Increasing participation in V2G through contract elements

Examining the preferences of Dutch EV users regarding V2G contract elements using a stated preference experiment

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A B S T R A C T

The increased usage of Electric Vehicles and Renewable Energy Sources causes issues regarding the balancing of the electricity grid. To avoid investment costs, Distribution System Operators desire flexibility solutions. One of these flexibility solutions is the usage of the battery of the Electric Vehicle as an electricity source. This concept is known as Vehicle to Grid (V2G). However, providing V2G services might cause discomfort for the Electric Vehicle user. A contract can be used to compensate the user for the experienced discomfort. Literature on these contracts is lacking and the behaviour of EV user to these contracts is unknown. This study aims to close this gap. Data is collected by means of a web survey and evaluated with a multinomial logit model. It is shown that the difference in expected demand for price- and volume-based contracts is minimal. In addition, three contract elements can solely increase demand for V2G but require high levels. More value is created when a combination of these three contract elements is used. It would be valuable to understand how and where V2G can provide value. To do so, the results of this study can be used as input for a dynamic model that evaluates day-to-day electricity supply and demand.

1. Introduction

Due to increased awareness regarding environmental effects of fossil fuels an upsurge of renewable energy sources and technologies is occurring (Marell, 2014). With this regard, there are currently two trends observable: the usage of Electric Vehicles is growing exponentially and the use of Renewable Energy Sources is increasing as well (EV outlook, 2018; IEA, 2018). These trends contribute to the reduction of CO2 emissions (Egbue & Long, 2012). On the contrary, these trends have consequences for the electricity grid (further: grid).

The exponential growth of EV's may result in: voltage deviations, quality of supply degradation, increase of power losses and infrastructure overloads (Pillai, Bak-Jensen, 2010; Foley, Tyther & Calnan et al., 2013; Putrus, Suwanapingkarl & Johnston et al., 2009). In addition, the increased usage of RES causes issues regarding the balancing of demand and supply on the grid due to its fluctuating nature (Romer, Reichhart, Kranz & Picot, 2012). This can result in grid instabilities. Combining these trends, results in problems for the grid operators.

Specifically for the Netherlands, another trend is accelerating the grid instabilities. The government aims to phase out the production and usage of gas by the end of the year 2050 (Ministerie van EZ, 2018). This is causing an extra demand for electricity at peak moments (NetbeheerNederland, 2017) which consequently results in issues for the grid operators in the Netherlands, Transmission System Operators (TSO) and Distribution System Operators (DSO). However, capacity issues are expected for DSO's. This results in the Dutch DSO's facing a decision; either invest and expand the grid or shift demand peaks.

The latter can be done via flexibility services which prevent high investment costs for grid expansion (Amin, 2009). Flexibility is defined as the ability of a system to deal with variability and uncertainty regarding the demand and supply of electricity, so the fluctuated nature of RES and increased demand of EV's can be coped with (Denholm & Hand, 2011). There are many flexibility options available i.e. hydrogen production and demand side management. Another potential source of flexibility can be provided by EV's. EV's can store electricity in their batteries and feed back electricity to the grid when necessary. This concept is denoted as Vehicle-to-Grid (further V2G).

However, V2G requires the participation of the EV user and may have two inconvenient consequences (further: discomfort of V2G) for the EV user:

1) The vehicle may not be fully charged whenever the users wants to use the car
2) The wear and tear of the EV's battery that affects the batteries longevity

A contract can be used to compensate EV users for the discomfort they experience during V2G. To exploit the potential of V2G, the contract should be designed towards the EV users desires and needs (Geske & Schumann, 2018). However, the participant behaviour still requires a detailed study (Sovacool, Axsen & Kempton, 2017; Hoarau & Perez, 2018).

Three studies have examined EV users' desires and needs concerning V2G contracts using Stated Preferences Studies methodology (Parsons et al., 2014; Kubli, Loock & Wustenhagen, 2018; Geske & Schumann, 2018). These studies neglect the effects of V2G on the battery's lifetime which requires additional research to determine the potential value of V2G. The studies serve as basis for the experiment, in which battery degradation will be added. The lack of research into user behaviour regarding V2G is also denoted in pilot studies (EV consult, 2018). It is expected that EV users are not homogenous regarding their preferences, therefore differences in EV users' characteristics will be explored as well. This paper aims to answer the following research question:

"To what extent do different contract elements influence the willingness to use V2G among EV users in the Netherlands?"

This study focusses on full battery EV's only and thereby excludes hybrid EV's and fuel cell EV's.

This paper proceeds as follows. The adoption of V2G in the current electricity market will be discussed in the next section. This leads towards a set of feasible contract elements that will be used in the experiment. This is followed by the explanation of the methodology. In the fourth section, the results will be discussed, followed by a conclusion and discussion.

2. Theoretical framework

Adding V2G to the current electricity market is not straightforward, as new roles and responsibilities originate. A Universal Smart Energy Framework (USEF) is developed to fluently add flexibility services to the traditional electricity market. In USEF, the market interactions of new roles with current parties are described. To accumulate flexibility, a new role is required: the aggregator (USEF, 2018). The aggregator collects electricity from consumers to trade flexibility in the electricity market, in this case the EV user (USEF, 2018). This study focuses on the relation that evolves between the aggregator and the EV user. The aggregator might offer the EV user some kind of compensation for the experienced discomfort when providing V2G. Contracts can be used to get commitment from EV users by compensating for their experienced discomfort. Here, a contract can be used to divide the property rights regarding electricity ownership (Coase, 1960; USEF, 2018). The importance of having a contractual relationship between the aggregator and EV user is also noted in literature (Guille & Gross, 2009; He et al., 2013; Parsons et al., 2014). As Guille & Gross (2009) state: "contracts are an effective way to coordinate EV users in the participation of V2G". It is the aggregator that formalizes the contract, which should be accepted by the EV user.

However, due to the novelty of the role of the aggregator multiple parties might fulfil this role in the future. This creates uncertainty regarding the elements that are present in a contract. In addition, this might have consequences for parties that are aiming to achieve benefits from V2G services as their objectives may be contradicting with the interests of the aggregator. As this study aims to contribute to DSO services, it is assumed that no contradicting contract elements are present in contracts. This might be the case in the future.

To define V2G contracts, literature on V2G contracts is sought for. As there is not much literature on V2G contracts a comparison is made with already existing and comparable service: demand response. According to the US Federal Energy Regulation Commission demand response is defined as: "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" (Balijepalli et al., 2011). It is shown that electricity customers are incentivized to use demand response either driven by price or volume. However, due to the differences between demand response and V2G the price and volume driven contracts need adjustments. It is expected that, same as in demand response, the income level of the consumer affects the participation. Therefore, income level will be considered as well in V2G contracts.

Park Lee (2018), uses price- and volume-based contracts from demand response to propose contracts for V2G provided via fuel cell EV's. Here

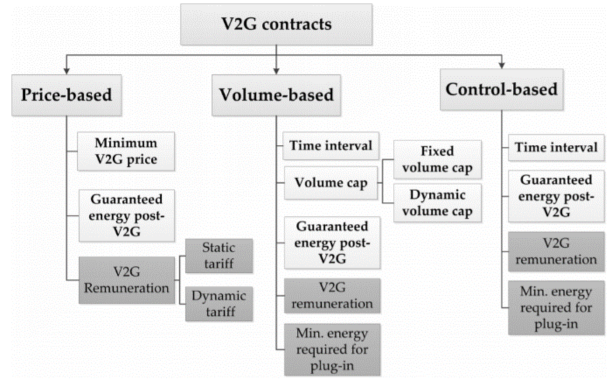

Figure 1: Contracts proposed by Park Lee (2018)

contract elements are added to adjust for V2G services. This is depicted in Figure 1.

However, to accommodate for battery EV's adoptions should be made to the proposed contracts by Park Lee (2018). To do so, a comparison is made with three already existing studies on the effect of contracts on the willingness to participate in V2G programs (Parsons et al. 2014; Geske & Schumann 2018; Kubli et al. (2018). The three studies are compared on the contract elements that are used, shown in Table 1.

Table 1: Contract elements in literature

Contract elements	Parsons et al. (2014)	Geske & Schumann (2018)	Kubli et al., (2018)
Guaranteed energy	X	X	X
Remuneration	X	X	X
Plug-in duration	X	X	
Contract duration			X
Flexibility			X
Power mix			X

It is observed that guaranteed energy, remuneration and plug-in duration is central in the contracts. This is in line with the proposed contracts by Park Lee (2018), to be more specific, the control-based contract. However, in V2G literature another factor is critical; battery (Marongiue et al., 2015; Saxena et al., 2015; Wang et al., 2016; Hu, et al., 2017). Both Parsons (2014) and Geske & Schumann (2018) neglect battery degradation in as element in their V2G contracts. Kubli et al. (2018) does consider battery degradation, but due to the set-up of the experiment this contract element is not measured independently. Research shows that V2G impacts the batteries' lifetime negatively, but the amount of degradation depends on the frequency of usage, meaning there exists a tradeoff in which the battery not wearied down more than uncontrolled charging (Uddin, Dubbary & Glick, 2018). However, in two pilot projects battery degradation is observed (INVENT, 2018; Parker, 2018). Considering literature and pilot project results, battery degradation is added to the proposed contracts by Park Lee (2018).

Besides, Kubli et al. (2018) mention the importance of contract duration on the participation in V2G projects. Burkhalter et al. (2009) found that contract duration does impact the choice of a product, but less than other attributes such as price or service. The length of the contract influences the product choice and is also observed in electricity products (Kaenzig et al., 2013). Moreover, Scarpa & Willis (2010) conducted a choice model considering RES and the contract lengths. They found that the higher the contract length for a RES, the more the utility of the respondent was reduced. Contract duration should therefore also be considered in V2G contracts.

After examining the existing literature on V2G, the contract types of Park Lee's (2018) should be extended with the following two elements:

1) Battery degradation
2) Contract duration

These are shown in as green boxes in Figure 2.

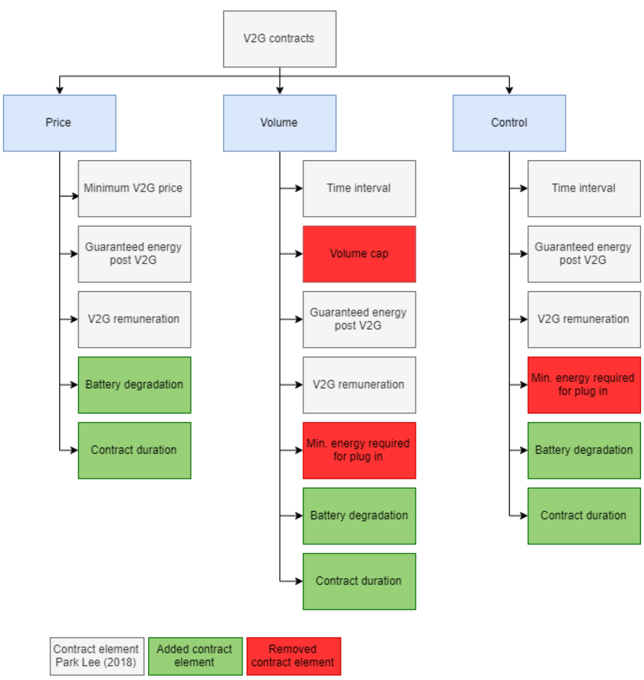

Figure 2: Adjusted contracts

Now, contract elements are present that are relevant for V2G provided via fuel cell EV's. To adjust the contract elements to battery EV's, two contract elements can be removed as these refer to the amount of hydrogen that is available in the fuel cell EV:

1) Volume capacity
2) Minimum energy required before plug-in

These are shown as red boxes in Figure 2.

In literature, the focus lies mostly on the control-based contract. This entails that the price and volume-based contracts are still neglected in the literature. Therefore, the focus of this research is on the price- and volume-based contracts. Since V2G services are location specific, the charging location might have an effect on the participation in V2G programs and will be considered in this study. This results in the following five contract elements and two user characteristics that are considered, depicted in a conceptual model, see Figure 3.

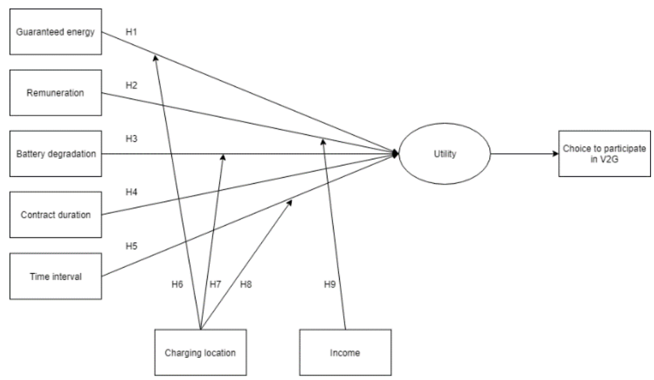

Figure 3: Conceptual model

3. Methodology

3.1. Data collection

A web survey is used to collect data on 120.000 Dutch EV users preferences regarding the five V2G contract elements. Since V2G is a completely new concept, revealed data is not available. Therefore, stated preference data collection is used. The survey consists of two parts: a choice experiment and few additional questions to test for representativeness and identification of additional effects. The choice experiment consists of 12 choice tasks in which two contracts with five contract elements are proposed to the respondents. an example is shown in Figure 44.

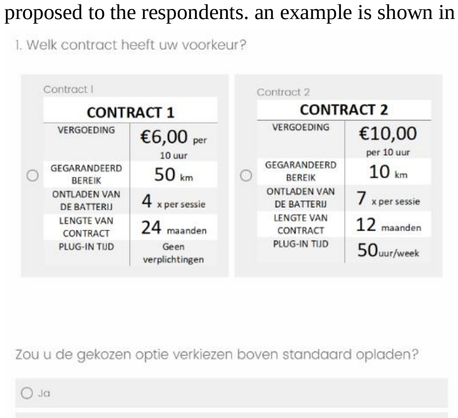

Figure 4: Choice set example

The additional questions consist of socio-demographic characteristics and EV user behaviour i.e. charging location of the EV.

The survey is distributed via three channels:

- VER
- Accenture
- Snowballing

Consequently, no random sample is obtained and bias in the results may be present. EV users who are committed to the VER are EV enthusiastic and may be more positive regarding V2G solutions. In addition, employees of Accenture have a high usage of their EV due to their work obligations and may be less positive regarding V2G.

3.2. MNL model

To determine the influence of the five contract elements on the perceived utility, a Multinomial Logit (MNL) model is estimated. The MNL model is derived from the Random Utility Models, which assumes that each alternative adds to the perceived utility of a person and an alternative with the highest utility is chosen. A distinction is made between systematic utility and an error term (Louviere et al., 2000). The systematic utility is captured in the experiment, while the error term refers to unobserved factors that are incorporated in the decision-making process of the respondent. The utility function of an alternative is given by:

$$U_i = \sum_m \beta_m X_{im} + \varepsilon_i = V_i + \varepsilon_i$$

Where: i represents an alternative
m represents an attribute
β_m represents the tastes of an attribute
X_{im} is the value of an attribute
ε represents the error term
j represents an alternative

For each alternative, the utility can be converted to a choice probability. The function of choice probability is given by:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_J e^{V_{ij}}}$$

Where: P_{ij} = the Probability that an individual/decision maker i chooses for alternative j
V_{ij} = the systematic utility that an individual/decision maker i perceives from alternative j
J = set of alternatives
e = the base of the natural logarithm

4. Results

A total of 96 completed surveys is collected. 91% of the respondents were male. The largest age group contains 38% of all respondents with an age of 45-54. In addition, high income levels are observed, 39% of the respondents earned more than €70.000 on yearly basis. The educational level of the respondents is high as well as 40% of the respondents belong to the highest education level group.

The results of the estimation of the MNL model are presented in Table 2.

Table 2: MNL estimations

	MNL non-linearity				
Parameter	Parameter	Value	Robust std error	Robust t-value	P-value
Guaranteed energy	Guaranteed energy	0.0159	0.00217	7.34	0.00
Remuneration	Remuneration1	1.14	0.147	7.75	0.00
	Remuneration 2	0.654	0.229	2.86	0.00
Discharging cycles	Discharging cycles 1	-0.421	0.166	-2.54	0.01
	Discharging cycles 2	-1.48	0.355	-4.18	0.00
Contract duration	Contract duration	0.0489	0.0155	3.15	0.00
Plug-in duration	Plug-in duration	-0.00483	0.00254	-1.90	0.06
V2G constant	V2G constant	-2.33	0.237	-9.84	0.00
Number of observations		1152			
Parameters		8			
Final Log-Likelihood		-1017.7			
Rho-square		0.196			

As can be observed from Table 2, seven out of eight parameters are significant at the 0.05 level. This includes four contract elements that thus significantly contribute to the decision to participate in V2G programs. Not all estimations are as expected, as discharging cycles and contract duration show unexpected behaviour and may have consequences for the conclusions. For discharging cycles, caution should be given to the estimation of the expected demand for V2G as the utility for V2G increases when using the maximum amount of discharging cycles. This was not expected, as more discharging cycles should logically result in a lower perceived utility. This is the case for having four discharging cycles, but when increasing this to seven, the perceived utility is increased. This may result in higher estimated expected demand than would be the case in reality. For contract duration the same applies, as longer contract durations result in a higher perceived utility. It was expected that longer contract durations would result in lower perceived utility. This also may result in higher estimated expected demand for V2G than it would be in reality. An explanation might be that EV users either saw no reason to change a contract or prefer V2G to be as long as their EV's lifetime.

The significant contract elements can be ordered in terms of relative importance. The ranking order, from highest relative importance to lowest is as follows:

1) remuneration
2) guaranteed energy
3) contract duration
4) discharging cycles
5) plug-in duration

In addition, it is observed that remuneration and discharging cycles have a non-linear effect on utility. An increase in remuneration at low levels (€2-€6 per 10 hour) has a larger effect on utility than an increase in remuneration at high levels (€6,00-€10,00).

As shown from the V2G constant, EV users do not prefer V2G per se, but they are willing to accept some level of discomfort in return for higher utility gains through other contract elements i.e. high remuneration (€10.00 for 10 hour plug-in) or high guaranteed energy (90km). Remuneration and guaranteed energy contribute for 55% of the perceived utility. In addition, plug-in duration only contributes for 5% of the perceived utility, while this contract element is seen as a key difference between the price- and volume-based contract.

In a realistic scenario, the expected demand for a price-based contract for V2G equals 28% and 22% for a volume-based contract. However, this is based upon a sample in which males are overrepresented. When more females are present it is expected that demand for V2G decreases. This is due to the fact that females are more sensitive to "range anxiety" and therefore might consider guaranteed energy as more important (Caperello, 2014). Varying remuneration, guaranteed energy and the amount of discharging cycles results in the singular effects of a contract element on the expected demand for V2G. It is shown that these three contract elements can increase the expected demand for V2G to promising percentages, such that the no-V2G option is decreased to at least 33%. In addition, it is shown that EV users with high income levels perceive less utility regarding V2G than EV users with a low income. The demand for V2G, in the "realistic" scenario, decreases with 13% and 10% for price-based and volume-based contracts respectively. In this sample, no significant relation was observed between the charging location and the demand for V2G services.

In comparison with the three studies that were used as basis for the experiment, this research provides three important insights:

1) the number of discharging cycles have a considerable effect on the decision whether or not to participate in V2G programs and should be taken in consideration when designing V2G contracts

2) guaranteed energy is still considered as an important contract element, however, the costs for an increase in guaranteed energy have dropped considerably. This is also shown in plug-in duration

3) plug-in duration is not considered that important for EV users when participating in V2G programs

5. Conclusion

The aim of this research was to determine to what extent different contract elements influence the willingness to use V2G among Dutch EV users. It is observed from literature that two contract types are relevant for the DSO; price- and volume-based contracts. These contracts differ in terms one contract element: plug-in duration. Since this contract element does not have a large contribution to the perceived utility of EV users, differences in usage of the contracts are not that large. This provides opportunities to propose volume-based contracts and generate predictable V2G behaviour without losing much demand for V2G. The contract elements that are considered to be important are remuneration, guaranteed energy and discharging cycles. It is shown that one of these three contract elements can be used to increase demand for V2G. It is not necessary to use a combination of these contract elements to increase demand. However, high levels of these contract elements are necessary. When realistic values are considered, combinations provide more value.

Based on the results, it is likely that a V2G solution provides value. However, it needs to be clear how much value and where value of V2G is provided. This can be done by applying the results of this study into a more dynamical model. This way, the day-to-day electricity supply and demand can be evaluated with the incorporation of V2G services.

6. Discussion

This study has a few limitations that have an influence on the results. A limitation is the accommodation of five contract elements, while in reality more contract elements may be used. The fulfilment of the role of the aggregator is currently uncertain resulting in the adoption of generic contract elements. Including other contract elements may result in in different preferences regarding V2G. Thus, drastic differences in preference may occur since the three most important contracts found in this study are necessary to achieve the expected demand for V2G.

In addition, the construction of the attributes may influence the results. In this study, two contract elements are chosen with attribute levels that do not encompass the whole range of the attribute. This applies to the guaranteed energy and the plug-in duration. The importance of guaranteed energy can decrease when a wider range is chosen. For plug-in duration, the complete opposite holds, longer plug-in durations might increase the relative importance of this attribute. This implies that then that the utility of volume-based contracts will decrease as well, making V2G less predictable.

Moreover, an MNL model is estimated. Due to the fact that this model holds the Independence of Irrelevant Alternatives property (IIA) the estimations for expected V2G demand are not entirely correct. In the MNL model it is assumed that when increasing remuneration in contract 1, both contract 2 and the no-V2G option lose an equal share of demand. In reality, only contract 2 should lose some demand and the no-V2G should merely remain the same.

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