts, which reveals changes in EV drivers' participation rates between two different recharging situations. Next, we elaborate on the result of the MNL model which reveals EV drivers' preferences for V2G contracts in terms of different contract attributes. Based on the model estimation result, we also simulate the participation rate of V2G programmes under different scenarios and calculate the value of willingness-to-pay for contract attributes.

4.1. Statistics on choosing "no V2G″

As described in Section 3.2, the respondents were asked to first choose among three choice options: two V2G contracts and a "no V2G″ option. These choices were made in two different contexts: current recharging time and fast recharging. Table 3 gives the share of choosing the "no V2G″ option in nine choice sets in two contexts. For each choice set, the share of choosing "no V2G″ is larger in the former context than it in the latter. This means the V2G participate rate is higher when the context is fast recharging. Take Choice set 7 as an example. Almost half of the respondents were reluctant to choose any of the V2G contract options, but this ratio reduced to one third in the context of fast recharging. This indicates that the recharging time of EVs does influence people's willingness to participate in V2G schemes; more people will participate in V2G if recharging time can be reduced considerably, such as reduced to 5 min in this experiment.

4.2. Model estimation result

The MNL model is estimated on data that contains choices made among two V2G contracts and the opt-out alternative. The model estimation result is presented in Table 4. We first look at the estimates of the constant. The parameter δ captures the general preference for participating in V2G contracts over the "no V2G″ alternative in the context of the current recharging time. The parameter δ' captures the change in general preference when the context shifts to fast recharging. The result shows that both parameters are highly significant, and as expected, the parameter δ is negative. With these estimates, we can obtain the constant associated with V2G in different contexts: in the context of the current recharging time, the constant for V2G over "no V2G″ is -1.03; while in the context of fast recharging, it becomes positive: $-1.03 + 1.29 = 0.26$.

We then move to main coefficients. Coefficients β_{REM},β_{GBL} and β_{DIS} are statistically significant and of the expected sign. Although the negative sign for the coefficient β_{EREM} is counter-intuitive, it is not significantly different from zero. The coefficient β_{PLUG} is not significant, but the parameter β_{PLUG^2} enters the model significantly and with the expected sign. As for the coefficient β_{CD}, it is negative as expected, but not statistically significant.

The result also shows that the parameter $\beta_{GBL_{RT}}$, which captures the interaction effect between the attribute GBL and the context variable *RT*, is estimated to be highly significant. With this parameter, we can compute the weight of the attribute GBL under the two contexts. Specifically, in the context of the current recharging time, the weight of the attribute GBL is 0.0437; in the context of fast recharging, it decreases to 0.0202. It can be clearly seen that the weight of the attribute GBL is almost halved when the recharging time changes to fast recharging.

Table 4
Model estimation result.

		Multinomial Logit Model		
		Estimate	*s. e.*	*t-value*
V2G constant	δ	−1.03	0.373	2.77
Changes in the constant	δ'	1.29	0.203	−6.36
Fixed remuneration (*REM*)	β_{REM}	0.0074	0.001	6.66
Extra remuneration (*EREM*)	β_{EREM}	−0.0878[a]	0.289	−0.30
Guaranteed minimum battery (*GBL*)	β_{GBL}	0.0437	0.004	10.76
Guaranteed minimum battery × Recharging time (*RT*)	$\beta_{GBL_{RT}}$	−0.0235	0.005	−5.01
Plug-in time (*PLUG*)	β_{PLUG}	0.0376[a]	0.068	0.56
Plug-in time × Plug-in time (*PLUG*^{2})	β_{PLUG^2}	−0.0085	0.003	−2.53
Discharge cycles (*DIS*)	β_{DIS}	−0.0504	0.016	−3.13
Contract duration (*CD*)	β_{CD}	−0.0319[a]	0.047	−0.68
Number of observations		1332		
Null Log-likelihood		−1463		
Final log-likelihood		−1345		

[a] Represents the parameter is not significant at the 95% level.

After inspecting the significance of each estimate, we proceed to a more detailed analysis of the model estimation result. The estimates of the alternative-specific constant reveal people's general preference for participating in V2G contracts. As expected, under the current recharging situation, there is a general preference for the "no V2G″ option over the V2G options. However, it is of great interest to see that the general preference is reversed when the context changes to fast recharging: people show a preference for the V2G options in the context of fast charging. This indicates that currently Dutch EV drivers are very reluctant to participate in V2G programmes, but the general preference for V2G would increase considerably if fast charging could be widely implemented in the future.

The result shows that the fixed monthly remuneration has a positive and highly significant impact on the V2G choices. This suggests that the higher the fixed amount of remuneration provided, the more likely EV drivers will participate in V2G contracts. Similar results were found in previous studies (Geske and Schumann, 2018; Parsons et al., 2014; Zonneveld, 2019). However, another financial attribute, extra remuneration, has no prominent impact on the preference for V2G contracts. A possible explanation is that extra financial compensation is related to extra plug-in time, as the respondents show a great dislike for increasing plug-in time (see the discussion below), they are unwilling to extend the plug-in time even when there is more financial compensation.

As expected, the guaranteed minimum battery level has a very strong and positive impact on the willingness to participate in V2G. This attribute is related to the guaranteed minimum driving range. The higher the battery level, the larger the driving range. Short driving ranges will arouse drivers' anxiety. Therefore, EV drivers prefer a high guaranteed battery level when participating in V2G contracts. This coincides with the findings in previous studies (Geske and Schumann, 2018; Kubli et al., 2018; Noel et al., 2019; Parsons et al., 2014; Zonneveld, 2019). In addition, we find that people's preferences for the guaranteed minimum battery level are strongly influenced by EV

Table 3
Share of respondents that chose the "no V2G″ option.

Choice set	1	2	3	4	5	6	7	8	9
Current recharging	39%	30%	28%	19%	41%	45%	48%	32%	24%
Fast recharging	22%	22%	19%	11%	33%	37%	32%	25%	15%

recharging time. When the context is the current recharging time, EV drivers are much concerned about the guaranteed minimum battery level. However, the concern is greatly reduced when they can quickly recharge their EVs. This indicates that EV drivers' demand for a high battery level (or a large driving range) can be compensated by a fast recharging speed. This also corresponds with expectations.

Long plug-in time is expected to cause much inconvenience to EV drivers. The quadratic component of plug-in time enters the model negatively, showing that plug-in time has a negative effect on the preference for V2G contracts, and the effect is non-linear. This is in line with the findings in Parsons et al. (2014): people dislike long plug-in time, and the degree of dislike is more intense with the increase of the plug-in time.

Discharging cycles have a strong negative effect on the preference for V2G. The higher the number of discharging cycles, the stronger the dislike. This is in line with expectations. Among all V2G contract attributes, discharging cycles are the attribute that EV drivers are most concerned about. Discharging cycles are related to battery degradation. As the high number of discharging cycles may affect the longevity of the battery, it is not surprising to see that people show a strong dislike for this attribute.

With regards to contract duration, although the sign for this attribute is negative as expected, there is no clear evidence that people are concerned about the duration of V2G contracts.

4.3. Model application: V2G participation rates under different scenarios

The model estimation result implies that EV recharging time significantly influences people's general preferences for V2G. In order to further illustrate the impact of EV recharging time, we simulate people's participation rates of V2G under different scenarios, as shown in Table 5. In addition to EV recharging time, the scenarios also vary in the amount of monthly remuneration. The base scenario is set as follows: EV recharging time is the current level, the monthly remuneration is €20, the guaranteed minimum battery level is 10%, average daily plug-in time is 10 h, and the discharge cycles are 7 times per session. The first scenario is to implement fast recharging: compared to the base scenario, the participation rate of V2G significantly increases from 18.7% to 43.5%. In scenarios 2 and 4 where the monthly remuneration changes to €50 and €100, the participation rates of V2G slightly increase to 21.5% and 29.2%, respectively. In addition to financial incentives, scenarios 3 and 5 also include the implementation of fast recharging. We can see a significant increase in the participation rates of V2G in these two scenarios, reaching more than 50%. The simulation result implies that (1) EV recharging time has a significant impact on the participation rate of V2G programmes; the implementation of fast recharging will greatly facilitate the widespread adoption of V2G; (2) although financial compensation also has a positive impact on the participate rate, its impact is relatively minimal, compared to the implementation of fast recharging.

Table 5
Participation rates of V2G in different scenarios.

Scenarios	Participation rates (%)
0: Base scenario	18.7
1: Implement fast recharging	43.5
2: Increase remuneration to €50 per month	21.5
3: Increase remuneration to €50 per month and implement fast recharging	50.9
4: Increase remuneration to €100 per month	29.2
5: Increase remuneration to €100 per month and implement fast recharging	63.0

4.4. Willingness to pay or get calculations

With the estimate of the financial attribute (i.e., β_{REM}), we calculate EV drivers' willingness to pay or get (WTP/G) for changes in the contract attributes. The marginal WTP/G values for changes in three contract attributes are summarized in Table 6. Specifically, for the attributes GBL and DIS, the marginal WTP value is computed as the ratio of the corresponding coefficient's estimate to the attribute REM's estimate: $MWTP_m = \beta_m/\beta_{REM}$. As for the attribute PLUG that enters the model in a quadratic form, the marginal WTP is computed as $MWTP_{PLUG} = (2 * \beta_{PLUG^2} * PLUG)/\beta_{REM}$. In this case, both β_{PLUG^2} and the level of the plug-in time play a role in the calculation of WTP. Moreover, as the estimate of attribute GBL is influenced by the context of recharging time, attribute GBL has two marginal WTP values under the contexts of current and fast recharging respectively.

Table 6 shows that, for every 1% increase in guaranteed minimum battery level, EV drivers are willing to spend about €6 per month. However, it reduces to about €3 per month if they can quickly recharge their cars. On the other hand, it implies that every 1% reduction in the guaranteed minimum battery level needs €6 financial compensation per month for EV drivers under the current recharging level, while it reduces to €3 under fast recharging. In our sample, the average driving range of EVs with a full battery level is approximately 280 km, thus 1% battery level corresponds to 2.8 km. Therefore, the reduction of 1 km in the guaranteed driving range is valued at about €2 per month, while under the situation of fast recharging, it reduced to about €1 per month.

The marginal WTG value for the attribute PLUG increases with the level of plug-in time. For example, if the plug-in time is 5 h per day, then one extra plug-in hour would result in around €12 compensation demanded per month, while if the plug-in time is 15 h per day, then one extra hour would create about €35 compensation per month. This also explains the insignificance of the attribute EREM in the estimation result. The maximum level of remuneration for the extra plug-in time is set at €0.3 per day in this experiment, so the maximum monthly compensation provided in the experiment is €9. This value is much lower than the marginal WTG value even in the case of 5 h plug-in time per day.

The marginal WTG calculation shows that, on average, EV drivers are willing to get about €7 financial compensation for one extra discharging cycle per session. Compared to the cost of battery degradation, this value seems to be very high. If we adopt the degradation cost of $0.042/kwh according to Peterson et al. (2010), the degradation cost for a Nissan Leaf with a 50 kwh battery is about €1.8 per cycle, and the cost for a Tesla Model S with a 100 kwh battery is about €3.6 per cycle. Since the battery is rarely fully discharged, the values would be even lower. This may indicate that our respondents show an excessive concern about battery damage caused by discharging cycles.

Table 6
The marginal WTP/G values for changes in V2G contract attributes (€/month)[a].

	Current recharging	Fast recharging
Guaranteed minimum battery level increase of 1%	5.91	2.73
When the plug-in time is *t* h/day, increase of 1 h plug-in time	2.30*t*	2.30*t*
Discharge cycles increase of 1 time per session	6.81	6.81

[a] The negative sign of the WTP values for plug-in time and discharge cycles are omitted, as the positive values for these two attributes are interpreted as the willingness-to-get.

5. Conclusions and policy implications

5.1. Conclusions

This study investigated Dutch EV drivers' preferences for participating in V2G contracts when the aggregator provided various contract schemes, which sheds light on the potential of implementing V2G in the Netherlands. Moreover, we explored the effect of recharging time on the V2G preference, by observing choices made under the contexts of current recharging time and fast recharging, respectively. Our results showed that the rates of "no V2G" being chosen dropped dramatically in the context of fast recharging, compared to the context of current recharging time. This implies that future technology development regarding EV recharging time is expected to facilitate the widespread adoption of V2G.

The MNL model was estimated on data that contains two V2G options and the opt-out option. The estimation result showed that four attributes hypothesized in the conceptual model played a role in the preference for V2G contracts. Specifically, we found that Dutch EV drivers prefer a larger amount of monthly remuneration and a higher level of guaranteed minimum battery. Discharging cycles are the attribute that EV drivers are most concerned with. Moreover, Dutch EV drivers also exhibit a strong dislike for a long plug-in time; the degree of the dislike increases with the required plug-in time. The contract duration seems to have no impact on their preferences for V2G.

Another contribution of this study is that we examined the interaction between EV attributes and V2G contract terms, and to our knowledge, this has not been studied before in existing literature. The interaction between recharging time and the guaranteed minimum battery level was highly significant. The guaranteed minimum battery level is one of the most important attributes to Dutch EV drivers. However, the importance of this attribute reduced dramatically when the EV could be recharged in a shorter time. This means with the development of EV battery technology, the guaranteed minimum battery level will not be a barrier to the widespread adoption of V2G.

5.2. Policy implications

The results of this study can provide implications and marketing strategies for aggregators. First, the development of EV technology can be very beneficial to aggregators. "Range anxiety" has long been considered as a major barrier to the large-scale adoption of EVs. Without a doubt it will also be a barrier to V2G adoption. As found in this study, people are very concerned about the guaranteed minimum battery level set in V2G contracts. But such concern may disappear when recharging time can be greatly shortened. For aggregators, if fast charging can be widely implemented, there seems to be no need to worry about the setting of the guaranteed minimum battery level when designing V2G contracts. The discomfort of a low battery level can be compensated with fast recharging time. Second, a long plug-in time in V2G contracts may frighten people away. Keeping the vehicle plugged in for a long time largely constrains EV drivers' freedom and flexibility. We offer two suggestions for this: (1) the aggregator should set flexible plug-in time in contracts, like an average daily plug-in time (as it is in this study) rather than a fixed amount of time per day, in order to return some flexibility to EV drivers; (2) the aggregator can design different contracts according to EV drivers' charging locations. Wolbertus et al. (2018) pointed out that average plug-in time for Dutch EV drivers who charge their cars at home is about 15.3 h per day. For this group of people, there can be a relatively long plug-in time included in the contract, while for other people who always charge at their work places or who use public charging infrastructures, a shorter plug-in time specified in contracts is recommended.

This study also provides several implications and recommendations for policy makers. First, our study reveals the potential for implementing V2G in the Netherlands. Almost half of the respondents indicated that they had heard about V2G or knew the concept, which implies that there are a considerable number of Dutch EV drivers who have some basic knowledge of V2G, and these people can be seen as the first group of potential V2G participants. Increasing the general public's awareness of V2G can enlarge the number of potential participants. Second, our study shows the importance of EV technology development to the widespread adoption of V2G. For policy makers, incentivizing innovation and investment in EV battery technology and fast charging infrastructures can stimulate not only the EV market but also the V2G market. For fast charging, we recommend focusing on the construction of public fast charging infrastructures. In the Netherlands, for example, the 3x25 A connection is the standard home connection which is, by far, not suitable for quickly charging an EV at home. A massive reinforcement of the distribution network is not cost-efficient, therefore the construction of public fast charging infrastructures needs to be accelerated to make V2G truly attractive to EV users.

An important question is: to what extent is a suitable business V2G model possible? Baser (2020) interviewed eleven Dutch experts and people working in the electricity market about their views. Their shared opinion was clear: the current market is not ready (at all) for a mature business model. They pointed out the three main barriers to a positive business model: technical, institutional and standardization issues. In this study, we provide two recommendations regarding institutional and standardization issues. One of the barriers towards a mature market is the relatively small EV market. There is no doubt that an increased market share of EVs needs to be maintained or implemented. The Dutch government recently released a new subsidy scheme to further implement EVs: up to €4000 subsidy for a new EV and up to €2000 subsidy for a used EV. Such incentive policies may effectively stimulate the EV market, creating an essential prerequisite for implementing V2G in the future. Second, governmental regulations that define interoperable V2G standards are much needed in order to overcome the standardization barrier. Currently, there are only a few numbers of EVs that are compatible with V2G, such as the Nissan Leaf and Mitsubishi Outlander. Both models apply the Japanese protocol standards for V2G services. Governmental regulations could be designed and even be introduced at a European level in order to guide the V2G market in the future.

6. Limitations and recommendations for future research

One limitation of this study is that the respondents' socio-demographics were not included in the modelling framework, which could be explored in future studies. As the average preference investigation only tells part of a story, advanced choice models considering taste heterogeneities (e.g., Latent class models) could provide deeper insights into the preference for V2G use. This would allow aggregators to design V2G contracts that are customized for different categories of EV drivers. Previous studies, such as Parsons et al. (2014) and Geske and Schumann (2018), have used the Latent class approach to analyse V2G preference. It was found that socio-demographic variables, such as gender, age, or lifestyle, can play a role. Furthermore, our study focuses on investigating EV drivers' preference regarding V2G, so the choice experiment was only conducted among EV drivers. This is a unique feature compared to previous studies. However, there might be a selection bias due to only focusing on EV drivers, as pointed out by one reviewer. Current EV drivers are predominantly well-educated males with high income and they might pay more attention to environmental protection and energy saving than the average. This group of people may have homogeneity in their choice behaviour. Therefore, it would be interesting to conduct large-scale surveys of potential EV users or general drivers for future research, for example combining EV leasing with V2G services.

CRediT authorship contribution statement

Bing Huang: Conceptualization, Formal analysis, Writing – original draft, Supervision, Writing – review & editing. **Aart Gerard Meijssen:** Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Jan Anne Annema:** Conceptualization, Supervision, Writing – review & editing. **Zofia Lukszo:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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