

# **Dutch electric vehicle drivers' preferences regarding vehicle-to-grid contracts**

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Examining the willingness to participate in vehicle-to-grid contracts by conducting a context-dependent stated choice experiment taking into account the EV recharging speed

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by

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# Preface

Amsterdam, 8 August 2019

Dear reader,

In fulfilment of the MSc Complex Systems Engineering and Management at the Delft University of Technology, this report presents the findings of my MSc thesis that I have been working on for the last six months. This report is intended for people interested in behavioural research within the field of energy and electric mobility.

I am thankful to KPMG for giving me the opportunity to graduate at their firm. In particular, I would like to thank Stijn de Groen for his supervision at KPMG and for involving me into other mobility-related projects. This has resulted in valuable practical perspectives on vehicle-to-grid.

I sincerely enjoyed working together with my thesis committee members. I would like to thank Jan Anne Annema for his overall supervision and creative thinking. I would like to thank Bing Huang for her assistance in carrying out the stated choice experiment and for the sharing of her choice modelling expertise. I would also like to thank Zofia Lukszo for her time, guidance and constructive feedback during the meetings, which have definitely improved the quality of this research.

Many thanks to all respondents who were willing to take the time to fill in the survey. I was grateful for their enthusiasm in partaking. Without their input, I would not have been able to execute this project.

Last but definitely not least, I would like to thank my parents, Maarten and Margaret, for both their critical view on my work and their support during the entire process.

Kind regards,

Aart Meijssen

## Executive summary

**A quantitative research was performed in order to obtain empirical evidence on Dutch electric vehicle (EV) drivers' preferences towards vehicle-to-grid (V2G) contracts. By use of a stated choice experiment, new insights into the V2G literature were obtained. Based on these insights, several academic as well as practical recommendations were suggested.**

The adoption of small-scale decentralized renewable energy sources combined with the uptake of the EV cause capacity problems and misalignments on the electricity grid (Bayindir, Colak, Fulli, & Demirtas, 2016; Huda, Aziz, & Tokimatsu, 2018). Intelligent flexibility measures, such as electricity storage solutions, are highly needed to cope with these problems. Flexibility can be defined as the ability to cope with the variability and uncertainty in balancing the electricity grid (Holtinen et al., 2013). Given that EVs contain a large battery and are not in use for driving for about 90% of the time (Hoogvliet, Litjens, & van Sark, 2017), an EV could become a decentralized electricity storage device that would create flexibility in the energy market. The concept of using an EV as source of electricity is called 'vehicle-to-grid' and can be defined as a system that allows for a bidirectional flow of electricity between the EV and the electricity grid (Sovacool, Axsen, & Kempton, 2017). In order to actually connect the EVs to bundle sufficient V2G capacity that could be used to reduce the problems on the electricity grid, the role of an aggregator is introduced (USEF, 2015). The interaction of this potential aggregator with an EV driver could be facilitated by use of a V2G contract.

V2G is a technically mature system that could offer many benefits to society (Geske & Schumann, 2018). However, a number of socio-technical dimensions, such as the complexity of EV drivers' motivations towards V2G, have been given little attention in previous studies. In order to measure the true potential of V2G, empirical evidence towards these motivations is highly demanded. In addition to these understudied socio-technical V2G dimensions, the technological developments of EV batteries could have an influence on the adoption of V2G (Parsons, Hidrue, Kempton, & Gardner, 2014). In particular, an increased EV recharging speed could have an effect on this adoption. This potential effect needs to be investigated as well.

As the understanding of EV drivers' motivations towards V2G is essential for a successful adoption of V2G, the main objective of this research was to obtain Dutch EV drivers' preferences regarding V2G contracts with a potential aggregator. This research specifically aimed at quantifying both the importance of several V2G contract attributes and the impact of an increased EV recharging speed. Therefore, the research question was formulated as follows:

- **What are Dutch EV drivers' preferences regarding V2G contract attributes in a hypothetical V2G contract with an aggregator?**

The collection of data was gathered by administering both an online and offline survey with stated choice experiment among Dutch EV drivers. An extensive literature review identified seven V2G contract attributes that would possibly influence EV drivers in their choice-making process regarding a V2G contract: fixed remuneration, variable extra remuneration, plug-in time, guaranteed minimum battery level, number of days drawn down to guaranteed minimum battery level, contract duration and discharging cycles. After conducting a small pilot that resulted in the exclusion of the attribute 'number of days drawn down to guaranteed minimum battery level', the final survey with stated choice experiment was completed by 148 Dutch EV drivers. In the stated choice experiment, the respondents received nine choice sets in which they had to choose between three alternatives: two hypothetical V2G contracts and one 'no V2G contract' option. The hypothetical V2G contracts were described by systematically varying levels of the six residual V2G contract attributes. The EV recharging speed was included as context variable for every choice set. At every

choice set, it was indicated whether the respondent had to assume a normal EV recharging speed or a hypothetical fast EV recharging speed while answering the questions. The normal EV recharging speed corresponded to the current recharging speed of the respondent's EV, while the fast EV recharging speed corresponded to a hypothetical recharging speed that could fully recharge an EV within five minutes. The two levels of the context variable were randomly assigned to every choice set.

The collected data was analysed by estimating a discrete choice model. By use of a Multinomial Logit (MNL) model, parameters were estimated that quantified both the importance of the V2G contract attributes and the influence of an increased EV recharging speed on the willingness to participate in a particular V2G contract. In order to test the V2G contract attributes for non-linear behaviour, a total of four MNL models were estimated.

The estimation results showed that EV drivers were influenced in their choice-making process regarding V2G contracts by four V2G contract attributes. Fixed remuneration as well as guaranteed minimum battery level positively influenced and plug-in time as well as discharging cycles negatively influenced EV drivers' preferences in choosing a particular V2G contract. Moreover, plug-in time had a quadratic effect on the perceived utility and the other three contract attributes a linear effect. Interestingly, the order of relative importance of these four contract attributes depended on the EV recharging speed. In the context of normal recharging, guaranteed minimum battery level was the most important attribute, followed by plug-in time. In the context of a fast EV recharging speed, it was interesting to observe that the plug-in time became more important than the guaranteed minimum battery level, as a statistically significant interaction effect between EV recharging speed and guaranteed minimum battery level was found. In fact, the respondents valued the guaranteed minimum battery level half as important if the EV would be able to fully recharge within five minutes, relative to current recharging speed of their EVs. For both contexts, discharging cycles was estimated to be the least important attribute and fixed remuneration the second least important.

The respondents' choice distributions also revealed the influence of an increased EV recharging speed on their potential willingness to participate in V2G. On average, more than one-third of the respondents preferred conventional charging over a V2G contract when considering the current EV recharging speed of their EVs, while only less than a quarter of the respondents would prefer conventional charging over a V2G contract with a hypothetical EV recharging speed of five minutes. This could indicate that a faster recharging speed of an EV has indeed a positive effect on the willingness to participate in V2G contracts.

Several recommendations for further academic research are suggested, based on the results. First, additional contract attributes, such as free parking solutions as an alternative to financial remuneration, or the availability of an on-board computer, can be explored. Second, additional contexts could be added to the choice sets as context variables. For instance, including the type of parking as a context variable could quantify the difference between short-term and long-term parking, or the ownership of a second vehicle could be included as context variable to measure the effect of having a second car on the willingness to participate in V2G. Even though both additional contract attributes and context variables would provide new insights, realistic selection should carefully be chosen in order to minimize the complexity of the experiment.

The results introduce several practical implications as well. First, potential aggregators are partly dependent on the development of battery technologies. If the EV recharging speed actually approximates the numbers used in this research, the total available V2G capacity might increase without the need to proportionately increase the financial compensation. If plug-in time is the most important attribute due to an increased EV recharging speed, the potential aggregator can be recommended to increase its secured V2G capacity by offering V2G contracts with low guaranteed minimum battery levels rather than long plug-in times. Second, recommendations related to governmental regulations are proposed with respect to the use of a standardized V2G protocol, the need for privacy and security measures and to the preservation of incentive schemes for EV drivers.

This research performed an in-depth analysis of Dutch EV drivers' motivations towards V2G contracts and obtained some interesting insights. This research was prone to several limitations regarding the survey design, the choice modelling and the context variable, which can be used as a starting point for further academic research in the V2G domain.

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## List of abbreviations

<b>ADS:</b>	Active Demand & Supply
<b>BRP:</b>	Balance Responsible Party
<b>DES:</b>	Decentralized Electricity Storage
<b>DR:</b>	Demand Response
<b>DSO:</b>	Distribution System Operator
<b>EV:</b>	Electric Vehicle
<b>FCEV:</b>	Fuel Cell Electric Vehicle
<b>IDT:</b>	Innovation Diffusion Theory
<b>LC:</b>	Latent Class
<b>ML:</b>	Mixed Logit
<b>MNL:</b>	Multinomial Logit
<b>PHEV:</b>	Plug-In Hybrid Electric Vehicle
<b>PV:</b>	Photovoltaic
<b>RP:</b>	Revealed Preference
<b>RRM:</b>	Random Regret Minimization
<b>RUM:</b>	Random Utility Maximization
<b>SP:</b>	Stated Preference
<b>TSO:</b>	Transmission System Operator
<b>USEF:</b>	Universal Smart Energy Framework
<b>UTAUT:</b>	Unified Theory of Acceptance and Usage of Technology
<b>V2G:</b>	Vehicle-to-Grid

# 1 Introduction

There is a growing body of literature that recognises the major trends that transform today's electricity supply and transport landscape. Among these trends, two developments cause huge challenges on the electricity grid. Firstly, centralised conventional power plants are gradually replaced by small-scale decentralised renewable sources and secondly, the electric vehicle (EV) is becoming popular and is starting to disrupt the mobility sector (Bayindir et al., 2016; Huda et al., 2018). The intermittent character of renewable energy sources asks for intelligent electricity storage, particularly as the adoption of EVs will increase the load. Without electricity storage, capacity problems on the grid and misalignments between electricity supply and demand will arise (Ellabban, Abu-Rub, & Blaabjerg, 2014).

In an effort to use EVs as an intelligent source of electricity storage, Kempton & Letendre (1997) introduced the concept of using car batteries as a new source of power, termed 'vehicle-to-grid' (V2G). With this technology, an EV could become an electricity storage device when being parked and plugged in. This makes an EV a potential source of flexibility, which can be defined as the ability to deal with variability and uncertainty in electricity supply and demand (Holtinen et al., 2013). Given that EVs are not in use for driving for about 90% of the time (Hoogvliet et al., 2017), EVs provide a high potential for electricity storage without the need for major reinforcements on the electricity grid. The use of EV batteries could therefore be an intelligent alternative to stationary storage (Tarroja, Zhang, Wifvat, Shaffer, & Samuelsen, 2016). However, as one single EV does not have sufficient capacity to make an impact on the grid, the role of an 'aggregator' is introduced (USEF, 2015). An aggregator gathers information and capacity from many different car batteries to aggregate them into a large source of electricity storage (Guille & Gross, 2009). The degree to which an aggregator could manage the EV driver's car battery could be specified in a contractual relationship (Guille & Gross, 2009).

This research aims to make a contribution to the V2G literature by empirically analysing the complexity of EV drivers' motivations towards V2G contracts. A stated choice experiment among Dutch EV drivers was conducted. Two V2G contract attributes were added on top of the attributes that have been measured in previous research. Additionally, the influence of the EV recharging speed was included in this research.

## 1.1 Problem statement

Even though V2G is a technically mature system that could offer many benefits (Geske & Schumann, 2018), a number of socio-technical dimensions are currently understudied. Firstly, only a few studies have focussed on the complexity of EV drivers' motivations towards V2G systems (Sovacool et al., 2017). Even more explicitly, according to the systematic review performed by Sovacool, Noel, et al. (2018), only 6% of the V2G papers were based on experiments and an even smaller share of 1.7% applied survey techniques. For this reason, empirical insights in specific requirements of V2G programmes are not yet widely available in V2G literature. Without these insights, future scenarios of the true potential of V2G remain unrealistic. In particular, social elements such as EV drivers' attitudes, perceptions and driving behaviour have been given little attention in previous studies. Secondly, only four studies have empirically analysed the willingness to participate in V2G contracts (Geske & Schumann, 2018; Kubli, Loock, & Wüstenhagen, 2018; Parsons et al., 2014; Zonneveld, 2019). Further insights on top of these four studies could be rather valuable for all actors in the transport and electricity supply sector. Moreover, these insights could be particularly interesting for potential aggregators, as they have to design their V2G contracts carefully in order to attract EV drivers that are most valuable to them (Broneske & Wozabal, 2017).

In addition to these neglected socio-technical dimensions, the ongoing technological process regarding the battery development of EVs should be considered in V2G research. Parsons (2014) argued that the recharging speed of an EV could have a potential influence on the overall success of V2G. In particular, the guaranteed minimum battery level, one of the contract attributes used in both former as well as in this research, could be affected by the recharging speed. The guaranteed minimum battery level in a V2G contract specifies a battery state of charge below which aggregators do not draw power from the EV battery (Parsons et al., 2014). In practice, the discomfort experienced by the EV driver brought about by a lower guaranteed minimum battery level could be compensated with a shorter recharging time – or a faster recharging speed. A quantification of this effect would expose whether EV attributes have an influence on the potential success of V2G and on specific V2G contract attributes, such as the guaranteed minimum battery level.

## 1.2 Research objectives

As the degree of social acceptance is an important driver of the success of V2G, the main objective of this research was to obtain Dutch EV drivers' preferences regarding participating in V2G contracts with aggregators. By use of a stated choice experiment in the Netherlands, the importance of several V2G contract attributes was analysed, as well as the impact of an increased EV recharging speed on the importance of the guaranteed minimum battery level. This research further builds on previously conducted stated choice experiments in the V2G domain (Geske & Schumann, 2018; Kubli et al., 2018; Parsons et al., 2014; Zonneveld, 2019).

In order to obtain empirical evidence about EV drivers' preferences on V2G contract attributes and to find out what the impact of an increased EV recharging speed is, the following research question was formulated:

- **What are Dutch EV drivers' preferences regarding V2G contract attributes in a hypothetical V2G contract with an aggregator?**

In order to answer the main research question, the following research sub-questions were formulated:

- Which attributes specified in the V2G contract are of influence on Dutch EV drivers' participation in V2G contracts and to what extent?
- What influence does the EV recharging speed have on the EV drivers' willingness to participate in V2G contracts?
- How does the EV recharging speed influence the importance of the guaranteed minimum battery level specified in the V2G contract?

## 1.3 Research approach

In order to be able to answer the questions specified in the previous section, the collection of data was gathered by administering both an online and offline survey with stated choice experiment among Dutch EV drivers. In total, 148 Dutch EV drivers completed the survey. In this survey, respondents had to choose multiple times between three options, namely two hypothetical V2G contracts and one option to opt out and stick to their conventional way of charging. Subsequently, the respondents' choices were analysed with a discrete choice model in order to estimate the importance of the V2G contract attributes and the impact of the recharging speed. A context variable was included in order to measure the impact of an increased EV recharging speed. The entire process of this research was split into three stages.

### 1.3.1 Literature review

In the first stage, a conceptual foundation of the socio-technical aspects of V2G was created. A literature review was performed to find out how V2G could provide flexibility in the electricity market and what factors influence the choice-making process of EV drivers regarding V2G contracts. The main output of this first stage was a conceptual model that hypothesized the effect of the contract attributes on the overall willingness in V2G participation. Additionally, the impact of an increased EV recharging speed on the guaranteed minimum battery level was hypothesized.

### 1.3.2 Data collection through stated choice experiment

The second stage focussed on the data collection. In this stage, the conceptual model was used as an input to create an experimental design in the software programme Ngene. After the conduction of a pilot, an efficient design was constructed. The stated choice experiment was constructed by use of this efficient design, which included nine choice sets with systematically varying attribute levels. The stated choice experiment was distributed by use of an online and offline survey and was accessible for several weeks. The survey tool Qualtrics was used to distribute the online survey, while several fast charging locations in the Netherlands were visited to distribute the offline survey.

### 1.3.3 Data analysis through discrete choice modelling

In the final stage, the obtained data from the stated choice experiment were analysed by use of a discrete choice model – a Multinomial Logit (MNL) model – in the software package Biogeme. By use of this model, the importance of the V2G contract attributes and the impact of an increased EV recharging speed on the guaranteed minimum battery level were estimated. Choice distributions considering an increased EV recharging speed as well as various EV driver characteristics were analysed as well. Finally, the obtained findings were interpreted and discussed from a higher level perspective, providing several scientific and practical recommendations.

## 1.4 Research contributions

This research contributes to the V2G domain in several ways. First, an empirical contribution is made to the scientific V2G literature. Second, social relevance arises from the interpretation of the results. Third, recommendations to V2G in practice are provided.

This research contributes to the empirical literature on V2G in several ways. The main contribution of this research is the empirical analysis of the effect of an increased EV recharging speed on the willingness to participate in V2G contracts. In particular, the quantification of the recharging speed's interaction effect on the importance of the guaranteed minimum battery level stands out. This stresses the importance of EV developments regarding the potential of V2G. Furthermore, this research is one of the select few studies that quantifies the relative importance of several V2G contract attributes (Geske & Schumann, 2018; Kubli et al., 2018; Parsons et al., 2014; Zonneveld, 2019). Therefore, supportive and contradicting findings compared to previous research are added to the empirical knowledge base on V2G contracts. On top of the reproduction, insight into the effects of two newly proposed V2G contract attributes on the overall willingness to participate in a particular V2G contract was obtained. Finally, with respect to the data collection, this is the first research that used both online and offline techniques to distribute the survey. During the offline distribution, EV drivers at public fast-charging locations were directly approached for their cooperation in the V2G survey. As these EV drivers were not known to the researcher, the variance and representativeness of the sample may have increased.

In addition, as understanding the complexity of EV drivers' motivations towards V2G programmes is essential for a successful implementation of this concept, this research is relevant for a societal transition as well. In fact, the adoption of intelligent solutions that provide flexibility in the electricity market is needed for further uptake and integration of

renewable energy sources. Taking advantage of these flexibility solutions could speed up the emergence of a circular economy, based on this increased use of renewable energy sources. Moreover, flexibility solutions could partly prevent the high investment costs that have to be made to reinforce the grid infrastructure.

Finally, the interpretation of the empirical results provides several practical contributions to the potential aggregators, utility companies, car manufacturers and governmental bodies. Based on the obtained results, utility companies could decide whether and how to enter the V2G market by fulfilling the aggregator role. Besides, car manufacturers could decide whether or not to equip their new EVs with V2G compatible hardware, in order to create a competitive advantage over other car manufacturers. Finally, governmental bodies can structure their regulations based on the implications brought about by this study's results.

## 1.5 Fit to the MSc's programme

The master's programme in Complex Systems Engineering and Management at the TU Delft teaches a student to design innovations in complex socio-technical environments with an international character. In a way, the technical complexity could be found in the smart grid infrastructure and the V2G concept itself, while social complexity arises with the relationships between various stakeholders, including the aggregator and EV drivers.

The grid-balancing problem and the need for decentralized energy storage are much-discussed topics in the Energy (E) track. Furthermore, stated choice experiments are widely used methods in the Transport & Logistics (T&L) domain in which mobility-related problems are discussed. As the currently understudied behavioural aspects of V2G systems are empirically analysed, this research intends to combine these two specialization tracks. A quantitative contribution to an energy-related problem is performed, using methods originating from the transportation domain.

Moreover, the Faculty of Technology, Policy and Management's mission is to develop solutions for today's complex challenges, based on insights from both the engineering as social sciences (TU Delft, n.d.). Energy and mobility are two out of six main application domains in which the Faculty's research projects are mostly grouped. This underscores the relevance of this research for the Faculty.

Even though the scope of this research is limited to the Netherlands, V2G could become an internationally applied technology and serve as a solution to grid-balancing problems for energy markets in other countries. Empirical insights from this study could be used for follow-up research in these countries.

In summary, this research is firmly linked to the objectives of the master's programme Complex Systems Engineering and Management and is in line with the mission statement of the Faculty.

## 1.6 Reporting structure

The remainder of this report is composed of five more chapters. In Chapter 2, a literature review is performed to conceptualize the factors that influence the participation in V2G contracts. The methods used to be able to test the conceptual model from Chapter 2, including data collection and analysis, are described in detail in Chapter 3. Chapter 4 presents the results from the stated choice experiment and the parameter estimates from the discrete choice model. These results are analysed and interpreted. In Chapter 5, the main conclusions that could be drawn from the results are outlined. Finally, these conclusions are discussed in Chapter 6 and positioned in the V2G literature. Chapter 6 concludes with scientific limitations to this research, recommendations for further academic research and practical implications.



## 2 Conceptual model

The aim of this chapter is to build a conceptual model by reviewing the V2G literature. In this conceptual model, factors influencing the choice-making process of EV drivers regarding V2G contracts are hypothesized. Subsequently, this conceptual model is used to construct the experiment described in Chapter 3. The conceptual model is tested with a discrete choice model, which is described in Chapter 4.

Section 2.1 explains how V2G could serve as a source of flexibility in the energy market. Section 2.2 reviews previous stated choice experiments on V2G to obtain the factors that make up the conceptual model in section 2.3.

### 2.1 Flexibility in the energy market

Due to the variability in supply brought about by solar and wind power generation, the uncertainty in power output increases (Holttinen et al., 2013). This drives the need for flexibility, which can be defined as the ability to cope with the variability and uncertainty in balancing consumption and generation of electricity (Holttinen et al., 2013). To place V2G as a potential flexibility resource in the energy domain, key concepts concerning flexibility are discussed in the following sections. These concepts are based on existing literature.

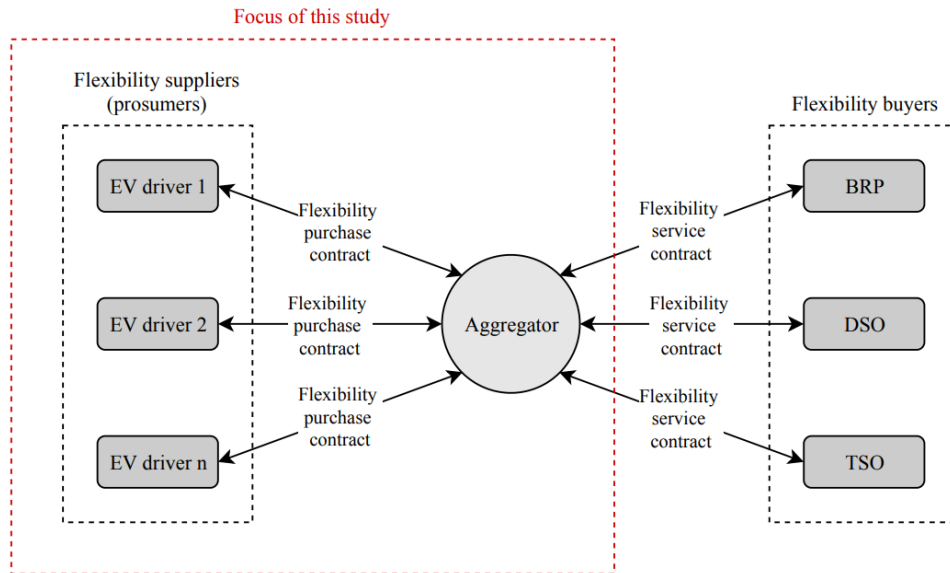
#### 2.1.1 Universal Smart Energy Framework and flexibility

The Universal Smart Energy Framework (USEF) is an initiative of a consortium of energy companies that stress the need for a new electricity market design (USEF, 2015). This framework has been developed to enable an efficient and affordable way to an integrated smart energy future. USEF introduces flexibility in the energy market by changing the load profile of intelligent devices, such as heat pumps, EVs and other domestic appliances. This is enabled by the smart grid, which can be defined as an intelligent electric system that uses two-way communication technologies from generation to consumption of electricity (Gharavi & Ghafurian, 2011). A new relationship of actors arises, with an aggregator as intermediary party.

##### 2.1.1.1 The role of the aggregator

In USEF, prosumers have evolved from traditional, passive consumers of electricity to more actively participating citizens who, for instance, install solar panels on their roofs and thus generate their own renewable electricity as part of their energy intake. These prosumers own various types of systems, among which possibly an EV, that either demand or generate electricity. These systems are so-called Active Demand & Supply (ADS) devices. As usage of these ADS devices can, to a certain extent, be actively controlled, they can be considered suppliers of flexibility. One single device, however, does not provide sufficient flexibility and for this reason, an aggregator is introduced (Guille & Gross, 2009). The aggregator combines the prosumers' ADS devices to create a large storage or source of electricity. Consequently, these storages or sources can be used by a balance responsible party (BRP), the Transmission System Operator (TSO) or a Distribution System Operator (DSO). These parties buy flexibility from the aggregator via flexibility service contracts in order to balance the electricity grid. To a certain extent, such an entity controls all the ADS devices in a specific area. The flexibility purchase contracts specify the limitations of the aggregator's control space.

This thesis specifically focusses on EVs as potential sources of flexibility. Therefore, as can be seen in **Figure 1**, the prosumer has become an EV driver. The main focus of this thesis is the interaction between the EV driver and the aggregator.



**Figure 1:** Focus of this study in the USEF actor relationship, derived from Lee, Lukszo, & Herder (2018)

### 2.1.1.2 Demand Response and Decentralized Energy Storage

Flexibility can be provided by two different concepts. On the one side, illustrated by USEF, matching consumption and generation can be facilitated by Demand Response (DR) measures. With these techniques, consumers are incentivized to shift their electricity consumption to a period with a lower price – and thus higher availability of electricity (Römer, Reichhart, Kranz, & Picot, 2012). On the other side, decentralized electricity storage (DES) is needed when DR measures reach their limits. In DES, a surplus of electricity is stored in a decentralized way. If, for instance, a prosumer generates more electricity than needed, this electricity could be stored for a later moment. In fact, Kempton & Letendre (1997) introduced the concept of using car batteries as electricity storage capacity for utility companies. According to Deivanayagam (2016), this V2G concept is one of the most promising technologies that could connect EVs with the power system in order to reduce the problems on the electricity grid and improve the sustainability of both systems. In V2G, an EV becomes a distributed resource – a load and storage device, integrated in the electricity grid (Guille & Gross, 2009). The electricity flow is characterized as bidirectional between the EV and the electricity grid, enabled by the smart grid (Sovacool et al., 2017). Therefore, V2G is an intelligent technology that uses car batteries to store excess energy from which can be drawn during peak hours. This is particularly interesting considering EVs are not in use around 90% of the time (Hoogvliet et al., 2017).

Galus, Gonzalez Vaya, Krause, & Andersson (2013) researched the opportunities of V2G in the smart grid and found that an EV could contribute to ancillary services for the power system. In fact, frequency control, peak-shaving power and a better integration of renewable energy sources are the most important opportunities introduced by V2G. Sovacool et al. (2017) have added two financial components to this list of opportunities, namely an increase in revenue for the power companies and a creation of new revenue streams for the EV owner.

The main difference of DR with DES with respect to EVs is the discomfort an EV driver could experience when the EV is used for DES. In smart charging, which is a form of DR, a deviation from the normal charging pattern could be applied during peak hours (Lee et al., 2018). However, with V2G, the EV becomes a controllable generation unit with an uncertain state of charge at any moment the vehicle is plugged in. Therefore, the motivations of EV drivers with respect to V2G are particularly important. Empirical evidence about user motivation towards V2G, however, is not yet widely collected in literature. This will be explained in the following section.

### 2.1.2 Neglected socio-technical dimensions of V2G

The vast majority of V2G literature, of which some case studies have been performed in different geographical areas (Sovacool, Noel, et al., 2018), has a technical character. All show promising results (Delgado, Faria, Moura, & de Almeida, 2018; Huda et al., 2018; Kam & Sark, 2015; Tarroja et al., 2016). General research has been performed on the technical application of V2G (Ehsani, Falahi, & Lotfifard, 2012), as well as on different charging strategies (Loisel, Pasaoglu, & Thiel, 2014). Another technical topic that has been studied in various papers is battery degradation. It has been shown that a minimal impact on battery degradation could be reached by making use of specific algorithms and when the batteries are only used when the need is high (Uddin, Dubarry, & Glick, 2018; Wang, Coignard, Zeng, Zhang, & Saxena, 2016).

An area that has been understudied, however, is the role of consumer acceptance towards V2G (Sovacool, Noel, et al., 2018). As V2G poses a discomfort to the EV drivers, understanding the complexity of user motivations is of great importance for a successful diffusion of V2G. Just a handful of studies have found empirical evidences from participation in V2G programmes. As argued by Sovacool et al. (2018), it should be understood how EV drivers value V2G attributes.

Some first insights into the willingness to participate in V2G programmes were obtained (Geske & Schumann, 2018; Kubli et al., 2018; Noel et al., 2019; Parsons et al., 2014; Zonneveld, 2019). These studies used a survey in combination with a stated choice experiment for the collection of data in order to estimate preferences and trade-offs for V2G attributes. Geske & Schumann (2018) investigated the willingness to participate in V2G, using a sample of vehicle users in Germany. Vehicle user's range anxiety and minimum driving range proved to be the most important factors of the willingness of vehicle users to participate in V2G. The paper also expressed the importance for aggregators to tailor the V2G design to customers' needs and that policies could improve awareness of V2G. This highlights the importance of the Universal Smart Energy Framework described in the previous section. Furthermore, Noel et al. (2019) conducted an experiment with vehicle users from Scandinavia and found their willingness-to-pay (WtP) for EVs with V2G capabilities. The paper found that inhabitants from Norway and Finland reacted positively towards V2G, whereas in Denmark, Sweden and Iceland, V2G was not considered valuable. This implies that more education and awareness of V2G is needed to accelerate the uptake of EVs. Parsons et al. (2014) researched the WtP for V2G contract terms with aggregators in the United States. The findings suggested that consumers would choose for pay-as-you-go services and advanced cash payments rather than required fixed payments. This, however, decreases the certainty of power capacity to the aggregator and thus introduces a conflict of interest between the EV driver and the aggregator. Kubli, Looock, & Wüstenhagen (2018) investigated the prosumers' willingness to participate in flexibility systems. As an addition to the flexibility of EVs, Kubli et al. (2018) also considered the potential flexibility opportunities of heat pumps and solar photovoltaic (PV) storage systems. It was concluded that EV and solar PV users possess a higher willingness to create flexibility than heat pump users. Finally, Zonneveld (2019) made a first step in examining the preferences of Dutch EV users with respect to V2G contracts in the Netherlands. In this study, the effect of battery degradation was also taken into account.

The attributes used in the stated choice experiments of these studies are reviewed in more detail in section 2.2. In the next section, the importance of contracts in the coordination of V2G is described.

### 2.1.3 V2G contracts

Broneske & Wozabal (2017) used the contract attributes from Parsons et al. (2014) to analyse the economic potential of V2G in Germany. They found that the value of the contract attributes for the aggregator was influenced by particular market characteristics. Broneske & Wozabal (2017) also found that contract parameters that had an effect on the energy volume were valued higher in markets with high energy supply. Conversely, in markets with a lower energy supply, the availability of storage capacity was worth more to the aggregator. Therefore, different types of contracts should be offered to serve different needs (Lee et al., 2018).

Parsons et al. (2014) proposed a non-contractual relationship to seek for EV driver participation. In this form, the EV driver does not have an obligation to provide its battery for service, but would be compensated on a pay-as-you-go basis for the capacity provided. This would reduce the inconvenience an EV driver experiences with contractual obligations and would improve the attractiveness of participating in V2G. However, according to Parsons et al. (2014), only contractual relationships provide sufficient certainty of capacity to the aggregator.

Lee et al. (2018) extended the demand response contracts from previous literature into V2G contracts, focussed on fuel cell electric vehicles (FCEV). According to Lee et al. (2018) and He et al. (2013), three different types of contracts could be applied to V2G, based on the DR contracts in the literature. Lee et al. (2018) stated that these types could be used for both EVs and FCEVs, with an extra challenge for the latter as these were not directly connected to the electricity grid. The first type of contract was a price-based contract that was only activated if a certain minimum electricity price was met, set by the EV driver. Included was a minimum price for activation that was defined by the EV driver, a guaranteed minimum level of electricity (or hydrogen) after the V2G operation and a financial compensation for the V2G operation. The second type of contract was a volume-based contract, which would be particularly interesting for people with a predetermined driving schedule. Compared to the price-based contract, a volume-based contract does not include a minimum V2G price, but requires a maximum volume usable for V2G, a required minimum fuel level at the moment of plugging in the EV and a required plug-in duration. The third type of contract was a control-based contract that made the EV driver fully lose control over the amount of electricity an aggregator could draw from the battery. The remuneration was based on the availability and volume provided by the EV driver, which could be a financial incentive to the EV driver. The different contract types with corresponding contract attributes are summarized in **Table 1**. Some contract attributes were converted to the case of EVs.

**Table 1:** Contract types from Lee et al. (2018)

Contract attribute	Price-based	Volume-based	Control-based
Minimum V2G price	X	X	X
Guaranteed battery level	X	X	X
V2G remuneration	X	X	X
Time interval		X	
Maximum volume		X	
Minimum electricity required at plug-in			

It can be concluded that contracts are needed for the operational coordination of V2G (Lee et al., 2018). Therefore, the experiment in this study was based on a contractual relationship between the EV driver and the aggregator. In the following section, the factors that influence EV drivers' participation in V2G contracts are defined, using previous stated choice experiments as a reference. These factors were used in the experiment of this research.

## 2.2 Factors influencing participation in V2G contracts

This section concentrates on the relevant, previously conducted stated choice experiments on V2G to obtain the most important factors that influence EV drivers in their participation in V2G contracts. The most important contract attributes, including the attribute levels used in the corresponding experiments, are shown in **Table 2** and form the base of the defined conceptual model introduced in section 2.3. On top of this base, two newly proposed contract attributes derived from the experiment in Parsons et al. (2014) – a variable remuneration component and an extra requirement to the guaranteed minimum battery level from the perspective of the aggregator – were added, distinguishing this research from the previous experiments. After discussing these V2G contract attributes, the EV attribute of recharging speed that was added to the conceptual model is also discussed. As suggested by Parsons et al. (2014), this EV attribute might have an effect on the potential success of V2G.

**Table 2:** Attributes and attribute levels used in previous stated choice experiments on V2G contracts. <sup>1</sup> Next to a monthly fixed reimbursement, a one-time EV purchase price reduction was also offered, respectively €1,000, €3,000, €5,000 and €7,000

Attribute	Attribute levels per article			
	Parsons et al. (2014)	Geske & Schumann (2018)	Kubli et al. (2018)	Zonneveld (2019)
Remuneration	500 \$/year	15 €/month <sup>1</sup>	50 CHF/month	0.20 €/hour
	1,000 \$/year	30 €/month <sup>1</sup>	70 CHF/month	0.60 €/hour
	2,000 \$/year	45 €/month <sup>1</sup>	90 CHF/month	1.00 €/hour
	3,000 \$/year	60 €/month <sup>1</sup>	110 CHF/month	
	4,000 \$/year			
Guaranteed minimum driving range	5,000 \$/year			
	25 miles	10 km	40%	10 km
	75 miles	20 km	60%	50 km
	125 miles	30 km	80%	90 km
Plug-in time	175 miles	40 km	100%	
	5 hours/day	50 km		
	10 hours/day	0 hours/day	–	0 hours/week
	15 hours/day	5 hours/day		25 hours/week
Discharging cycles	20 hours/day	7 hours/day		50 hours/week
	–	10 hours/day		
		14 hours/day		
		–	0 per day	1 per session
Contract duration			1 per day	4 per session
			3 per day	7 per session
			Unlimited	
			0 months	1 month
		12 months	12 months	
		24 months	24 months	
		48 months		

### 2.2.1 Contract attributes

In this section, the seven V2G contract attributes that are included in the conceptual model are described. These are the five attributes used in previous V2G research as well as the two newly added ones.

#### 2.2.1.1 Plug-in time

An aggregator should be able to control sufficient battery capacity in order to provide flexibility. In order to improve the predictability of storage capacity for the aggregator, an attribute for plug-in time is part of a V2G contract. Plug-in time can be defined as average plug-in duration over a specific period. Parsons et al. (2014) and Geske & Schumann (2018) based this period on days, varying respectively from 5 to 20 and 0 to 14 hours per day. Zonneveld (2019) based the contract element of plug-in time on a weekly basis. The corresponding levels were 0, 25 and 50 hours per week, implying an obligation of being plugged in for 0 to 10 hours per working day.

The attribute levels for all attributes have been converted to the same unit in **Table 3**. With reference to the plug-in time, this has resulted in a total attribute level range of 0 to 20 hours per day. In this research, it was not an option to have no plug-in restrictions, as an alternative was given in which a ‘no V2G contract’ option could be chosen by the respondents. As 20 hours plugged in implies almost the entire day, it would be hard for EV drivers to actually realise an average plug-in of 20 hours per day. Therefore, the attribute levels were set to 5, 10 and 15 hours.

**Table 3:** Attributes and attribute levels used in previous stated choice experiments on V2G contracts, adjusted for the same units. <sup>2</sup> Based on five working days; <sup>3</sup> Per day instead of per session; <sup>4</sup> Based on the exchange rates on 1 May 2019, and rounded off; <sup>5</sup> Based on average of five hours plug-in time per day; <sup>6</sup> Based on average battery range of 290 km (Elektrische Voertuigen Database, n.d.-a; Newmotion, n.d.-a)

Attribute	Attribute levels per article			
	Parsons et al. (2014)	Geske & Schumann (2018)	Kubli et al. (2018)	Zonneveld (2019)
Remuneration <sup>4</sup> [€ / month]	35	15	40	30 <sup>6</sup>
	75	30	60	90 <sup>6</sup>
	150	45	80	150 <sup>6</sup>
	225	60	100	
	300			
	375			
Guaranteed minimum driving range [km]	40	10	110 <sup>5</sup>	10
	120	20	170 <sup>5</sup>	50
	200	30	230 <sup>5</sup>	90
	280	40	290 <sup>5</sup>	
	50			
Plug-in time [hours / day]	5	0	–	0 <sup>3</sup>
	10	5		5 <sup>3</sup>
	15	7		10 <sup>3</sup>
	20	10		
	14			
Discharging cycles [# / day]	–	–	0	1 <sup>2</sup>
			1	4 <sup>2</sup>
			3	7 <sup>2</sup>
			∞	
Contract duration [months]	–	–	0	1
			12	12
			24	24
			48	

### 2.2.1.2 Guaranteed minimum driving range and battery level

Guaranteed minimum driving range can be defined as a minimum battery state of charge below which power aggregators will not draw power from the battery (Parsons et al., 2014). Therefore, this attribute guarantees the EV driver will not be faced with an uncharged EV for unexpected trips. Parsons et al. (2014), Geske & Schumann (2018), Kubli et al. (2018) and Zonneveld (2019) all expressed this attribute in a driving-distance-equivalent charge. Parsons et al. (2014) used a rather broad range, from 25 to 175 miles. The attribute level range in the experiment by Geske & Schumann (2018) was quite narrow, varying from only 10 to 50 km. Since the average driving range is 38 km in Germany, most EV drivers would still not be restricted by V2G at all (Geske & Schumann, 2018). Zonneveld (2019) based his range on the maximum distance to a hospital in The Netherlands and the average daily distance driven by Dutch vehicle users. This resulted in a range between 10 and 90 km. Additionally, Kubli et al. (2018) expressed the guaranteed minimum driving range as a percentage of the EV's battery state of charge, varying from 40% to 100% – the latter implying that an aggregator would not be able to draw from the battery at all.

Based on the average battery range of current EVs, these percentages were converted into equivalent distances, resulting in an attribute level range of 10 to 290 km. In this research, it was assumed that the lowest level of the guaranteed minimum driving range almost equalled the average daily driving range. Assuming the aggregator does not always draw the battery down to its minimum level, this implies that EV drivers would, on average, be able to drive the average daily driving distance. It was decided to express this range in percentages as done by Kubli et al. (2018), rather than in kilometres. Showing the attribute levels in kilometres could be confusing as to whether this corresponds to the theoretical or the practical distance that is left in the battery. By showing percentages, an EV driver would be able to recognise the practical distance the EV would be able to travel. The final calculations in Chapter 4 are based on the average range of the EVs from the sample. Therefore, the minimum level was set to 10%, approximately corresponding to the average daily driving distance. The maximum level was set to 50%, corresponding to half the EV's maximum driving range. The middle level was set to 30% in order to preserve attribute level

equidistance, which is beneficial for the experiment. As this attribute was expressed in percentages, ‘guaranteed minimum battery level’ is the term used in this research.

In the experiment of Parsons et al. (2014), the respondents were told that the aggregator would barely discharge the battery to its guaranteed minimum battery level and that EV drivers would always be able to skip plug-in time terms as long as the monthly average was met. However, in retrospect, Parsons et al. (2014) indicated that the effect of this maximum could be modelled directly by adding the attribute ‘number of days per month the battery is drawn down to its minimum’. As this attribute would give an extra indication of the importance of the guaranteed minimum battery level, the ‘number of days drawn down to the guaranteed minimum battery level’ was the first newly added V2G contract attribute to the conceptual model. A sub-set of the proposed attribute levels in Parsons et al. (2014) were used in this experiment. These were set to 4, 7 and 10 times per month.

### 2.2.1.3 Remuneration

In V2G contracts, EV drivers are to a certain extent obliged to have their EVs plugged in. This creates discomfort, which has to be compensated. Therefore, remuneration can be defined as any form of compensation for the cost of discomfort experienced by EV drivers with a V2G contract (Kubli et al., 2018). In previous stated choice experiments, remuneration was mainly based on frequent fixed payments. Parsons et al. (2014) used fixed yearly payments, varying from \$500 to \$5,000 per year. Kubli et al. (2018) and Geske & Schumann (2018) both used a monthly structure, with payments between CHF 50 and CHF 110 and €15 and €60. Geske & Schumann (2018) also provided the respondents a one-time EV purchase price reduction, varying between €1,000 and €7,000. This range was determined as net present value of the monthly payment. Lastly, Zonneveld (2019) used a slightly different remuneration scheme. EV drivers were financially compensated for every 10-hour plug-in time, from €2 up to €10 per 10 hours.

Parsons et al. (2014) proposed several other strategies to the strict cash-back-contract approach. One of them was a pay-as-you-go contract, which required no plug-in obligations. EV drivers would be paid for power capacity on an hourly basis. In Lee et al. (2018), these contracts were defined as control-based contracts. Zonneveld (2019) included a remuneration scheme per provided time unit. However, a required plug-in time was still included in its proposed contracts. It would be interesting to investigate how EV drivers would value another remuneration approach. Next to the fixed periodical payments based on the plug-in time, a variable extra remuneration could be provided for every extra hour an EV is plugged in on top of the pre-specified plug-in time. This would result in a backup capacity for the aggregators secured by the plug-in time, as well as in an incentive for EV drivers to plug in their EVs more often. Therefore, in this research, remuneration was based on these two components. The first component includes a fixed monthly payment, as being used in the previous studies. On top of that, a variable extra remuneration component was added as a contract attribute. Therefore, ‘variable extra remuneration’ was the second newly added V2G contract attribute to the conceptual model. Both remuneration components make up the hybrid remuneration structure, which includes a fixed as well as a variable monthly payment. This variable monthly payment was based on an hourly rate, multiplied by the number of hours an EV is plugged in above the required plug-in time per month.

The conversion of the attribute levels to the same unit has resulted in an attribute level range of €15 to €375 per month. The attribute levels of the remuneration in this research were chosen to be less than those in the research of Zonneveld (2019), as extra variable remuneration could be obtained by being plugged in for more hours than the EV driver is obliged to. Therefore, the levels of fixed remuneration were set to €20, €60 and €100 per month and the levels for variable extra remuneration to €0.00, €0.15 and €0.30 per extra hour outside of the plug-in time obligations. An average extra plug-in time of five hours per day would thus correspond to respectively €0, €23 and €45 variable extra remuneration per month.

### 2.2.1.4 Discharging cycles

Battery degradation is a current research topic. It is, however, still unclear what the direct impact of V2G on the quality of the battery is. Kubli et al. (2018) introduced a flexibility attribute, implying the level of flexibility a prosumer could

create. Next to the guaranteed minimum driving range, this flexibility attribute also included a unit for battery degradation. This degradation was defined in terms of number of discharging cycles per day. Therefore, the flexibility attribute indicated the number of times an aggregator used the battery discharging in a day, varying from 1 to unlimited numbers per day. This attribute level range is, in fact, infinite. Zonneveld (2019) narrowed this range down to three attribute levels of 1, 4 and 7 discharging cycles per session, implying a barely, moderate or large effect on the batteries' longevity.

For conversion, it was assumed in this research that one session corresponded to one day. As not many new insights have been obtained in literature regarding battery degradation, the same attribute levels and range as in Zonneveld (2019) were used in this study.

#### 2.2.1.5 Contract duration

The contract duration was included as a contract attribute in the studies of Kubli et al. (2018) and Zonneveld (2019). Contract duration can be defined as the length of the contract between the aggregator and EV driver. Kubli et al. (2018) varied the attribute levels from 0 months – implying that a contract could be cancelled anytime – to 48 months. Zonneveld (2019) based these levels on the contract duration of phone subscriptions, resulting in contract durations of one month, one year or two years. As it might be the case that an aggregator will pay for the V2G charger, a contract of one month is rather short. Therefore, the one-month contract from Zonneveld (2019) was replaced by a six-month contract in this research. This resulted in attribute levels of 6, 12 and 24 months.

The chosen attributes for this research, including the corresponding attribute levels, are summarized in **Table 4**.

**Table 4:** Chosen attributes and attribute levels for this research

Attributes	Attribute levels
Fixed remuneration [€ / month]	€ 20.00 per month € 60.00 per month € 100.00 per month
Variable extra remuneration [€ / extra hour]	No variable extra remuneration € 0.15 per extra hour plugged in outside of contract € 0.30 per extra hour plugged in outside of contract
Guaranteed minimum battery level [%]	10% 30% 50%
Plug-in time [hours / day]	5 hours per day 10 hours per day 15 hours per day
Number of days drawn down to the guaranteed minimum battery level [# / month]	4 times per month 7 times per month 10 times per month
Discharging cycles [# / day]	1 time per day 4 times per day 7 times per day
Contract duration [months]	6 months 12 months 24 months

#### 2.2.2 The influence of an increased EV recharging speed

Recharging speed has always been an important attribute for the adoption of EVs. The same barriers regarding the complexity of EV drivers' preferences towards EV attributes now apply to V2G attributes. Various studies have been performed on preferences and trade-offs of EV attributes. In fact, Hackbarth & Madlener (2016) and Hidrue, Parsons, Kempton, & Gardner (2011) both conducted a stated choice experiment to calculate the WtP for EV attributes. The choice sets included three alternatives: two EV-alternatives and one alternative that corresponded to 'the respondent's preferred conventional gasoline car'. The common EV attributes included in their choice sets were driving range,



recharging time, purchasing price, air pollution and fuel costs. According to Hidrue et al. (2011), the respondents were willing to pay up to \$3,250 for an hour reduction in recharging time. Parsons et al. (2014) built on the research by Hidrue et al. (2011) by adding V2G attributes to the choice sets. However, as the preference for EV attributes were estimated in a separate experiment and were kept constant in the experiment with V2G attributes, no information about trade-offs between EV attributes and V2G attributes could be observed. In particular, Parsons et al. (2014) expressed the need for a carefully examined trade-off between the EV attribute of recharging time and the V2G attribute of guaranteed minimum driving range. The relative importance of guaranteed minimum driving range might be lower if it takes less time to recharge the EV (Parsons et al., 2014). This was also expressed by a survey distributed in 2012, which found that respondents were more concerned about the battery range than the purchasing price of an EV (Egbue & Long, 2012).

Currently, many research and development departments are trying to develop batteries with a faster recharging speed. Among others, BMW, Porsche and Siemens are working on a system that would charge an EV ten times faster than current fast chargers (Kottasova, 2018). Furthermore, an Israeli car battery manufacturer is currently working on a new solid-state flash battery and claims it could fully recharge an EV to a range of 300 miles in only five minutes (StoreDot, n.d.). Manufacturing of these type of batteries should start in 2022. Finally, as described in Blik op nieuws (2018), a potential EV driver always asks how long it takes to fully recharge the particular EV.

As the development of batteries is an ongoing process, the speed of recharging could be of influence on the willingness to participate in V2G programmes. In particular, as proposed by Parsons et al. (2014), it would be interesting to measure the importance of the guaranteed minimum battery level in a hypothetical future scenario in which the speed of recharging of EVs approximates the recharging speed proposed by Kottasova (2018) and StoreDot (n.d.). Therefore, the EV recharging speed was included in this research as interaction effect with the guaranteed minimum battery level.

### 2.2.3 Order of relative importance of contract attributes

With the use of discrete choice models, parameters were estimated for every contract attribute. Every parameter corresponds to a particular attribute. The value of the estimated parameter reveals the importance of the particular attribute in the choice-making processes of the respondents. The theory behind this choice-making process is further explained in the next chapter.

The parameter estimates differed in terms of relative importance across the different studies. **Table 5** gives an overview of this order. As can be seen, three out of four studies have found remuneration to be the attribute of most importance and plug-in time of least importance to the respondents. Contrary to this, Geske & Schumann (2018) found a different ranking. Guaranteed minimum battery level was estimated to be the factor of most influence for the respondents, while remuneration ended up as the least important attribute for the respondents. In Chapter 4, the parameter estimates of the contract attributes found in this research are compared to those from **Table 5** in terms of relative importance.

**Table 5:** Order of relative importance of contract attributes. Note that the attribute ‘on-board computer’ from Geske & Schumann (2018) is not considered in this table. Furthermore, note that the attribute ‘electricity mix’ from Kubli et al. (2018) is also not considered in this table. Furthermore, the attribute ‘monthly electricity costs’ from Kubli et al. (2018) is assumed to be the inverse of remuneration and the flexibility attribute is a combination of ‘guaranteed charging level’ and ‘discharging cycles’, which makes the relative importance indifferent.

	Geske & Schumann (2018) (N=611)	Parsons et al. (2014) (N=3,029)	Kubli et al. (2018) (N=300)	Zonneveld (2019) (N=96)
Remuneration	3 <sup>rd</sup>	1 <sup>st</sup>	1 <sup>st</sup>	1 <sup>st</sup>
Guaranteed minimum battery level	1 <sup>st</sup>	2 <sup>nd</sup>	2 <sup>nd</sup>	2 <sup>nd</sup>
Contract duration	–	–	4 <sup>th</sup>	3 <sup>rd</sup>
Discharging cycles	–	–	2 <sup>nd</sup>	4 <sup>th</sup>
Plug-in time	2 <sup>nd</sup>	3 <sup>rd</sup>	–	5 <sup>th</sup>

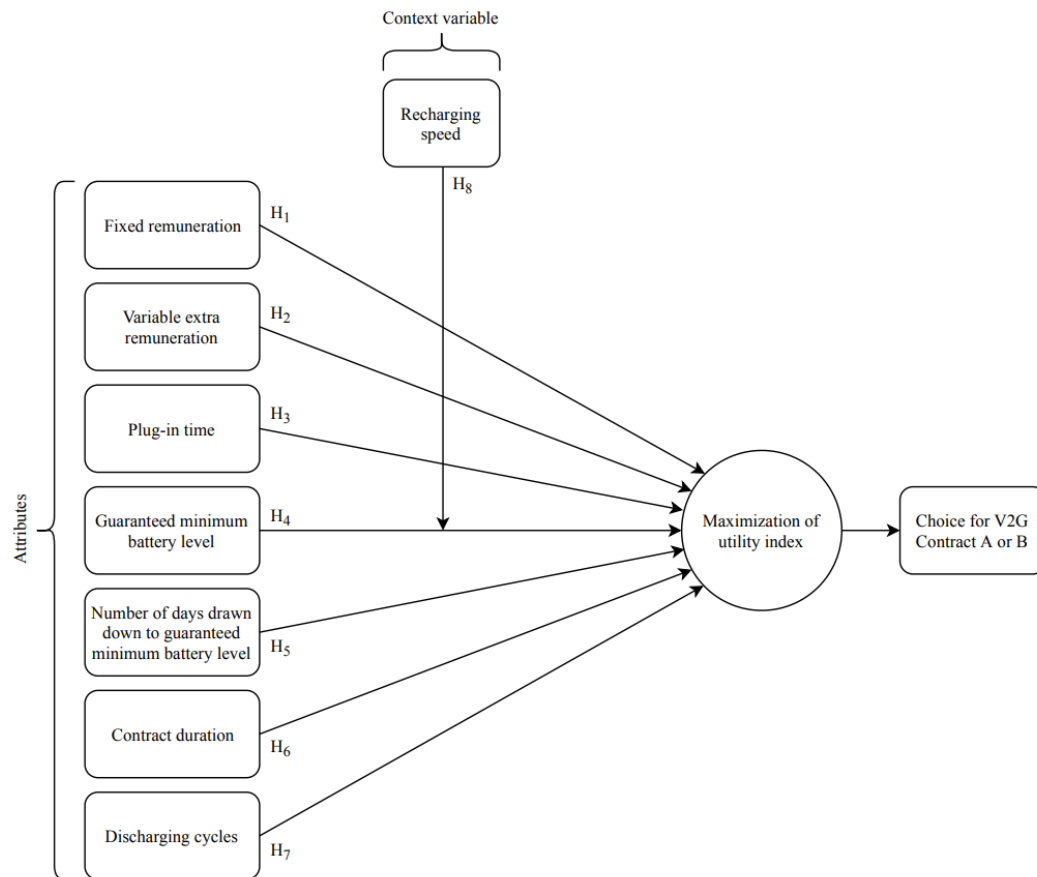
## 2.3 Towards a conceptualization

This section combines all found factors (contract attributes and context variable) from section 2.2 in a conceptual model. Furthermore, the potential effects of these factors are hypothesized.

### 2.3.1 Conceptual model

The factors that could have an effect on the willingness to participate in a V2G contract are conceptualized in this section. In order to build a conceptual model, the choice-making process described by Mcfadden (2001) was used. When human beings make choices, they run through a cognitive choice-making process (Mcfadden, 2001). The final choice is based on many determinants. An individual collects information about the different choice alternatives, converts this into perceived attributes and aggregates these perceived attribute levels into a utility index based on the individual's preferences and constraints, such as monetary or time based factors. Finally, the alternative with the highest utility is chosen. The theory behind this choice-making process is further explained in the next chapter.

For the conceptual model in **Figure 2**, it was assumed that all seven attributes had an influence on the perceived utility. Furthermore, a context variable was added to measure the effect of an increased recharging speed on the importance of the guaranteed minimum battery level. This resulted in a total of eight parameters to be estimated. These eight parameters are hypothesized ( $H_1 - H_8$ ) in the next section.



**Figure 2:** Conceptual model

### 2.3.2 Parameter hypotheses

It was expected that four out of seven contract attributes would have a positive effect on the perceived utility function. Firstly, it was expected that a higher remuneration would result in a higher utility for the willingness to participate in V2G contracts, as all previous choice experiments on V2G concluded this. This would thus be expected for both the fixed and variable extra remuneration. Furthermore, the higher the state of charge of an EV, the longer the driving range is. Therefore, it was expected that a higher guaranteed minimum battery level would result in a higher utility. Finally, Zonneveld (2019) found unexpectedly that contract duration had a positive effect on the perceived utility, contrary to the findings in Kubli et al. (2018). His main explanation was that due to the absence of alternative options in the market, people are willing to subscribe for a longer contract. As the target group in this thesis is the same, this positive effect was also expected in this experiment.

The effects on the perceived utility function were expected to be negative for the other three contract attributes. Firstly, as the required plug-in time limits an EV driver's EV use, it was expected that a higher level for plug-in time would result in a lower utility to participate in V2G. Furthermore, even though the impact of V2G on the battery degradation has not been determined yet, EV drivers would probably be sceptic towards this contract attribute. It was therefore expected that a higher number of discharging cycles would result in a lower willingness to participate. Lastly, the number of times an aggregator discharges the battery to the guaranteed minimum battery level has not yet been measured in literature. Assuming that people value a higher driving range, it was expected that a higher value of this attribute would result in a lower utility for the EV driver's willingness to participate in a particular V2G contract.

The following hypotheses with respect to the contract attributes were formulated:

- H<sub>1</sub>: Fixed remuneration has a positive effect on the perceived utility
- H<sub>2</sub>: Variable extra remuneration has a positive effect on the perceived utility
- H<sub>3</sub>: Plug-in time has a negative effect on the perceived utility
- H<sub>4</sub>: Guaranteed minimum battery level has a positive effect on the perceived utility
- H<sub>5</sub>: Number of days drawn down to the guaranteed minimum battery level has a negative effect on the perceived utility
- H<sub>6</sub>: Discharging cycles has a negative effect on the perceived utility
- H<sub>7</sub>: Contract duration has a positive effect on the perceived utility

The moderation effect of the EV recharging speed on the importance of the guaranteed minimum battery level was estimated as well. In order to do this, a context variable was added to the conceptual model. As an increase in recharging speed results in faster recharging of the EV, it was expected that EV drivers would be less sensitive to the guaranteed minimum driving range in the context of a fast recharging speed.

The following hypothesis with respect to the context variable was formulated:

- H<sub>8</sub>: EV drivers are less sensitive to guaranteed minimum battery level if the speed of recharging becomes faster

## 2.4 Conclusion

As can be concluded from the literature review, many factors could play a role in the choice-making process of participation in V2G programmes or contracts. The commonly used contract attributes are some form of financial compensation, a particular plug-in time, a defined minimum battery level that is guaranteed after the V2G service, the maximum number of discharging cycles in a particular period and the length of the V2G contract. In this research, the estimated parameters of these contract attributes were compared to previous findings. Therefore, a replication of the current literature was made.

The main scientific contribution of this research is the quantification of the effect of an increased recharging speed on the potential success of V2G. Specifically, the influence of a fast recharging speed compared to a normal ‘status quo’ recharging speed on the guaranteed minimum battery level could be of particular interest. The speed of recharging was thus added as a context variable in this research, which makes this the first research that empirically analyses the effect between an EV attribute and a V2G contract attribute.

As a second contribution to the current V2G literature, two newly proposed V2G contract attributes were added to the conceptual model. First, a hybrid remuneration scheme was proposed, taking into account a variable remuneration component on top of the fixed payments. Furthermore, the actual maximum number of times an aggregator draws the battery down to the guaranteed minimum battery level was also quantified. These two contract attributes have, to the knowledge of the researcher, not been measured yet.

These eight parameters make up the conceptual model shown in **Figure 2**. All effects of these parameters were hypothesized and tested by use of a stated choice experiment. This experiment, as well as the discrete choice modelling part, is explained in the next chapter.

## 3 Methods

As already mentioned, a survey with stated choice experiment among Dutch EV drivers was conducted to estimate preferences and trade-offs regarding the contract attributes and context variable defined in the conceptual model from the previous chapter. This chapter reports the methods used to collect the data and describes the discrete choice model used to analyse this data.

In section 3.1 the motivation for conducting a stated choice experiment is explained. The main theory behind the data analysis is introduced in section 3.2. In section 3.3, different types of experimental designs are explained and motivations are given for the type of design used in the pilot and final survey. The process of designing and distributing the survey is described in section 3.4, including the pilot survey results. Finally, in section 3.5, the tasks performed to prepare the dataset for the data analysis are discussed.

### 3.1 Data collection

Two data collection paradigms that are based on experiments exist: Revealed Preference (RP) and Stated Preference (SP). In this section, motivations for conducting a stated choice experiment as main data collection method for this research are given.

RP data is information collected from real-market alternatives, based on historical choices made by individuals in the past. SP data, however, is gathered by use of a stated choice experiment. In a stated choice experiment, respondents are asked to make a choice out of hypothetical alternatives, which makes it a data collection method based on an experimental design constructed by the researcher. Stated choice experiments have several advantages over revealed preference experiments. Firstly, choices for new alternatives with not-yet existent attributes and attribute levels can be observed. Secondly, a high variation in the data is created, as the researcher may construct any choice options. Furthermore, the correlations between the attributes are managed, resulting in low or even no multicollinearity among the attributes. Finally, as each respondent is usually asked to make eight to twelve choices in a stated choice experiment, multiple choices are observed from one respondent. Therefore, an SP experiment requires a smaller sample size in order to estimate reliable parameters compared to an RP experiment.

Stated choice experiments do have drawbacks. As revealed choice studies focus on historical choices and stated choice experiments do not, outcomes of stated choice experiments could result in a lower validity. It will remain uncertain whether respondents would choose the same alternative in real life. Reasons that the same alternative might not be chosen in life are the fact that consequences of the choices are not felt, that the provided information will be absent in real life and that new levels and alternatives have not yet been experienced.

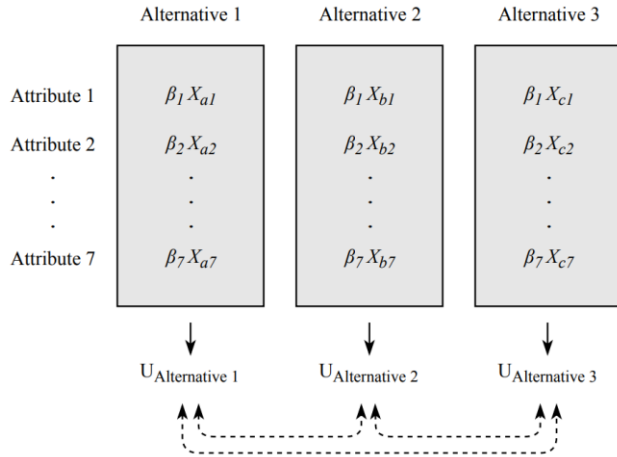
For this study, it was chosen to use a stated choice experiment to investigate Dutch EV drivers' preferences towards V2G contracts, because V2G has not yet been implemented in the market and real-market data are therefore not available. In addition, stated choice experiments provide more flexibility to collect the data that the researcher is interested in, allowing the impact of the EV recharging speed on EV drivers' preferences in V2G contracts to be included.

## 3.2 Data analysis

The discrete choice data obtained from the stated choice experiment could be analysed with a Random Utility Maximization (RUM) model. Various estimation models are derived from the RUM theory. This section briefly discusses this RUM theory and the actual estimation model used in this research.

### 3.2.1 Random Utility Maximization Theory

A decision maker chooses one alternative from a choice set with several alternatives. Each of the alternatives is described by several attributes, such as cost-based or time-based attributes. For each attribute, several attribute levels are constructed. The structured combination of alternatives, attributes and attribute levels make up the experimental design, which is described in section 3.3. RUM theory assumes that the decision maker aims to maximize utility. The mechanism behind the RUM theory is described as follows. First, RUM theory assumes that the decision maker sums up the multiplication of all attribute levels  $X_{im}$  with corresponding weights (or importance)  $\beta_m$  of each alternative to obtain the utility per alternative. For instance, as can be seen in **Figure 3**,  $U_{\text{Alternative 1}} = \beta_1 X_{a1} + \beta_2 X_{a2} \dots \beta_7 X_{a7}$ . Second, the decision maker compares the utility levels of the alternatives, which is indicated by the dashed arrows in **Figure 3**. RUM theory assumes that only utility levels are compared to each other. Third, the decision maker chooses the alternative that has the highest utility. In the context of this research, the choice sets consisted of three alternatives (V2G Contract A, V2G Contract B and ‘no V2G contract’) and every alternative was described by seven attributes that consisted of three attribute levels each (defined in **Table 4** in Chapter 2).



**Figure 3:** RUM model choosing process

The total utility consists of both a systematic utility and an error term, from the researcher’s perspective. The systematic utility contains factors that can be observed and measured by the researcher. The error term is based on all other factors that have an influence on the total utility, but cannot be observed and measured by the researcher. This could, for instance, be the case if an important attribute is missing in the choice set. Therefore, based on the RUM theory, the total utility of alternative  $i$  chosen by decision maker  $n$  is expressed in equation (1):

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

In equation (1),  $U_{in}$  denotes the total utility of alternative  $i$ ,  $V_{in}$  denotes the systematic utility and  $\varepsilon_{in}$  denotes the unobserved error. The systematic utility is expressed in equation (2):

$$V_{in} = \sum_m \beta_m \times X_m \quad (2)$$

In equation (2),  $V_{in}$  denotes the systematic utility of alternative  $i$  and  $\beta_m$  denotes the weight parameter associated with attribute  $X_m$ , which represents the importance of the attribute. The  $\beta_s$  correspond to the parameters that are to be estimated with a discrete choice model, which is described in section 3.2.2. Furthermore, alternative  $i$  is chosen over the other alternative  $j$  if  $U_{in}$  has the maximum value. This is expressed in equation (3):

$$\sum_m \beta_m \times X_{im} + \varepsilon_i > \sum_m \beta_m \times X_{jm} + \varepsilon_j, \forall j \neq i \quad (3)$$

### 3.2.2 Multinomial Logit model

The Multinomial Logit (MNL) model is an easy-to-use estimation model based on the RUM theory and proposed by Daniel McFadden. This closed form estimation model is one of the most widely used RUM models and is based on the assumption that the error term is independently and identically distributed across all alternatives with a type I extreme-value distribution and are thus drawn independently from distribution with the same variance. The systematic utility  $V_{in}$  is based on attributes with linear parameters. Hence, the linear-additive utility maximization. The choice probability  $P_i$  of alternative  $i$  chosen by the decision maker  $n$  could be found using the formula in equation (4):

$$P_i = \frac{\exp(V_{in})}{\sum_{j=1..J} \exp(V_{jn})} \quad (4)$$

Kubli et al. (2018) and Zonneveld (2019) both used an MNL model to estimate preferences and trade-offs for V2G contract attributes.

## 3.3 Experimental design

In order to be able to set up a stated choice experiment, an experimental design has to be constructed. This section describes the most widely applied types of experimental designs that are currently being used in the literature. First, a distinction is made between full factorial and fractional factorial designs. Secondly, orthogonal and efficient designs are elaborated on. Finally, context dependency is explained.

### 3.3.1 Full factorial versus fractional factorial design

A full factorial design includes all possible combinations of attributes and levels. Being able to estimate all main and interaction effects is the main advantage of this type of design (Rose & Bliemer, 2007). A main effect is the effect of a single attribute on the perceived utility, while interaction effects modify the main effects. However, full factorial designs result in a high number of choice situations. With equation (5), the total number of combinations for a full factorial design can be calculated.

$$S = \prod_{j=1}^J \prod_{k=1}^{K_j} L_{jk} \quad (5)$$

For this study, two V2G contract alternatives ( $J=2$ ) with seven V2G contract attributes each ( $K=7$ ) and three levels per attribute ( $L=3$ ) would have resulted in  $3^7 \times 3^7 = 4,782,969$  combinations. Therefore, full factorial designs are only suitable for rather small experiments. The third alternative in this research – the ‘no V2G contract’ option – was not included in the calculation of combinations, as this alternative functioned as a constant base alternative.

A fractional factorial design is a subset of a full factorial design. Orthogonal designs and efficient designs are two design types that are mostly used to construct a fractional factorial design in a structured way (ChoiceMetrics, 2018). They are described in more detail in the next sections.

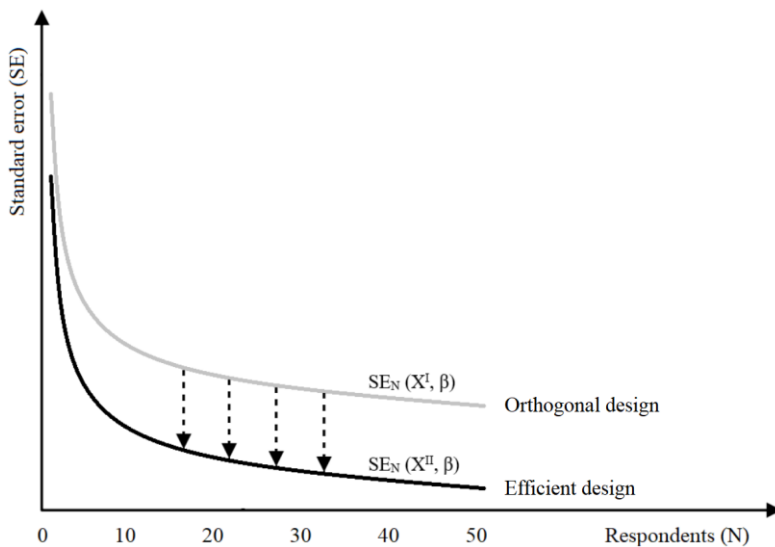
**3.3.2 Orthogonal design**

An orthogonal design can be defined as a design type in which attribute level balance is satisfied and in which all parameters are independently estimable (ChoiceMetrics, 2018). This implies that attribute levels need to be uncorrelated for each attribute column, as this results in low standard errors. With increasing numbers of attributes and attribute levels, determining an orthogonal design becomes harder. Basic plans are standard schemes published by mathematicians that result in orthogonal designs when correctly applied. These schemes are suitable for particular numbers of attributes and attribute levels. However, only relatively small designs can be constructed. Larger designs can be constructed by computer programmes, such as Ngene, that try to approximate an orthogonal design. As the construction of an orthogonal design is relatively simple by use of the Ngene software, this design type was used to construct the experimental design for the pilot in this research. The process of constructing an orthogonal design for the pilot survey is described in section 3.4.1

A first drawback is the possible existence of dominant alternatives within orthogonal designs. A dominant alternative is at least better on one attribute and not worse on all others. As this alternative will (almost) always be chosen, no information on trade-offs between attributes is created. Another drawback is that orthogonal designs are only suitable for linear models, since orthogonality only persists in linear models. Therefore, as discrete choice models are not linear, many researchers have recently begun to question the relevance of orthogonal designs when applied to stated choice experiments. Therefore, the efficient designs have grown in popularity.

**3.3.3 Efficient design**

Efficient designs try to minimize the standard errors of the estimated parameters, instead of minimizing correlation in the data as orthogonal designs do. The graph in **Figure 4** shows the relationship between standard errors and the number of respondents for both orthogonal and efficient designs. According to the graph, efficient designs result in smaller standard errors than orthogonal designs, with the same number of respondents (Rose & Bliemer, 2007).



**Figure 4:** Standard errors in orthogonal and efficient designs (Rose & Bliemer, 2007)

Efficient designs help to avoid dominance, may increase the reliability of the parameters, may reduce the number of choice sets and help determine the number of required respondents in order to reach statistical significance. However,



prior information to the parameters is needed in order to construct an efficient design and if these priors are wrong, the efficiency of the design will decrease. Prior information can be obtained from a pilot study or from previous stated choice experiments on the same topic. In this research, a small pilot study was conducted to estimate these prior parameters. This is described in section 3.4.1. As an efficient design can result in lower standard errors, less choice sets are needed to obtain statistical significance. Therefore, an efficient design type was chosen for the final stated choice experiment in this research.

### 3.3.4 Context dependency

In context-dependent stated choice experiments, the respondents make their choices assuming a particular context (Molin, 2014). This could be, for instance, a background variable or a certain weather condition. In many context-dependent stated choice experiments, such as in Molin & Timmermans (2010), several context variables are combined. These types of experiments need to construct a second experiment that systematically varies the context variables to create a set of context descriptions. However, as only one context variable with two levels was used in this study, no second experiment was needed.

In this research, the EV recharging speed functioned as the context variable with two context levels. The first level corresponded to a normal EV recharging speed, the so-called ‘status quo’ scenario. The second level corresponded to a hypothetically increased EV recharging speed announced by StoreDot (n.d.), termed fast EV recharging speed. This level made the respondents assume their EVs could be fully recharged within five minutes. According to Parsons et al. (2014), the guaranteed minimum battery level might be influenced by the EV recharging speed. For this reason, recharging speed was included as an interaction effect with the guaranteed minimum battery level in the MNL model. An additional parameter was estimated for this interaction effect. As normal recharging speed functioned as a reference level, the influence of a fast recharging speed on the guaranteed minimum battery level was estimated relative to the normal recharging speed. The additional parameter of the interaction effect would thus only be added to the parameter estimate of the guaranteed minimum battery level if the context of fast recharging speed applied.

As one of the two context levels – normal or fast recharging speed – was randomly assigned to a choice set, one respondent could have received more questions within the same context than another respondent. However, by increasing the number of respondents, the total observations for both contexts were averaged out and approximately equal. In fact, out of the 1,332 choice observations, 674 observations were obtained for the normal recharging speed and 658 observations for the fast recharging speed.

## 3.4 Survey design and distribution

This section describes the development of constructing the pilot and final survey. As this pilot study provided the prior parameters for the efficient design used in the final experiment, the results of the pilot study are discussed first, followed by an explanation of the process of designing and distributing the final survey.

### 3.4.1 Pilot survey

An extensive pilot was conducted in order to correct for errors and unexpected bias, to test the comprehensibility of the survey and to gather information prior to the final survey. The online pilot survey was built in Qualtrics and consisted of an introduction section, the stated choice experiment and a feedback page.

#### 3.4.1.1 Experimental design of pilot study

The conceptual model in **Figure 2** from the previous chapter includes the seven contract attributes that were used in the pilot. As in Ryan, Gerard, & Amaya-Amaya (2008), the construction of this stated choice experiment consists of three consecutive steps: (1) identifying the relevant attributes and attribute levels, (2) selecting the experimental design type

and constructing the choice sets and (3) selecting the experimental context and developing the survey. These three steps are described in the next sections.

#### Step 1: Attributes and attribute levels

Based on the literature review in the previous chapter, seven contract attributes were chosen to study their influence on the willingness to participate in V2G contracts. The five attributes that were used in previous stated choice experiments were reused in this study. Two extra attributes – ‘variable extra remuneration’ and ‘number of days drawn down to the guaranteed minimum battery level’ – were added. Table 6 shows these chosen attributes with their corresponding attribute levels.

**Table 6:** Chosen attributes and attribute levels for the pilot survey

Attributes	Attribute levels	Ngene code
Fixed remuneration [€/ month]	€ 20.00 per month	0
	€ 60.00 per month	1
	€ 100.00 per month	2
Variable extra remuneration [€/ extra hour]	No variable extra remuneration	0
	€ 0.15 per extra hour plugged in outside of contract	1
	€ 0.30 per extra hour plugged in outside of contract	2
Guaranteed minimum battery level [%]	10%	0
	30%	1
	50%	2
Plug-in time [hours / day]	5 hours per day	0
	10 hours per day	1
	15 hours per day	2
Number of days drawn down to the guaranteed minimum battery level [# / month]	4 times per month	0
	7 times per month	1
	10 times per month	2
Discharging cycles [# / day]	1 time per day	0
	4 times per day	1
	7 times per day	2
Contract duration [months]	6 months	0
	12 months	1
	24 months	2

All attributes included three attribute levels, as three attribute levels allow for the testing of the linearity assumption. Furthermore, a wide attribute level range was chosen. This increased validity, as interpolation of attribute levels is more reliable than extrapolation. In addition, a wide attribute level range increases the reliability, as the estimated parameters will have smaller standard errors. Finally, equidistance was mostly preserved in the attribute levels, which satisfied the orthogonality between the attributes.

#### Step 2: Experimental design type and choice sets

The experimental design was created in the software programme Ngene, which is a software programme for generating experimental designs that can be used in stated choice experiments (ChoiceMetrics, 2018). It could be classified as an orthogonal fractional factorial design, constructed using the following Ngene syntax in Code 1.

**Code 1:** Ngene syntax for experimental design in pilot survey. Note that the attribute levels are coded into 0, 1 and 2, which correspond to the attribute levels in **Table 6**. ‘A’ up until ‘G’ correspond to the seven attributes and ‘b1’ up until ‘b7’ to the to be estimated parameters.

```
? pilot survey design
design
;alts = alt1, alt2
;rows = 12
;orth = seq
;model:
U(alt1) = b1*A[0,1,2] + b2*B[0,1,2] + b3*C[0,1,2] + b4*D[0,1,2] + b5*E[0,1,2] + b6*F[0,1,2] +
b7*G[0,1,2]/
U(alt2) = b1*A + b2*B + b3*C + b4*D + b5*E + b6*F + b7*G
$
```

With reference to the syntax in **Code 1**, ‘rows’ corresponds to the number of choice sets Ngene creates. To satisfy orthogonality,  $S \geq K / (J-1)$  should hold. In this equation,  $S$  is the total number of choice sets,  $K$  the number of the to be estimated parameters and  $J$  the number of alternatives. In the case of the pilot study, at least seven choice sets should have been constructed. However, in order to obtain attribute level balance, the number of choice sets should be divisible by all the numbers of attribute levels. Therefore, in order to satisfy orthogonality, at least nine choice sets were needed. However, as the pilot sample would be small and considering as many choice observations as possible would be preferred, it was chosen to create twelve choice sets. This step is arbitrary, as a trade-off is made between the possible number of choice observations and the number of choice set one respondent is willing to answer. Hence, increasing the number of choice sets would reduce the number of total completed surveys. The Ngene syntax in **Code 1** resulted in the following experimental design, shown in **Table 7**.

**Table 7:** Experimental design for pilot survey. For example, 1.a corresponds to attribute a – fixed remuneration – in alternative 1.

Choice set	Alternative 1							Alternative 2						
	1.a	1.b	1.c	1.d	1.e	1.f	1.g	2.a	2.b	2.c	2.d	2.e	2.f	2.g
1	60	0.15	10	10	7	1	24	100	0.30	10	10	4	7	6
2	100	0.30	10	50	7	1	6	60	0.15	10	10	7	1	24
3	100	0.00	15	50	10	4	12	100	0.30	10	50	7	1	6
4	20	0.00	15	30	7	7	6	60	0.15	5	30	7	7	24
5	100	0.00	5	10	10	4	12	20	0.30	15	10	10	4	12
6	20	0.30	15	10	10	4	12	60	0.15	15	30	4	1	24
7	60	0.15	10	50	4	7	24	20	0.00	15	30	7	7	6
8	60	0.15	15	30	4	1	24	100	0.00	15	50	10	4	12
9	100	0.30	10	10	4	7	6	60	0.15	10	50	4	7	24
10	20	0.00	5	30	4	1	6	20	0.30	5	50	10	4	12
11	20	0.30	5	50	10	4	12	100	0.00	5	10	10	4	12
12	60	0.15	5	30	7	7	24	20	0.00	5	30	4	1	6

### Step 3: Pilot survey design

In the third step, the experimental design was converted into twelve choice tasks that could be used in the stated choice experiment in the survey. The final design of the pilot survey was composed of an introduction page, an explanation section with video clip, twelve choice sets and a feedback page. An example choice set from the pilot survey is shown in Appendix C.

#### 3.4.1.2 Recruiting of pilot respondents

The pilot was accessible for respondents for a ten-day period, from 13 to 22 May 2019. A total of 31 respondents fully completed the pilot survey. Several strategies for recruiting the respondents were applied. To start with, fellow KPMG colleagues were approached. Family members and close friends that drive EVs were personally asked to fill in the pilot survey. A snowballing technique was applied simultaneously, as respondents were able to fill in the email address of EV drivers they knew. On top of this, in order to improve demographic diversity, a hyperlink to the online pilot survey was posted in the comment section of news website NU.nl. This actually started a small online discussion

about the feasibility of V2G. Finally, flyers were clamped under the windscreen wipers of electric cars in and around Amsterdam. They included a QR-code which directly linked them to the online pilot survey. Flyer, NU.nl-discussion and Facebook post are shown in Appendix D.

### 3.4.1.3 Pilot results

The parameters were estimated with an MNL model in Biogeme (Bierlaire, 2018). An extra function in Qualtrics was activated, which forced the respondents to give an answer. Therefore, all completed surveys were fully filled in. As 31 respondents completed twelve choice sets, the total number of observations was 372. The results are shown in **Table 8**.

**Table 8:** Parameter estimates from the pilot. \* corresponds to insignificance. The parameter names correspond to the following contract attributes: B\_CON = contract duration, B\_DIS = discharging cycles, B\_EREM = variable extra remuneration, B\_GUAR = guaranteed minimum battery level, B\_MIN = number of times battery discharged to guaranteed minimum level, B\_PLUG = plug-in time and B\_REM = fixed remuneration

Parameter	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
B_CON	-0.0181	0.0101	-1.80	0.07*	0.0104	-1.73	0.08*
B_DIS	0.0694	0.0534	1.30	0.19*	0.0544	1.28	0.20*
B_EREM	0.847	0.717	1.18	0.24*	0.707	1.20	0.23*
B_GUAR	0.0328	0.00559	5.87	0.00	0.00578	5.68	0.00
B_MIN	-0.0775	0.0402	-1.93	0.05*	0.0392	-1.98	0.05
B_PLUG	-0.251	0.0657	-3.82	0.00	0.0657	-3.83	0.00
B_REM	0.00586	0.00368	1.59	0.11*	0.00373	1.57	0.12*

As the sample size was relatively small (N=31), only two estimated parameters were statistically significant. This was acceptable, considering that the sign of the priors was most important. When the attribute parameters were compared to estimations from previous studies, most of the parameters showed an expected sign. Only the attribute ‘discharging cycles’ showed an unexpected sign. However, as the parameter estimate was statistically insignificant, no conclusions could be drawn. Both Kubli et al. (2018) and Zonneveld (2019) estimated a statistically significant parameter with negative sign. For this reason, the parameter estimate of Zonneveld (2019) was used as prior parameter for this attribute. **Table 9** shows all the signs for the estimated attribute parameters in the previous stated choice experiments.

**Table 9:** Comparison of parameter signs from several experiments

Parameter	Parameter sign				
	Geske & Schumann (2018)	Parsons et al. (2014)	Kubli et al. (2018)	Zonneveld (2019)	This pilot
B_CON	–	–	Negative	Positive	Negative
B_DIS	–	–	Negative	Negative	Positive
B_EREM	–	–	–	–	Positive
B_GUAR	Positive	Positive	–	Positive	Positive
B_MIN	–	–	–	–	Negative
B_PLUG	Negative	Negative	Negative	Negative	Negative
B_REM	Positive	Positive	Positive	Positive	Positive

Another interesting outcome of the pilot was the received feedback on one contract attribute. The attribute ‘number of days drawn down to the guaranteed minimum battery level’ was, according to several respondents, not easily understandable and not considered in their choice making process. Therefore, this attribute was excluded after the pilot and not considered in the final survey. The fact that the parameter estimate was almost statistically significant seemed a pure coincidence. Therefore, the experimental design was reduced from seven to six contract attributes. This made the final survey more compact and easier to understand for the respondents.

### 3.4.2 Final survey

The same three steps that were taken for the pilot survey were followed to create the final stated choice experiment. In the first step, the contract attribute ‘number of days drawn down to the guaranteed minimum battery level’ was

deleted. In step 2, an efficient design was created in Ngene by using the obtained prior parameters from the pilot survey. The Ngene syntax is displayed in **Code 2**.

**Code 2:** Ngene syntax for experimental design in final survey

```
? final survey design
design
;alts = alt1, alt2
;rows = 9
;eff = (mnl,d)
;model:
U(alt1) = b1[0.00586]*A[20,60,100] + b2[0.847]*B[0,0.15,0.30] + b3[-0.251*C[5,10,15] +
b4[0.0328]*D[10,30,50] + b5[-0.0754]*E[1,4,7] + b6[-0.0181]*F[6,12,24]/
U(alt2) = b1*A + b2*B + b3*C + b4*D + b5*E + b6*F
$
```

As shown in the Ngene syntax in **Code 2**, one contract attribute was excluded. Therefore, only six contract attributes with six corresponding to be estimated parameters remained. Furthermore, the priors were placed in brackets after the betas. Finally, nine choice sets were constructed instead of the twelve choice sets used for the pilot. Many respondents from the pilot indicated that they found the number of choice sets quite large. It was therefore chosen to construct an experimental design with less choice sets. This was feasible for two reasons. First, an efficient design could result in reliable parameters with less observations. Second, the final survey included extra questions already, extending the required duration to complete the survey. An efficient design without dominant alternatives was obtained after 1,160 iterations. The nine choice sets are displayed in **Table 10**.

**Table 10:** Experimental design for final survey. For example, 1.a corresponds to attribute a – fixed remuneration – in alternative 1.

Choice set	Alternative 1						Alternative 2					
	1.a	1.b	1.c	1.d	1.e	1.f	2.a	2.b	2.c	2.d	2.e	2.f
<b>1</b>	100	0.00	5	30	7	24	20	0.30	5	10	1	6
<b>2</b>	20	0.30	5	10	7	24	100	0.00	10	30	1	6
<b>3</b>	60	0.00	5	10	4	6	60	0.30	10	50	4	24
<b>4</b>	60	0.15	10	30	4	6	60	0.15	5	50	4	24
<b>5</b>	100	0.30	15	50	1	12	20	0.00	10	10	7	12
<b>6</b>	100	0.30	10	10	4	12	20	0.00	15	50	4	12
<b>7</b>	20	0.15	15	50	7	6	100	0.15	15	10	1	24
<b>8</b>	20	0.00	10	30	1	24	100	0.30	15	30	7	6
<b>9</b>	60	0.15	15	50	1	12	60	0.15	5	30	7	12

With reference to the outcomes in Appendix B, the D-error was 0.0108 and the S-estimate 46. The D-error is a commonly used measure to indicate the efficiency of an experimental design. An S-estimate of 46 implies that at least 46 respondents were required to obtain statistically significant parameters, assuming that the obtained prior parameters were correctly estimated. Furthermore, according to the rough rule of thumb, the probability of choosing an alternative should be less than 90%. The closer an expected probability of an alternative to 100%, the more limited the information about trade-offs. As shown by the MNL probabilities in Appendix B, none of the alternatives had a probability larger than 90%. Therefore, no dominant alternatives were included in the experimental design.

3.4.2.1 The context of recharging speed

The context variable of the recharging speed of the EV was included in the final survey. This variable consisted of two levels. In the first level, the respondents were made to imagine that the EV recharges according to current recharging speeds. In the second level, a hypothetical future scenario was created, in which the respondents were made to imagine that the EV was able to fully recharge within five minutes at every charging point. Even though this would probably never be the case in real life, the effect of an increasing recharging speed (or decreasing recharging time) on the sensitivity of guaranteed minimum battery level could be measured. In order to increase the variance, it was chosen

to randomly assign one context per choice set. The respondents' annoyance regarding the varying contexts within the survey remained limited, as only two contexts existed. Therefore, one respondent received choice sets within the first as well as within the second context.

#### 3.4.2.2 Structure of the final survey

The final survey was designed in step 3. It was composed of an introduction and informed consent page, an explanation section with video clip, nine choice sets and additional questions on socio-demographics and individual characteristics. The additional questions were presented in the final part of the survey in order to make sure that respondents were fully focussed on answering the choice set questions. The full online version of the final survey is shown in Appendix C.

In the introduction section, the topic as well as the experiment was explained. Two simple questions that were related to the topic were asked. First, as a respondent would only qualify if he or she drove a full EV, a multiple choice question asked whether the respondent had a full EV, a plug-in hybrid electric vehicle (PHEV) or something else. In addition to this question, the respondent was asked if he had ever heard of V2G. In 2013, only 1% of the German vehicle users indicated that they had heard of V2G and that they knew something about it (Geske & Schumann, 2018). As part of the introduction, an informed consent page was added.

Information about V2G and the experiment was given in the explanation section. As respondents are generally not willing to read long texts of information, a short video clip was created in PowToon and uploaded on YouTube. The clip was embedded in the online pilot survey and could be viewed directly. It explained the concept of V2G and what was expected from the respondents in the experiment. In the video the contract attributes were explained. For convenience, these were written out in the survey as well.

In the experimental stage of the survey, the respondents were asked to choose between three contracts nine times in a row. Two out of three alternatives consisted of a V2G contract – V2G Contracts A and B. The third option was a 'no V2G contract' alternative. In order to be able to still gather information on trade-offs between options A and B, the respondents were asked two questions for every choice set. In the first question, the respondents had a choice between all three alternatives. In the second question, though, the respondents had to choose between one of the two contracts. The 'no V2G contract' alternative was not an option in the second question. The respondents were made to answer each question, which resulted in less uncompleted surveys.

#### 3.4.2.3 Distribution of the final survey

The final survey was distributed online as well as offline. The following section briefly explains both strategies.

The online survey was distributed by use of an anonymous link, accessible from 28 May to 4 July 2019. A list of EV drivers at KPMG had been provided, which included 150 EV drivers. They were sent the survey by email and after a couple of days they received an extra email as a reminder. In addition, the anonymous link was shared on the Facebook page 'Vereniging Elektrische Rijders (VER)', which translates to 'EV Driver Association'. The post was re-shared several times. In August 2019, this page contained 2,080 members.

For the offline distribution, another sampling approach was executed. Several public charging points were visited. In order to be able to sample as efficiently as possible, the charging points that were carefully picked from Oplaadpalen.nl had to meet four requirements. The locations should (1) include fast chargers, (2) show characteristics of a 'charge-and-ride' location, which maximizes the probability of EV drivers waiting in their vehicles during the charging process, (3) be easily accessible and (4) have a large capacity and therefore be busy. By fulfilling these requirements, the locations in **Table 11** were assorted.

**Table 11:** Assorted charging point locations for offline survey distribution (Tesla, 2019; Fastned, 2019)

Charging point	Location	Highway	Capacity	Rationale	Times visited	Note
Fastned	Hoofddorp (Den Ruygen Hoek-West)	A4	16 fast chargers (Fastned, 2019)	Busiest Fastned in the Netherlands and close to KPMG	1	–
Tesla Supercharger	Badhoevedorp (Schiphol)	A4	32 fast chargers (Tesla, 2019)	Largest Tesla Supercharger in the Netherlands, close to KPMG	3	Only Tesla
Tesla Supercharger	Zwolle (Van der Valk Hotel)	A28	16 fast chargers (Tesla, 2019)	Location close to the researcher’s parental house	3	Only Tesla

As many EV drivers wait in their EVs for at least twenty minutes while charging, this turned out to be an excellent strategy to increase the number of respondents. Practically every single one of the approached EV drivers reacted friendly on approach, were willing to fill in the survey and were genuinely interested in the research. As offline distribution increases the sample variance in terms of socio-demographic factors, the validity of the research increased as well. The printed surveys were filled in by pen on the spot and later that day imported into the digital data file. In order to avoid becoming too personal, the question regarding the respondent’s income was deleted from the offline survey.

### 3.5 Data preparation

Some tasks had to be performed in order to make full use of the dataset. Moreover, some extensions had to be made in order to be able to model the interaction effect of the context variable and to test for non-linear behaviour of certain attributes. This section briefly describes the preparation of the data.

#### 3.5.1 Adjustments to the dataset

The dataset obtained from Qualtrics could not directly be used to estimate the parameters in Biogeme. In the exported dataset from Qualtrics, every row corresponded to one single respondent. All choices from this single respondent were to be found in this row. However, Biogeme works with datasets that include one choice observation for every row. As every respondent answered nine choice sets, one respondent should take up nine rows in the dataset. Therefore, the dataset was transformed into the format in **Table 12**. As can be seen, every row corresponds to a choice observation (total of 1,332 in the column ‘#’) and every nine rows to a respondent (total of 148 in the column ‘ID’). As all respondents received the same choice sets, the column ‘SET’ repeats all nine choice sets for all respondents. Note that the respondents had to answer a second question if their first answer had been the ‘no V2G contract’ option. With reference to the columns ‘CHOICE1’ and ‘CHOICE2’ from **Table 12**, 1, 2 and 3 correspond to choices for respectively V2G Contract A, V2G Contract B and ‘no V2G contract’. Furthermore, the attribute levels for all attributes in every choice set are included in the columns ‘1.a’ up until ‘2.f’, as Biogeme needed this information to estimate the parameters.

**Table 12:** Dataset format used to estimate the discrete choice model

#	ID	SET	CHOICE1	CHOICE2	1.a	1.b	1.c	1.d	1.e	1.f	2.a	2.b	2.c	2.d	2.e	2.f	SPEED	GUARSPEED1	GUARSPEED2	1.c <sup>2</sup>	1.d <sup>2</sup>	2.c <sup>2</sup>	2.d <sup>2</sup>
1	1	1	1	1	100	0.00	5	30	7	24	20	0.30	5	10	1	6	0	0	0	25	25	900	100
2	1	2	1	1	20	0.30	5	10	7	24	100	0.00	10	30	1	6	1	10	30	25	100	100	900
3	1	3	2	2	60	0.00	5	10	4	6	60	0.30	10	50	4	24	1	10	50	25	100	100	2500
4	1	4	1	1	60	0.15	10	30	4	6	60	0.15	5	50	4	24	0	0	0	100	25	900	2500
5	1	5	1	1	100	0.30	15	50	1	12	20	0.00	10	10	7	12	0	0	0	225	100	2500	100
6	1	6	2	2	100	0.30	10	10	4	12	20	0.00	15	50	4	12	0	0	0	100	225	100	2500
7	1	7	1	1	20	0.15	15	50	7	6	100	0.15	15	10	1	24	1	50	10	225	225	2500	100
8	1	8	2	2	20	0.00	10	30	1	24	100	0.30	15	30	7	6	1	30	30	100	225	900	900
9	1	9	2	2	60	0.15	15	50	1	12	60	0.15	5	30	7	12	0	0	0	225	25	2500	900
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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1324	148	1	3	2	100	0.00	5	30	7	24	20	0.30	5	10	1	6	0	0	0	25	25	900	100
1325	148	2	2	2	20	0.30	5	10	7	24	100	0.00	10	30	1	6	1	10	30	25	100	100	900
1326	148	3	3	1	60	0.00	5	10	4	6	60	0.30	10	50	4	24	0	0	0	25	100	100	2500
1327	148	4	3	2	60	0.15	10	30	4	6	60	0.15	5	50	4	24	1	30	50	100	25	900	2500
1328	148	5	1	1	100	0.30	15	50	1	12	20	0.00	10	10	7	12	1	50	10	225	100	2500	100
1329	148	6	3	1	100	0.30	10	10	4	12	20	0.00	15	50	4	12	1	10	50	100	225	100	2500
1330	148	7	3	2	20	0.15	15	50	7	6	100	0.15	15	10	1	24	0	0	0	225	225	2500	100
1331	148	8	3	1	20	0.00	10	30	1	24	100	0.30	15	30	7	6	0	0	0	100	225	900	900
1332	148	9	3	1	60	0.15	15	50	1	12	60	0.15	5	30	7	12	0	0	0	225	25	2500	900

**3.5.2 Interaction effect of EV recharging speed**

In order to capture the influence of the recharging speed on the guaranteed minimum battery level, the context variable was included as interaction effect with the guaranteed minimum battery level. As can be seen in Table 12, the column ‘SPEED’ takes up 0 or 1. 0 corresponds to a choice set with the context of a normal recharging speed and 1 to a choice set with the context of a fast recharging speed. As normal recharging speed was regarded as the ‘status quo’ and corresponded to the reference level, the effect of a fast recharging speed was estimated relative to a normal recharging speed. An additional parameter was estimated for this interaction effect. By adding the parameter estimate for the interaction effect with the parameter estimate for the guaranteed minimum battery level, the effect of an increased EV recharging speed could be captured. The columns ‘GUARSPEED1’ and ‘GUARSPEED2’ are obtained by the multiplication of the column ‘SPEED’ with the columns ‘1.d’ and ‘2.d’. This multiplication had to be made within the dataset, as Biogeme was not able to make this calculation.

**3.5.3 Testing for non-linearity**

Parsons et al. (2014) found that the contract attributes of plug-in time and guaranteed minimum battery level showed a quadratic effect on the perceived utility. For this reason, these contract attributes were tested for non-linearity. This required extending the utility functions. Two quadratic components that estimated two quadratic parameters for these contract attributes were added. If these parameters were statistically significant, the effect of the contract attributes would be non-linear. The columns ‘1.c<sup>2</sup>’ up until ‘2.d<sup>2</sup>’ in Table 12 are the quadratic components of the columns ‘1.c’ up until ‘2.d’. These calculations had to be made within the dataset as well, as Biogeme was also not able to make this calculation.



## 4 Results

This chapter shows the results of the final survey with stated choice experiment and provides answers to the three research sub-questions:

- Which attributes specified in the V2G contract are of influence on Dutch EV drivers' participation in V2G contracts and to what extent?
- What influence does the EV recharging speed have on the EV drivers' willingness to participate in V2G contracts?
- How does the EV recharging speed influence the importance of the guaranteed minimum battery level specified in the V2G contract?

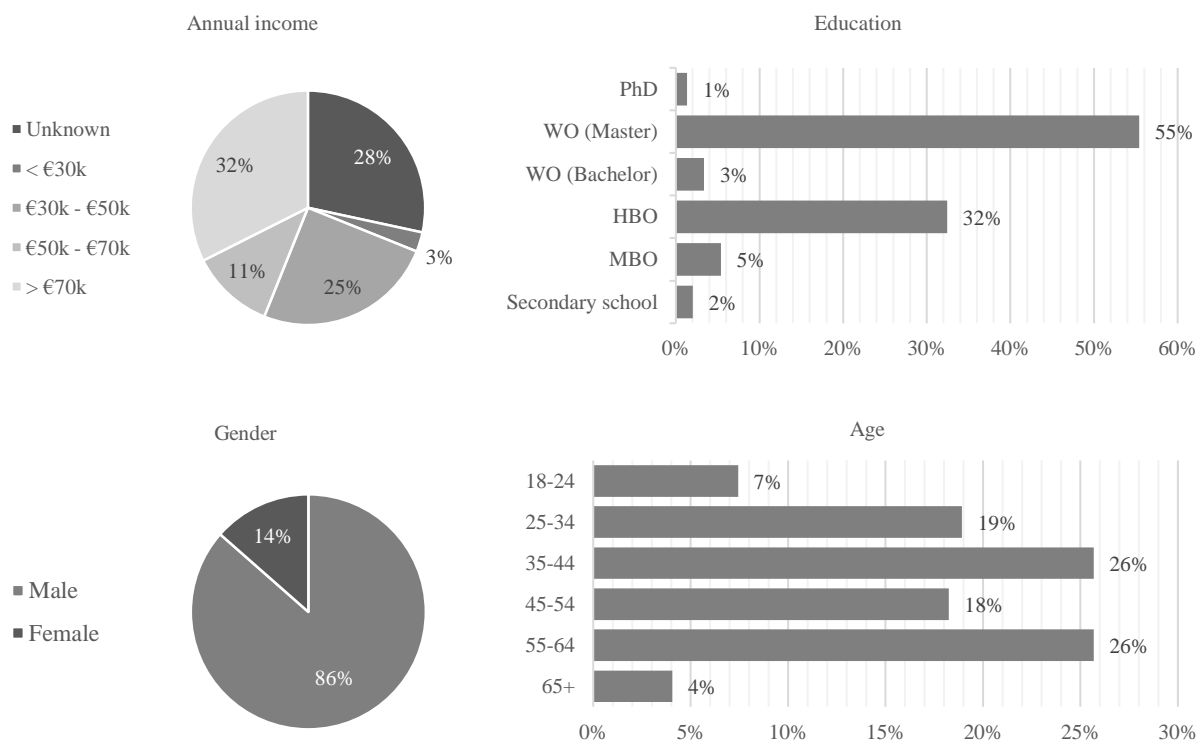
In section 4.1, sample statistics and representativeness are described for both socio-demographic and other EV driver characteristics. The effect of the recharging speed on the respondents' choices and the effect of other EV driver characteristics on the respondents' choices are described in section 4.2. The MNL model estimation results are shown in section 4.3 and reflected on in section 4.4. The estimation results are further analysed in section 4.5.

### 4.1 Sample statistics

This section shows the socio-demographic characteristics of the sample and compares the representativeness with the population of EV drivers. Furthermore, other EV driver characteristics of the sample are described.

#### 4.1.1 Socio-demographic characteristics

By 4 July 2019, 115 respondents had fully completed the online survey and 42 respondents the offline survey. As nine of the completed online surveys were excluded from the dataset, a total of 148 useful respondents were gathered. The main reasons for excluding some surveys were that a couple of respondents completed the survey even though they did not drive an EV and that a minor error in Qualtrics occurred. Alongside the useful responses, 104 respondents started the online survey without completing it. The informed consent page, three-minute video clip and the quantity of choice sets were the main dropout reasons. The socio-demographics of this sample are visualized in **Figure 5**.



**Figure 5:** Socio-demographic characteristics of the sample population (n=148)

As can be deduced from **Figure 5**, the sample mainly consisted of high-income, middle-aged males. In detail, 86% of the sample is male, 93% is highly educated (an ‘HBO’ degree or higher), 63% belongs to the age category 25-54 and, based on the 106 online respondents, 61% earns more than €50,000 per year. Note that the income distribution is only based on the online respondents, as the offline respondents were not asked about their income.

Practically no specific socio-demographic statistics about the Dutch EV drivers’ population are available, which makes it hard to determine the representativeness of the sample. However, Hoekstra & Refa (2017) conducted a survey among Dutch EV drivers to obtain their socio-demographic characteristics. They found that 92% of the population was male, 74% had obtained a degree in higher education and 68% had a yearly income above €50,000. Furthermore, the average age of an EV driver happened to be 50 years old, with 77% of the population being in the age category of 41 to 61 year old. Additionally, Sovacool, Kester, Noel, Zarazua, & Rubens (2018) found that mostly men with a high level of education and aged in the range of 30 to 45 years old were most likely to drive an EV. Even though these characteristics from Sovacool, Kester, et al. (2018) were based on EV drivers from the Nordic region, it suggests EV drivers are at the moment mostly middle-aged men with a relatively high income.

Gender and income distribution are rather close compared to the sample in Hoekstra (2017). However, the sample in this study is both a little younger as well as higher educated than the obtained findings in Hoekstra (2017). This could be explained by the fact that relatively many young professionals at KPMG drive an EV and most of them are highly educated.

According to the SparkCity model from Hoekstra, Steinbuch, & Verbong (2017), which forecasts future scenarios of EV adoption, approximately three million EVs will be on the road in the Netherlands from 2030. This would correspond to one-third of the total number of vehicles in the Netherlands. As the share of EVs in the Netherlands was less than 1% by June 2019 (RWO, 2019), the socio-demographic characteristics of Dutch EV drivers will gradually

shift towards those of normal vehicles drivers. Therefore, the sample representativeness in this study is likely to deteriorate over time.

#### 4.1.2 Other EV driver characteristics

In the final part of the survey, the respondents were asked to answer a couple of questions related to their personal characteristics on top of their socio-demographic characteristics described in the previous section. **Table 13** summarizes these personal characteristics. As can be seen, more than 66% of the sample had already heard about V2G. This is rather contradictory to the sample in Noel et al. (2019), in which only 10% had already heard about V2G. An explanation for this large difference is the fact that the sample in Noel et al. (2019) consisted of vehicle drivers, while the sample in this study only consisted of EV drivers. Furthermore, the high share of EV leasers could be explained by a relatively high number of KPMG employees in the sample, who almost all lease their EVs. The statistics of the other three EV driver characteristics in **Table 13** – yearly travelled distance, EV experience and perceived radius reduction – were not exceptional.

**Table 13:** Other EV driver characteristics

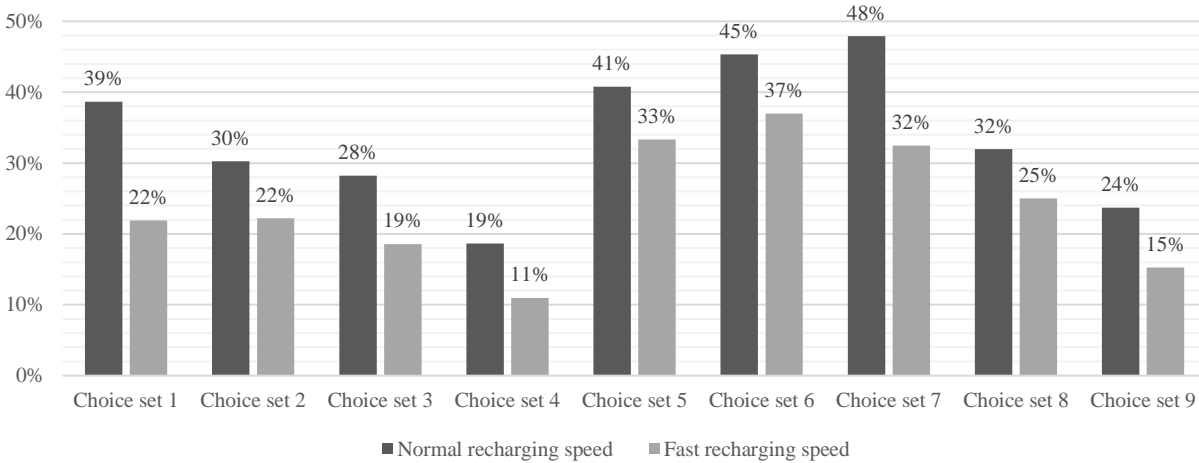
Other EV driver characteristic	Level	Frequency	Percentage
V2G familiarity	Yes, fully	71	48.0%
	Yes, partly	27	18.2%
	No	40	33.8%
Type of ownership	Leaser	96	64.9%
	Buyer	52	35.1%
Yearly travelled distance	Less than 10,000 km	9	6.1%
	10,000 km – 20,000 km	47	31.8%
	20,001 km – 40,000 km	62	41.9%
	More than 40,000 km	30	20.3%
EV experience	Less than 3 months	14	9.5%
	3 months – 1 year	66	44.6%
	1 year – 3 years	44	29.7%
	More than 3 years	24	16.2%
Perceived radius reduction	Less than 10%	21	14.2%
	10% – 20%	57	38.5%
	21% – 30%	42	28.4%
	More than 30%	28	18.9%

## 4.2 Descriptive results

This section analyses the outcomes of the first question, which reveals the choice distribution per choice set for all three alternatives. In the first question, the respondents were asked to make a choice between three options – V2G contract A, V2G contract B or ‘no V2G contract’. The second question was only shown when respondents had chosen the ‘no V2G contract’ option. In this question, they were forced to choose between the two previously displayed V2G contracts. The outcomes of this second question were used to estimate an MNL model in section 4.3. The outcomes of the first question were used to analyse the effect of an increased EV recharging speed on the choice distribution, as well as the effect of other EV driver characteristics on the choice distribution.

### 4.2.1 The effect of an increased EV recharging speed

Every choice set contained a particular context. In the first context – the ‘status quo’ – the respondents had to assume a normal EV recharging speed. In the second context – the hypothetical future scenario – the respondents had to assume that their EV could fully recharge within five minutes. The number of times the ‘no V2G contract’ option was chosen by the respondents for every choice set for both context levels suggests the importance of recharging speed on their willingness to participate in V2G programmes. **Figure 6** gives an overview of this.



**Figure 6:** Share of respondents that have chosen the ‘no V2G contract’ option for every choice set

Interestingly, as can be deduced from **Figure 6**, the ‘no V2G contract’ option was less preferred within the context of a fast recharging speed. This is so for every choice set. More specifically, the percentage range of the respondents choosing for the ‘no V2G contract’ option decreased from 48-19% in the context of normal recharging speed to 37-11% with a fast recharging speed, which is on average a reduction from 34% to 24%. In other words, more than one-third of the respondents at the moment does not prefer a V2G contract over conventional charging, while only less than a quarter would not prefer this if the recharging speed was faster. This could indicate that a faster recharging speed of an EV has indeed a positive effect on the willingness to participate in V2G contracts.

**4.2.2 The effects of other EV driver characteristics**

The effects of the other EV driver characteristics could, in a way, be analysed. For every characteristic, the choice distribution of the ‘no V2G contract’ option was also measured. This gives a first indication about a possible effect on their choice-making process. The characteristics that are shown in **Table 13** are classified into different groups that fall under the other EV driver characteristics, in order to capture the effects. This classification is shown in **Table 14**.

**Table 14:** Classification of groups according to other EV driver characteristics

Other EV driver characteristic	Classified group	Requirement
EV experience	Pioneer EV driver	EV driver for more than 3 years
	Mainstream EV driver	EV driver for less than 3 years
V2G familiarity	Familiar to V2G	EV driver has heard about V2G
	Not familiar to V2G	EV driver has never heard about V2G
Ownership	EV leaser	EV driver leases the EV
	EV buyer	EV driver has bought the EV
Driving behaviour	Frequent driver	EV driver travels more than 20,000 km per year
	Non-frequent driver	EV driver travels less than 20,000 km per year
Perceived radius reduction	Large radius reducers	EV driver perceives a radius reduction larger than 20%
	Small radius reducers	EV driver perceives a radius reduction smaller than 20%

**4.2.2.1 EV experience**

Pioneer EV drivers are the early adopters of EVs that already have some experience with EVs. Contrary to pioneer EV drivers are mainstream EV drivers, who form the other part of the EV drivers. According to Axsen, Goldberg, & Bailey (2016), pioneer EV drivers’ motivations regarding V2G could substantially differ from the motivations of mainstream EV drivers. In fact, Sovacool et al. (2017) found that pioneer EV drivers required two to three times more financial compensation in order to be triggered to participate in V2G programmes than mainstream EV drivers. In this research, pioneer EV drivers were classified as EV drivers that had been driving electric for at least three years. Looking at the choice distribution of the ‘no V2G contract’ option for both contexts, 34% of the pioneer EV drivers

chose the ‘no V2G contract’ option, whereas only 28% of the mainstream EV drivers chose this option. This supports the theory described in Axsen et al. (2016), as pioneer EV drivers in this sample seemed more sceptical towards V2G than mainstream EV drivers. This could be explained by the fact that pioneer EV drivers have already experienced the implications brought about by their EVs, such as the limited driving range and the plug-in dependence.

#### 4.2.2.2 V2G familiarity

The respondents were also classified in two V2G groups, based on their familiarity towards V2G. 37% of the respondents who indicated to have never heard of V2G were in favour of the ‘no V2G contract’ option, against 25% that were not familiar with V2G yet. In other words, EV drivers that were familiar with V2G seemed to be more in favour of V2G than EV drivers that had never heard of V2G. This is in line with the recommendations in Noel et al. (2019), which state that the benefits of V2G should be better explained to the consumers in order to increase the potential success of V2G.

#### 4.2.2.3 Ownership

EV leasers and buyers might respond differently to the presented V2G contracts, as the potential impact on the battery might be less valued by EV leasers than by EV buyers. Somewhat unexpectedly, it was found that 31% of the EV leasers chose the ‘no V2G contract’ option against 25% of the EV buyers, implying that EV leasers were more in favour of choosing the ‘no V2G contract’ option.

#### 4.2.2.4 Driving behaviour

The EV drivers’ driving behaviours could also influence their choices. Therefore, the sample was grouped into frequent drivers and non-frequent drivers. The first group drives more than 20,000 km per year on average and the second group less. Frequent drivers might have less time to plug in their EVs and might thus choose the ‘no V2G contract’ option more often. It was found that 30% of the frequent drivers chose to opt out, against 27% of the non-frequent drivers. Therefore, no large difference was observed.

#### 4.2.2.5 Perceived radius reduction

The respondents were also asked to fill in the theoretical driving range of their EVs and the practical driving range in reality. The difference between theoretical and practical driving range varied from 0% all the way up to 56%. On average, this perceived radius reduction was 20%. For example, an EV with a theoretical range of 300 km would be able to drive 240 km on average within this sample. Respondents that experienced a larger perceived radius reduction were classified as ‘large radius reducers’ and the other group as ‘small radius reducers’. The latter group might have a more positive attitude towards EVs and therefore also towards new technological concepts like V2G, as they might complain less about the limited range of their EVs. It was found that 32% of the large radius reducers chose the ‘no V2G contract’ option, against 27% of the small radius reducers.

### 4.3 Model estimation results

As already mentioned in the previous section, an MNL model was estimated by using the outcomes of the choice sets’ second questions. All 148 respondents completed nine choice tasks, which resulted in a total of 1,332 useful choice observations. Based on this dataset, an MNL model was estimated in the software package Biogeme (Bierlaire, 2018). The Biogeme code for the MNL model is shown in Appendix E. The next section describes the estimation results of an MNL that only included linear components. Section 4.3.2 describes the estimation results of three MNL models that also included quadratic components to test the attributes of guaranteed minimum battery level and plug-in time for non-linearity.

### 4.3.1 MNL model with linear components

The two utility functions for the two V2G contracts are given in equation (6) and (7), both only including unlabelled alternatives without an alternative specific constant, as the ‘no V2G contract’ option was excluded from this question.  $V_1$  corresponds to the utility function of V2G Contract A and  $V_2$  to V2G Contract B. The context variable  $SPEED$  is included in the utility functions as an interaction effect with guaranteed minimum battery level. This variable is coded in the dataset – 1 for the context of fast recharging speed, 0 otherwise (normal recharging speed). Therefore, if  $SPEED$  equals 0, only the utility of guaranteed minimum battery level is estimated. However, if this variable equals 1, the moderation effect – or interaction effect – of the fast recharging speed on the weight ( $\beta$ ) of the guaranteed minimum battery level is estimated, relative to the context of the normal recharging speed. Furthermore, this MNL model only contained linear components. The estimation results are summarized in **Table 15**.

$$V_1 = \beta_{REM} \cdot REM_1 + \beta_{EREM} \cdot EREM_1 + \beta_{PLUG} \cdot PLUG_1 + \beta_{DIS} \cdot DIS_1 + \beta_{CON} \cdot CON_1 \quad (6)$$

$$+ (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_1$$

$$V_2 = \beta_{REM} \cdot REM_2 + \beta_{EREM} \cdot EREM_2 + \beta_{PLUG} \cdot PLUG_2 + \beta_{DIS} \cdot DIS_2 + \beta_{CON} \cdot CON_2 \quad (7)$$

$$+ (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_2$$

$\beta \cdot X$  = Linear component

  = Interaction effects

**Table 15:** Estimation results from linear MNL model. \* corresponds to a statistically insignificant parameter estimate.

Parameter	Name	Value	Robust Std err	Robust t-test	p-value
Contract duration	$\beta_{CON}$	-0.00464	0.00436	-1.06	0.29*
Discharging cycles	$\beta_{DIS}$	-0.0485	0.0141	-3.45	0.00
Variable extra remuneration	$\beta_{EREM}$	-0.243	0.254	-0.96	0.34*
Guaranteed minimum battery level	$\beta_{GUAR}$	0.0411	0.00369	11.14	0.00
Plug-in time	$\beta_{PLUG}$	-0.143	0.0175	-8.17	0.00
Fixed remuneration	$\beta_{REM}$	0.00697	0.000983	7.09	0.00
Interaction effect of recharging speed on guaranteed minimum battery level	$\beta_{GUARSPEED}$	-0.0216	0.00405	-5.34	0.00
Number of estimated parameters	7				
Number of observations	1,332				
Null log-likelihood	-923.272				
Final log-likelihood	-822.116				
Rho-squared	0.110				

The MNL model did converge. As can be seen in **Table 15**, the parameter estimates for the contract attributes discharging cycles, guaranteed minimum battery level, plug-in time and fixed remuneration are statistically significant at 1% level. Additionally, the parameter estimate for the interaction effect of recharging speed on the guaranteed minimum battery level is also statistically significant at 1% level. The attributes of contract duration and variable extra remuneration are statistically insignificant.

The null log-likelihood, which is the log of the likelihood function that indicates how well the model with parameters set to zero fits the data for a particular set of observations, is -923.3. Furthermore, the final log-likelihood, which indicates how well the model with estimated parameters fits the data for a particular set of observations, equals -822.1. Using McFadden’s rho-squared function  $(1 - LL_{\beta}/LL_0)$ , an indication could be given how much better the estimated model fits the data than the model with parameters set to zero does. In this function,  $LL_{\beta}$  corresponds to the final log-likelihood and  $LL_0$  to the null log-likelihood. As can be seen in **Table 15**, the rho-squared value equals 0.110. This indicates that the estimated model fits the data reasonably. A rho-squared value of zero means that the estimated model does not fit the data better than the model with parameters set to zero does.

### 4.3.2 Non-linearity

Parsons et al. (2014) found that the utility functions for guaranteed minimum battery level and plug-in time showed a quadratic relationship. This means that the utility functions for both contract attributes are non-linear. These two contract attributes are therefore tested for non-linearity in this research.

Three MNL models (MNL model A, B and C) were estimated in order to test these quadratic components. MNL model A, B and C all contained a different combination of quadratic components to test the non-linearity of guaranteed minimum battery level and plug-in time. The linear components of all other parameters remained the same in all three MNL models. The Biogeme code for these three MNL models is shown in Appendix E. All parameter estimates are summarized in Table 16. The full estimation results of all three MNL models, including robust standard errors and t-tests, are shown in Appendix F.

#### 4.3.1.1 MNL model A

In the first MNL model, the utility functions were extended with a quadratic component for both guaranteed minimum battery level and for plug-in time that both included an additional to be estimated parameter and the corresponding attribute level squared. This resulted in the following utility functions:

$$V_1 = \beta_{REM} \cdot REM_1 + \beta_{EREM} \cdot EREM_1 + \beta_{PLUG} \cdot PLUG_1 + \beta_{DIS} \cdot DIS_1 + \beta_{CON} \cdot CON_1 \quad (8)$$

$$+ (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_1 + \beta_{GUARQUA} \cdot GUAR_1^2 + \beta_{PLUGQUA} \cdot PLUG_1^2$$

$$V_2 = \beta_{REM} \cdot REM_2 + \beta_{EREM} \cdot EREM_2 + \beta_{PLUG} \cdot PLUG_2 + \beta_{DIS} \cdot DIS_2 + \beta_{CON} \cdot CON_2 \quad (9)$$

$$+ (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_2 + \beta_{GUARQUA} \cdot GUAR_2^2 + \beta_{PLUGQUA} \cdot PLUG_2^2$$

$\beta \cdot X^2$  = Quadratic component

$\beta \cdot X$  = Linear component

  = Interaction effects

A convergence was reached for MNL model A. Furthermore, the null log-likelihood remained -923.3. The final log-likelihood improved to -815.2. However, as can be seen in Table 16, many parameters became statistically insignificant. Therefore, this model did not fit the data better than the linear model. However, a statistically significant quadratic component of plug-in time was estimated. For this reason, the statistically insignificant quadratic component of guaranteed minimum battery level was excluded from the MNL model, implying a linear effect for the guaranteed minimum battery level. The parameters were re-estimated using MNL model B.

#### 4.3.1.2 MNL model B

As shown by equation (10) and (11), the quadratic component for guaranteed minimum battery level was deleted. Both quadratic and linear components of plug-in time were still included for estimation. The utility functions of MNL model B were as follows:

$$V_1 = \beta_{REM} \cdot REM_1 + \beta_{EREM} \cdot EREM_1 + \beta_{PLUG} \cdot PLUG_1 + \beta_{DIS} \cdot DIS_1 + \beta_{CON} \cdot CON_1 + (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_1 + \beta_{PLUGQUA} \cdot PLUG_1^2 \quad (10)$$

$$V_2 = \beta_{REM} \cdot REM_2 + \beta_{EREM} \cdot EREM_2 + \beta_{PLUG} \cdot PLUG_2 + \beta_{DIS} \cdot DIS_2 + \beta_{CON} \cdot CON_2 + (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_2 + \beta_{PLUGQUA} \cdot PLUG_2^2 \quad (11)$$

$\beta \cdot X^2$  = Quadratic component

$\beta \cdot X$  = Linear component

  = Interaction effects

MNL model B converged as well. With reference to **Table 16**, The null log-likelihood remained -923.3 and the final log-likelihood remained more or less the same (-815.6) compared to MNL model A. Furthermore, the parameter estimate for the linear component of plug-in time remained statistically insignificant, while the quadratic component of this attribute remained statistically significant. This led to the deletion of the statistically insignificant linear component for plug-in time, resulting in a third parameter estimation using MNL model C.

#### 4.3.1.3 MNL model C

MNL model C thus included only a quadratic component for plug-in time and no linear component for plug-in time anymore. Consequently, MNL model C included linear components for fixed remuneration, variable extra remuneration, discharging cycles and contract duration and a quadratic component for plug-in time. This resulted in the following utility function for MNL model C:

$$V_1 = \beta_{REM} \cdot REM_1 + \beta_{EREM} \cdot EREM_1 + \beta_{DIS} \cdot DIS_1 + \beta_{CON} \cdot CON_1 + (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_1 + \beta_{PLUGQUA} \cdot PLUG_1^2 \quad (12)$$

$$V_2 = \beta_{REM} \cdot REM_2 + \beta_{EREM} \cdot EREM_2 + \beta_{DIS} \cdot DIS_2 + \beta_{CON} \cdot CON_2 + (\beta_{GUAR} + \beta_{GUARSPEED} \cdot SPEED) \cdot GUAR_2 + \beta_{PLUGQUA} \cdot PLUG_2^2 \quad (13)$$

$\beta \cdot X^2$  = Quadratic component

$\beta \cdot X$  = Linear component

  = Interaction effects

MNL model C did converge. With reference to **Table 16**, the null log-likelihood remained -923.3 and the final log-likelihood became -816.3. The quadratic component of plug-in time remained statistically significant, implying that the linear effect of this component was explained away by the quadratic component. This demonstrated the quadratic effect of the parameter estimate of plug-in time on the perceived utility. Compared to the final log-likelihood from the first MNL model without considering non-linearity (-822.1), it could be concluded that this model fitted the data better than the first estimated model in this chapter, which included a linear instead of a quadratic component for the plug-in time.



**Table 16:** Estimation results accounted for non-linearity (MNL model A, B and C). \* corresponds to a statistically insignificant parameter estimate.

Parameter name	MNL model A		MNL model B		MNL model C	
	Value	p-value	Value	p-value	Value	p-value
$\beta_{CON}$	-0.00782	0.11*	-0.00603	0.18*	-0.00621	0.16*
$\beta_{DIS}$	-0.0339	0.04	-0.0406	0.00	-0.0449	0.00
$\beta_{REM}$	-0.306	0.34*	-0.132	0.61*	-0.156	0.54*
$\beta_{GUAR}$	0.0212	0.37*	0.0429	0.00	0.0439	0.00
$\beta_{GUARQUA}$	0.000375	0.35*	–	–	–	–
$\beta_{PLUG}$	0.114	0.13*	0.0761	0.22*	–	–
$\beta_{PLUGQUA}$	-0.0132	0.00	-0.0111	0.00	-0.00753	0.00
$\beta_{REM}$	0.00791	0.00	0.00704	0.00	0.00710	0.00
$\beta_{GUARSPEED}$	-0.0218	0.00	-0.0218	0.00	-0.0218	0.00
Number of estimated parameters	9		8		7	
Number of observations	1,332		1,332		1,332	
Null log-likelihood	-923.272		-923.272		-923.272	
Final log-likelihood	-815.188		-815.608		-816.336	
Rho-squared	0.117		0.117		0.116	

#### 4.4 Conceptual model reflection

This section compares the parameter estimates with the parameter hypothesis from Chapter 2. The testing of these eight hypotheses are summarized in **Table 17**.

**Table 17:** Hypotheses correctness for the V2G contract attributes and context variable

#	Hypothesis	Statistical significance	Correctly hypothesized
H <sub>1</sub>	Fixed remuneration has a positive effect on the perceived utility	Significant at 1% level	Yes
H <sub>2</sub>	Variable extra remuneration has a positive effect on the perceived utility	Not significant	No
H <sub>3</sub>	Plug-in time has a negative effect on the perceived utility	Significant at 1% level	Yes
H <sub>4</sub>	Guaranteed minimum battery level has a positive effect on the perceived utility	Significant at 1% level	Yes
H <sub>5</sub>	Number of days drawn down to the guaranteed minimum battery level has a negative effect on the perceived utility	Excluded after the pilot	No
H <sub>6</sub>	Discharging cycles has a negative effect on the perceived utility	Significant at 1% level	Yes
H <sub>7</sub>	Contract duration has a positive effect on the perceived utility	Not significant	No
H <sub>8</sub>	EV drivers are less sensitive to guaranteed minimum battery level if the speed of recharging becomes faster	Significant at 1% level	Yes

When the weights of the estimated parameters that were statistically significant were substituted in the utility functions, the following systematic utility function for a V2G contract was found:

$$V_{V2G \text{ Contract}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429 - 0.0218 \cdot SPEED) \cdot GUAR - 0.0449 \cdot DIS$$

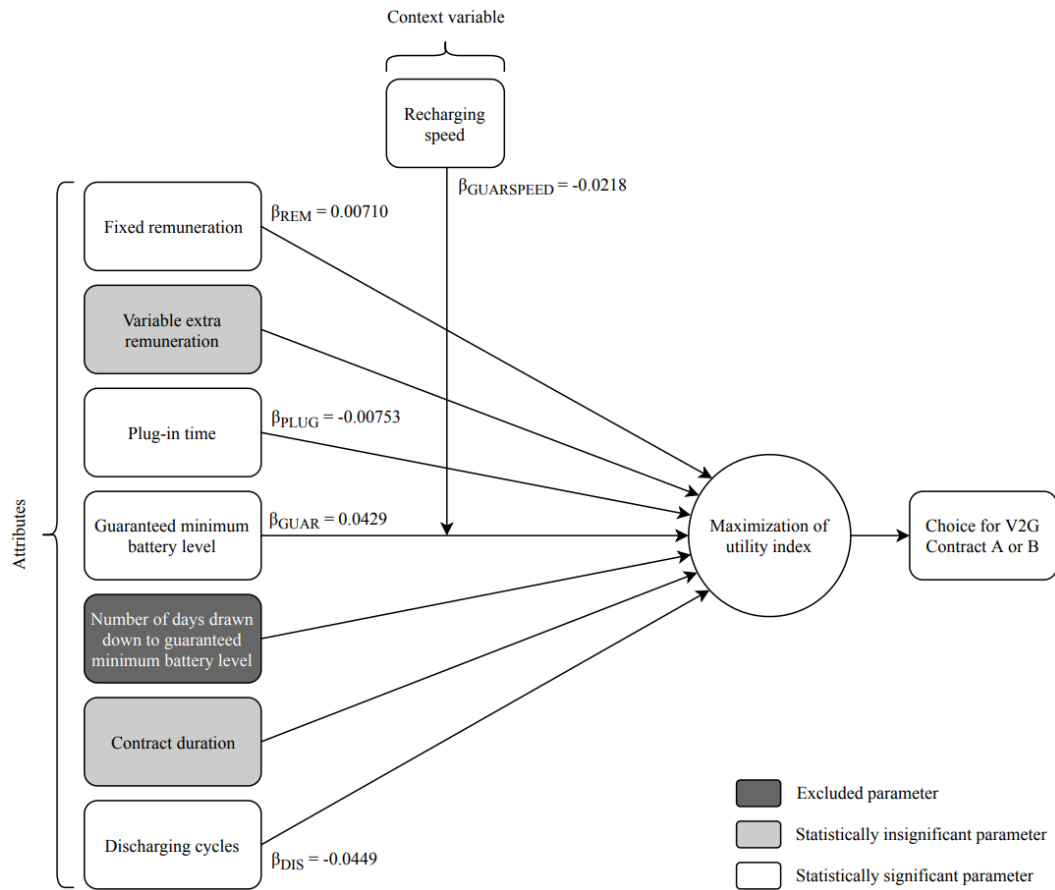
The weight of the guaranteed minimum battery level depended on the context variable. Therefore, by substituting the two variables for *SPEED* (0 or 1), the following two systematic utility functions for both normal recharging speed as well as for fast recharging speed arose:

$$V_{V2G \text{ Contract, Normal Recharging Speed}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429) \cdot GUAR - 0.0449 \cdot DIS$$

$$V_{V2G \text{ Contract, Fast Recharging Speed}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429 - 0.0218) \cdot GUAR - 0.0449 \cdot DIS$$

As shown by the two utility functions, the weight for the guaranteed minimum battery level depends on the recharging speed. Note that the terms for variable extra remuneration as well as for contract duration were excluded from the utility function, as their parameter estimates were statistically insignificant. The null hypotheses for the estimated parameters that were statistically insignificant – contract duration and variable extra remuneration – were accepted. No conclusions could be drawn from these parameter estimates. This also applied to the attribute that had already been excluded after the pilot, which was the number of days drawn down to the guaranteed minimum battery level.

The null hypotheses of the five other estimated parameters that turned out to be statistically significant – fixed remuneration, plug-in time, guaranteed minimum battery level, discharging cycles and the interaction effect of recharging speed – were rejected, as all parameters were correctly hypothesized. All statistically significant effects and relationships are quantified in the tested conceptual model in **Figure 7**.



**Figure 7:** Tested conceptual model with estimated parameters. Note that  $\beta_{PLUG}$  is a quadratic component.

#### 4.5 Analysis of the estimation results

This section analyses the obtained results from the previous section. The estimation results from MNL model C are used for the analysis, as this model fitted the data best. Firstly, the relative importance of the contract attributes is calculated, taking into account the influence of EV recharging speed on the guaranteed minimum battery level. Thereafter, all contract attributes are analysed in more detail.

### 4.5.1 Relative importance

Five out of seven estimated parameters were found to be statistically significant at 1% level (Table 16). The relative importance could be calculated by multiplying the weights of these parameter estimates (which are the  $\beta$ s) with the total attribute level range. The latter are shown in parentheses in the attribute level range's column in Table 18.

**Table 18:** Contract attribute calculations. <sup>7</sup> As the  $\Delta$  utility per  $\Delta$  unit for the plug-in time changes due to the quadratic component, the average  $\Delta$  utility per  $\Delta$  unit is displayed. <sup>8</sup> The implicit prices were calculated by dividing the parameter estimates of the particular contract attribute by the parameter estimate of the fixed remuneration. Therefore, the monthly willingness-to-pay (positive sign) or monthly demanded financial compensation (negative sign) for a one-unit increase of a particular contract attribute was calculated.

Contract attribute	Attribute level range	$\Delta$ utility per $\Delta$ unit	Utility contribution	Implicit price <sup>8</sup>	Price range
Fixed remuneration	€20-100 (80)	0.00710	0.57	–	–
Guaranteed minimum battery level (normal recharging speed)	10-50% (40)	0.0429	1.72	€6.04	€241.69
Guaranteed minimum battery level (fast recharging speed)	10-50% (40)	0.0211	0.84	€2.97	€118.87
Discharging cycles	1-7 cycles (6)	-0.0449	-0.27	-€6.32	-€37.94
Plug-in time	5-15h (10)	-0.1506 <sup>7</sup>	-1.51	-€21.21	-€212.11

According to the utility contributions in Table 18, the contract attribute specifying the number of discharging cycles was the least important, followed by the fixed remuneration. When the respondents assumed a context of normal recharging speed, the guaranteed minimum battery level was the most important contract attribute. Furthermore, plug-in time was the second most important factor for EV drivers' decision making regarding V2G contracts. However, when the respondents assumed a context of fast recharging speed, an interesting observation could be made. The weight of the interaction effect of recharging speed on the guaranteed minimum battery level was -0.0218 (Table 16). Consequently, the calculated weight of the guaranteed minimum battery level was moderated by the context variable from 0.0429 to 0.0211 (0.0429 minus 0.0218). Therefore, the guaranteed minimum battery level became half as important in the context of fast recharging speed, relative to the normal recharging speed. Consequently, plug-in time became the most important attribute in the context of fast recharging speed. The relative importance for both contexts is shown in Table 19.

**Table 19:** Relative importance of V2G contract attributes

Importance	Context 1: Normal recharging speed	Context 2: Fast recharging speed
1	Guaranteed minimum battery level	Plug-in time
2	Plug in time	Guaranteed minimum battery level
3	Remuneration	Remuneration
4	Discharging cycles	Discharging cycles

### 4.5.2 Statistically significant parameters

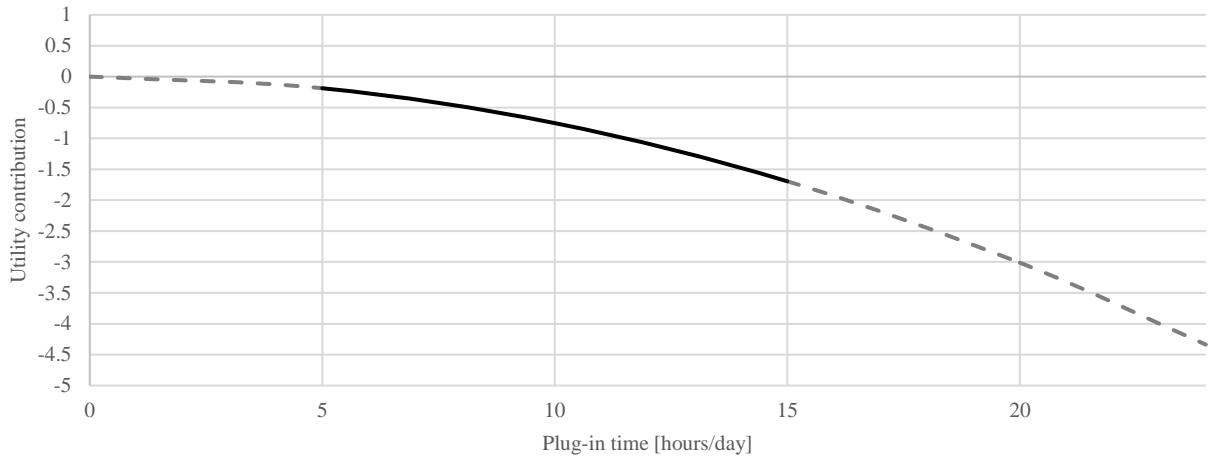
The statistically significant parameters are interpreted in detail in this section. All calculation are shown in Appendix G.

#### 4.5.2.1 Fixed remuneration

To start with, the weight of the parameter estimate of fixed remuneration had a positive effect on the perceived utility. This is fully in line with previous studies and expectations. The effect is linear, implying that the marginal utility increase – or in other words, the direction coefficient of the utility function of fixed remuneration – is constant. The weight of the fixed remuneration is in line with the findings of Geske & Schumann (2018), as remuneration was apparently not the most important contract attribute. This is in contrast with the estimation results of Kubli et al. (2018) and Parsons et al. (2014). An explanation for this could lie in the relatively high income levels of the sample in this study. High income individuals might be less sensitive to financial incentives.

#### 4.5.2.2 Plug-in time

As shown in **Table 18**, respondents experience a large inconvenience for plug-in time. Therefore, this attribute had a negative effect on the perceived utility. The utility function of this attribute shows a quadratic effect, implying a utility contribution with an increasing rate. This effect is graphically shown in **Figure 8**. This quadratic component is in line with the findings in Parsons et al. (2014). Here, increasing the plug-in time from 5 to 10 hours per day, would have to be financially compensated with €79.54 per month. Further increasing the required plug-in hours from 10 to 15 hours, would correspond to a demanded financial compensation of €132.57. This implies a required per-hour incremental financial compensation of €15.91 (5-10h) and €26.51 (10-15h) per month. In Parsons et al. (2014), these were estimated at €247.96 (5-10h) and €534.61 (10-15h) per year, respectively €20.66 and €44.55 per month. As an average vehicle is parked for around 95% of the day in the United States, Parsons et al. (2014) argued that these incremental costs were surprisingly high. Apparently, respondents did not treat plug-in time as a potential of increasing the productivity of their parked vehicles. Instead, they only focussed on the inconveniences a high plug-in time would cause. In this study, the respondents did seem to see more potential for their parked vehicles, as they demanded less financial compensation for an increase in plug-in time. This could partly be explained by the fact that the survey in Parsons et al. (2014) was distributed as early as 2009, even before EVs were widely adopted. Another explanation could be that the sample in this study only consisted of EV drivers, while the sample in Parsons et al. (2014) also included conventional vehicle drivers



**Figure 8:** Quadratic utility contribution of the plug-in time attribute. The grey dashed line is an extrapolation of the results.

This insight has a beneficial as well as a disadvantageous implication for the aggregator. On the one side, the potential inconveniences respondents expected with plug-in times seemed to be reduced, allowing an aggregator to increase its predictability of available battery capacity for ancillary services. On the other side, increasing the number of required plug-in hours to above 10 hours per day would result in a relatively high demanded financial compensation.

#### 4.5.2.3 Guaranteed minimum battery level

The contract attribute of guaranteed minimum battery level had a positive effect on the total utility. Therefore, increasing the level of this attribute resulted in a higher probability that a particular V2G contract would be preferred. When considering the context of normal recharging speed, the respondents valued this attribute as most important. Interestingly, when assuming a fast recharging speed, the weight of this parameter estimate became half as important.

The average per-kilometre incremental WtP from a range of 10-50km was calculated at €5.13 per month by Geske & Schumann (2018). Parsons et al. (2014) found the utility contributions to behave as a quadratic function. An increase in the range of 40-120km would be worth €4.01 per month for every one-kilometre increase. Furthermore, these valuations reduced to €3.19 and as little as €0.46 in respectively the ranges of 120-200km and 200-280km.

In this study, the utility contribution for guaranteed minimum battery level behaves as a linear function. It was calculated that a 1%-increase in guaranteed minimum battery level was worth €6.04 per month to the respondents in a battery level range of 10-50%, considering a normal recharging speed. Interestingly, this valuation reduced to €2.97 in the context of a fast recharging speed. As the average range of a full EV battery in this study's sample equalled approximately 360 km, this range corresponded to 36-180km. This means that an increase in one kilometre is at the moment valued at €1.68 per month and reduces to €0.83 in the context of a fast recharging speed. The lower the specified guaranteed minimum battery level in a V2G contract, the higher the value for an aggregator is. Therefore, the development of battery recharging speed could influence the social acceptance of V2G contracts in a positive way.

#### 4.5.2.4 Discharging cycles

As was expected, the attribute of discharging cycles had a negative effect on the perceived utility. Even though an effect of discharging cycles existed, it was the least important factor of the statistically significant parameters of the contract attributes. One extra discharging cycle would have to be financially compensated with €6.32 per month in order to be accepted by the respondents.

An explanation for the relatively low importance of the number of discharging cycles could be that a large part of this sample (68.8%) leases an EV. They might be less concerned about battery degradation, as they do not own the vehicles themselves. However, this does introduce an implication for the leasing companies, as they own the vehicles and could be more concerned about potential damage to the batteries.

### 4.5.3 Statistically insignificant parameters

This section briefly discusses the statistically insignificant parameters. Note that the contract attribute 'number of days drawn down to guaranteed minimum battery level' is not discussed, as it was already excluded after the pilot survey.

#### 4.5.3.1 Contract duration

The parameter estimate for contract duration was estimated to be statistically insignificant. This either implies that the respondents in the sample did not base their choices on this parameter or that not enough respondents completed the survey. This is contrary to the findings of Kubli et al. (2018), who found this parameter to be statistically significant and negative. This could be explained by the fact that Kubli et al. (2018) only considered four attributes in their choice sets, whereas this study included six. With less attributes, respondents could have focussed more on the contract duration. Another possible explanation for this significance could be that the study of Kubli et al. (2018) did not only investigate potential V2G contracts, but applied a more integrated approach to measure the willingness to create distributed flexibility. Their study also included contracts for the prosumers' solar PV, storage systems and heat pumps. Therefore, more implications could have been experienced by the respondents, resulting in less preferences for longer contract durations. However, if the relative importance of the attribute of contract duration was low in the study of Kubli et al. (2018), it could be reasonable to assume that respondents do not base their decisions on the duration of a V2G contract.

#### 4.5.3.2 Variable extra remuneration

The second estimated parameter that turned out to be statistically insignificant was the variable extra remuneration. As the effect of this attribute had not yet been measured in previous literature, comparisons could not be made. The insignificance could however be explained in the following way. The variable extra remuneration was presented right next to the fixed remuneration in the survey. The attribute level range of fixed remuneration varied from €20 to €100 per month. The attribute level range of variable extra remuneration, varying from €0.00 to €0.30 per month for every extra hour plugged in on top of the required plug-in time, seemed negligible for the respondents when compared to the fixed remuneration. However, if respondents had calculated the potential monthly payments this attribute could have yielded, they would probably have concluded that this type of remuneration was worth considering. For instance, an EV driver could decide to plug in the EV for 15 hours per day on average even though the required plug-in time is

set to only 5 hours per day. If the fixed remuneration was set to €20 and the variable extra remuneration to €0.30, this would imply that the EV driver could earn an extra €90 per month on top of the €20 fixed remuneration.

## 4.6 Conclusion

Dutch EV drivers in the sample of this research based their choices for a particular V2G contract on four contract attributes: fixed remuneration, guaranteed minimum battery level, plug-in time and discharging cycles. The parameter estimates for variable extra remuneration as well as for contract duration were statistically insignificant, which could imply that EV drivers did not base their decisions on these contract attributes. The statistically insignificant estimated parameters were not included in the final utility functions that estimate the systematic utility for a particular V2G contract.

The respondents' choice distributions revealed the effect of an increased EV recharging speed on their willingness to participate in V2G contracts. On average, 34% of the respondents preferred conventional charging over a V2G contract assuming current recharging speeds, while only 24% of the respondents would prefer this with a hypothetical recharging speed of five minutes.

Interestingly, the speed of recharging also had a statistically significant effect on the importance of the guaranteed minimum battery level. In fact, the respondents valued this contract attribute half as important within the context of a fast recharging speed compared to the context of a normal recharging speed.

## 5 Conclusions

This thesis aims to provide deeper insights into EV drivers' behaviour regarding V2G contracts. V2G is a promising technology that could contribute to the stabilization of the electricity grid and the integration of renewable energy sources. However, little empirical evidence about the complexity of user motivations is currently available in literature. In order to empirically contribute to the field of V2G, a stated choice experiment was performed to estimate Dutch EV drivers' preferences and trade-offs on V2G contract attributes.

To the knowledge of the researcher, this is the first research that has empirically analysed the effect of an increased EV recharging speed on the willingness to participate in V2G contracts. In fact, a statistically significant moderation effect of the EV recharging speed on the guaranteed minimum battery level was found: the respondents in the sample valued the guaranteed minimum battery level – relative to the 'status quo', or normal recharging speed – half as important if the EV would be able to fully recharge within five minutes. Even though this hypothetical recharging speed is not yet feasible and perhaps a little overdone, this would confirm that interesting trade-offs between EV and V2G attributes provide valuable insights. Moreover, it was observed that, on average, 34% of the respondents did not prefer a V2G contract over conventional charging in the 'status quo' scenario, against only 24% in a fast recharging speed context. Therefore, the development of the battery recharging speed could have a beneficial influence on the adoption of V2G contracts.

Four out of seven contract attributes had a statistically significant effect on the perceived utility for a V2G contract and were correctly hypothesized, according to the parameter estimations. Guaranteed minimum battery level and fixed remuneration both had a positive effect on the perceived utility, while plug-in time and discharging cycles negatively influenced the perceived utility. In particular, with an increasing attribute level, the utility contribution of plug-in time increased with an increasing rate. Therefore, plug-in time had a quadratic effect on the perceived utility for a V2G contract, implying a potential V2G limit per EV driver.

Interestingly, the order of relative importance of the statistically significant contract attributes differed per context. Within the context of normal recharging speed, guaranteed minimum battery range had the largest utility contribution. However, due to the interaction effect of recharging speed on the guaranteed minimum battery level, plug-in time became the most important contract attribute within the context of fast recharging speed. In particular, due to the quadratic function, plug-in time became the constraining contract attribute with levels above 10 hours per day.

In addition to the statistically significant parameters, three contract attributes turned out to be statistically insignificant. The attribute that quantified the maximum number of times an aggregator would draw the EV's battery to the minimum guaranteed battery level had in fact already been excluded from the final survey, as respondents perceived this attribute as too complex. The contract attribute for variable extra remuneration did not have a statistically significant influence on the perceived utility either, which could be explained by the fact that the respondents did not take the time to properly calculate the financial compensation this attribute could have yielded. The duration of a V2G contract seemed relatively unimportant to the respondents, compared to the other statistically significant attributes.

In order to increase the tangibility of the results, implicit prices for every statistically significant contract attribute were calculated. Compared to previous studies, these implicit prices seemed to decrease. This could imply that EV drivers are slowly starting to recognize the need for such flexibility solutions. In fact, a one-kilometre increase in guaranteed minimum battery level was worth €1.68 per month assuming the current speed of recharging. This reduced to €0.83 per month when the speed of recharging reduced to five minutes. Furthermore, one extra discharging cycle per V2G session should be compensated with €6.32 per month. Finally, a one-hour increase in plug-in time in the

range of 5 to 10 hours per day should be financially compensated with €15.91 per month. Due to the quadratic utility function for plug-in time, this required financial compensation increased to €26.51 per month for every one-hour increase in the range of 10 to 15 hours.

Even though initially outside the scope of this research, it could be concluded that several other EV driver characteristics might have an effect on the willingness to participate in V2G contracts. In fact, EV drivers that were already familiar to the concept of V2G chose for a 'no V2G contract' option in 25% of cases. EV drivers without prior V2G knowledge, preferred the 'no V2G contract' option in 37% of cases. This implies that EV drivers need to be better informed about the potential value V2G could introduce. Furthermore, pioneer EV drivers seem to have other motivations towards V2G than mainstream EV drivers, as 34% of the pioneer EV drivers would prefer conventional charging over a V2G contract, while only 28% of the mainstream EV drivers would. This was in line with previous studies that found pioneer EV drivers to be more sceptical towards V2G.



## 6 Discussion

This chapter elaborates on the results from this research and places them within both the scientific literature and the practical domain of V2G. First, scientific limitations are discussed and recommendations for further research are given. Secondly, practical implications that stress societal relevance are discussed.

### 6.1 Scientific limitations and suggestions

This research is subject to several scientific limitations. This section discusses the limitations to the survey, to the use of the context variable and to the discrete choice model that was used to estimate the parameters.

#### 6.1.1 Survey limitations

The survey design was prone to several limitations. To start with, the survey had a complex design. This could well explain why one contract attribute was excluded from the final survey, why the parameter estimate of variable extra remuneration was statistically insignificant and why a large number of incomplete surveys were obtained.

The respondents' feedback on the pilot survey was the main reason for excluding the contract attribute that defined the number of days an aggregator draws the battery down to the guaranteed minimum battery level. Several respondents mentioned that they had ignored this contract attribute in their choice-making process, because they did not fully grasp the idea behind the attribute.

The insignificance of the contract attribute of variable extra remuneration can also be related to the complex survey design. This hourly variable extra remuneration was presented next to the monthly fixed remuneration in the final survey. As monthly compensation could not directly be compared to hourly compensation, the respondents might just have based their decisions on the fixed remuneration levels. Follow-up research should carefully think of a new way to present these two contract attributes in a survey. A suggestion for the presentation of variable extra remuneration would be to include a calculation of the potential monthly financial compensation this contract attribute would have added. In that case, respondents will not have to make a calculation themselves in order to be able to make a choice.

The large number of incomplete responses is another limitation to the survey design. Apparently, respondents lost focus while completing the survey. As mentioned in Chapter 4, the total number of incomplete responses equalled 104. This is a rather high number compared to the 148 completed surveys. Simplicity and easy-to-understand surveys are extremely important for an effective data collection process. Therefore, it is recommended to focus on the quality rather than the quantity of the attributes in future stated choice experiments.

Limitations also arose concerning the survey approach. First, the survey approach may have been prone to selection bias, because only people expressing interest in the topic took the time to complete the survey. Furthermore, explaining the concept of V2G to the EV drivers during the offline conduction of the survey could have steered them towards a particular choice. Moreover, it might have also been the case that the respondents did not fully understand the survey, which may have resulted in meaningless responses. As the sample in this research was relatively small and not fully representative of the population of Dutch EV drivers, it is important to bear in mind the possible bias in the estimation results.

### 6.1.2 Limitations to the use of an increased EV recharging speed

The statistically significant parameter estimate for the context variable of recharging speed has provided a valuable insight for the potential aggregator. Namely, an increased EV recharging speed that could recharge an EV within five minutes would reduce the importance of the guaranteed minimum battery level for EV drivers in their choice for a particular V2G contract. However, a first limitation to the use of this context variable is that this hypothetical recharging time of five minutes was based on announcements from battery manufacturers that have not been proven yet (Kottasova, 2018; StoreDot, n.d.). Furthermore, the context level of normal recharging speed was rather subjective in this research. As some EVs could already recharge faster than other EVs (Elektrische Voertuigen Database, n.d.-b), some EV drivers gain more than other EV drivers when assuming the fast recharging speed. Therefore, only relatively simple financial calculations could be made with the estimated parameters. By explicitly stating a value for the normal recharging speed instead of an average ‘status quo’, analyses in monetary terms become more realistic. Finally, as the context variable only contained two levels, not all information on the effect of an increased EV recharging speed was revealed. By adding more levels of this particular context variable, more detailed insights on the importance of recharging speed might be obtained. Therefore, it would be interesting to measure, for instance, three attribute levels of recharging speed, instead of the binary approach that was chosen for in this research. The linearity assumption of this parameter could then also be tested. Furthermore, it could be possible that the moderation effect does not increase any further after a particular recharging speed. This gives a first indication of the maximum potential that an increased EV recharging speed could have on the importance of the guaranteed minimum battery level.

### 6.1.3 Choice modelling limitations

This study used an MNL model to estimate the parameters. The elegance and easy-to-use character are the main advantages of MNL models. However, MNL models do have some limitations.

A first limitation is that an MNL model assumes that choices are fully based on rational decisions. However, according to the theory of reasoned action, attitudes and perceptions of behavioural control can have an effect on the choices made by people (Madden, Ellen, & Ajzen, 1992). Therefore, people might make another choice in real-life situations than in stated choice experiments.

Secondly, the distribution of the error term might be unrealistic in MNL models, as the error terms are independently and identically distributed. Therefore, the Independence of Irrelevant Alternatives property (IIA-property) holds. This property does not consider correlations between alternatives or choices made by the same individual. This could lead to biased parameter estimates, because variation across individuals is summarised into the error term. The use of other types of discrete choice models could result in a better model fit. This would also increase the reliability of the estimated parameters. In order to capture potential correlations among the choices of the same individual to account for taste heterogeneity, a Panel Mixed Logit (ML) model could be used to estimate the parameters. This would result in more reliable error terms. The origins of this taste heterogeneity can, however, not be explained by the ML model. The reasons for this taste heterogeneity could lie in, for instance, socio-demographic characteristics or behavioural patterns. By estimating a Latent Class (LC) model, different groups of individuals could be identified that all share common characteristics (Greene & Hensher, 2003). This would cluster different groups of EV drivers that all have related socio-demographic characteristics or attitudes towards V2G contracts. In the context of this research, this would mean that deeper insights into the effects of other EV driver characteristics (EV experience, V2G familiarity, ownership, driving behaviour and perceived radius reduction) on their willingness to participate in V2G contracts could be estimated. However, due to the limited number of respondents in this research, the effect of these other EV driver characteristics on the respondents’ choices could only be analysed with relatively simple calculations. With a larger sample, these interaction effects could be estimated with an LC model. This would result in several classified groups of EV drivers with similar attitudes towards V2G contracts. For every group, separate parameters could be estimated. These estimation results would provide even more valuable insights to an aggregator, as different target

groups could be distinguished. These could then be approached in a more personalised way with a V2G contract customised to their desires and needs. This would probably increase the diffusion of V2G programmes.

Choices might also be driven by the avoidance of regret, instead of maximizing the utility (Chorus, Arentze, & Timmermans, 2008). These Random Regret Minimization (RRM) models might result in other parameter estimates for the contract attributes used in this research. For instance, a relatively low specification of guaranteed minimum battery level might result in a higher regret among respondents, as discomfort experienced by a limited driving range outweighs utility experienced. Therefore, the use of RRM models for parameter estimation of V2G contract attributes could shed light on this topic from another angle.

## **6.2 Additional recommendations for further scientific research**

This section proposes recommendations for further scientific research as an addition to the suggestions based on the previously discussed limitations

### **6.2.1 Additional V2G contract attributes**

With inclusion of the pilot survey, this research considered a total of seven V2G contract attributes in the stated choice experiment. However, two interesting contract attributes that have not been measured yet can be proposed.

First, free parking as an alternative remuneration method could be explored. Instead of a financial compensation, citizens would be able to take advantage of free parking initiatives in exchange for V2G services. It would be interesting to quantify how EV drivers would value such remuneration schemes compared to rather straightforward remuneration schemes from previous studies. Secondly, Geske & Schumann (2018) measured the importance of an on-board computer in which EV drivers could specify their trips. In this way, they could plan trips in advance. This would increase the reliability of plug-in times for the aggregator. In Geske & Schumann (2018), the relative importance of an on-board computer was estimated to be higher than both plug-in time and remuneration. Even though this contract attribute would increase the complexity of the survey for the respondents, a stated choice experiment could be designed that would measure this contract attribute in particular.

Noted must be, however, that if the number of the to be estimated parameters increases by enlarging the number of contract attributes, more respondents will be needed to be able to estimate statistically significant parameters. Therefore, a realistic selection of V2G contract attributes should be chosen.

### **6.2.2 Additional V2G context variables**

This research only included one context variable. Two additional context variables that would also be interesting to analyse are proposed for further scientific research.

First, the difference in short-term and long-term parking could be investigated. This study did not make an explicit distinction between these two types of parking. It would be interesting to measure the potential of V2G from the perspective of long-term parking relative to short-term parking. It would, for instance, be interesting to find out whether the V2G contract attributes would be valued differently compared to this research if the EV driver was not using the EV for an extended period during a holiday by plane. If so, exploiters of parking spaces at airports could investigate new business models. Long-term parked EVs at airports could also function as a large battery that could be used as a temporarily emergency supply during power failures, such as at Schiphol in the spring of 2018 (Geels, Dallinga, Bouma, & Eerten, 2018). Secondly, several respondents mentioned having a second car and argued to be in favour of V2G programmes due to the ownership of this second car. The potential positive effect on the willingness to participate in V2G contracts because of being able to use a second car could also be quantified by using a context

variable. In fact, having a second vehicle would take away much of the discomfort experienced by long plug-in time requirements or low battery levels. This would give the aggregator an indication on whether to target more heavily on EV drivers that own more than one vehicle or not.

As the number of the to be estimated parameters increases as well by enlarging the number of context variables, noted must be that more respondents will be needed to be able to obtain statistically significant parameter estimates.

### **6.2.3 Data generated from V2G pilot projects combined with SP data**

As not enough historical data from V2G projects are available, defining the attribute levels for this stated choice experiment was hard. In this research, attribute levels were mainly based on the hypothetical attribute levels defined in previously conducted stated choice experiments on V2G contracts. However, by using the generated data from V2G pilot projects, such as in Everoze (2018), the attribute levels might be chosen more realistically. If V2G were actually implemented on a larger scale, the same research approach could be followed as in Axsen, Mountain, & Jaccard (2009) and Brownstone, Bunch, & Train (2000), in which a combination of RP and SP data was used to measure the respondents' choices for alternative-fuel vehicles. RP data would provide realistic information about attribute levels, while SP data would still allow for not-yet experienced attribute levels.

## **6.3 Recommendations for practical applications**

The results of this research introduce several practical implications for various stakeholders, such as utility companies, EV manufacturers, aggregators and EV drivers. This section discusses these implications and provides recommendations for the potential aggregators and for governmental regulations in the energy domain.

### **6.3.1 Implications for aggregators**

The obtained results could have implications for the aggregators concerning the design of their V2G contracts. These implications are described in this section.

The obtained findings regarding the recharging speed could be advantageous to the potential aggregator. To start with, the speed of recharging has a statistically significant effect on the guaranteed minimum battery level. Currently, the guaranteed minimum battery level is the most important attribute that determines an EV driver's choice for a particular V2G contract. However, the speed of recharging is of influence on this importance. Therefore, the aggregators are partly dependent on the development of battery technologies regarding their V2G contract design. If the recharging speed actually approximates the numbers proposed by several battery manufacturers, aggregators will be able to increase the percentages of the guaranteed minimum battery level without the need to proportionately increase the financial compensation.

On the other hand, the quadratic negative effect of plug-in time on the perceived utility for a particular V2G contract could be a limit in the V2G possibilities for aggregators. By increasing the required plug-in time over 10 hours per day, the negative utility contribution increases considerably. This means that many EV drivers will not be willing or will not even be able to comply to long plug-in times. As the importance of the guaranteed minimum battery level decreases with an increasing EV recharging speed, while the importance of plug-in time is not influenced, the potential aggregator can be recommended to focus on contracts that include low guaranteed minimum battery levels rather than long plug-in times in order to increase the secured V2G capacity.

The potential battery degradation caused by the charging and discharging of the battery does not seem a large concern for the aggregators. An increase in the number of discharging cycles could relatively simply be compensated by a proportionate increase in remuneration. However, as the technical impact on V2G is currently being studied, newly

obtained evidence on the true impact of V2G on the battery degradation could have an effect on the importance of this contract attribute.

As averages only tell part of a story, detailed profiles considering socio-demographics and other EV driver characteristics could provide deeper insights. Previous research has already demonstrated the different motivations of, for instance, pioneer against mainstream EV drivers (Axsen et al., 2016). Aggregators should carefully design the V2G contracts taking into account different EV driver classes with different motivations.

### **6.3.2 Recommendations for governmental regulations**

In this section, several recommendations for governmental regulations in the energy domain are discussed.

#### **6.3.2.1 Standardized V2G protocol**

No large investments on the electricity grid are needed to implement V2G, as flexibility solutions mainly require smart communication technologies from the smart grid (USEF, 2015). Therefore, no large governmental intervention is required for aggregators to introduce V2G. However, the technical potential is influenced by the degree of standardization in hardware and communication protocol (Kaufmann, 2017). The ISO 15118 protocol is being introduced as potential V2G mechanism in the Netherlands (ElaadNL, 2018). Only two EVs – the Nissan Leaf and Mitsubishi Outlander – are currently equipped with V2G capability. As these two models use the Japanese CHAdeMO protocol for V2G services (Newmotion, n.d.-b), Dutch aggregators are dependent on the type of V2G protocol the car manufacturers are going to use. Governmental regulations that define interoperable V2G standards are highly needed. These regulations should be designed and could even be introduced on a European level. As the V2G enabled charging hardware is currently five times more expensive than normal chargers, regulatory incentives that boost the adoption of V2G are needed as well.

#### **6.3.2.2 Privacy and security issues**

Other practical implications brought about by V2G are privacy and security issues. Policymakers should rather carefully design strict regulations to deal with these ethical principles. Bailey & Axsen (2015) investigated consumer perceptions of smart charging. They found privacy concerns to be the largest barrier for consumers to this form of controlled charging. As EV charging patterns include rather sensitive information about the lifestyle patterns of a household, it should be out of the question that these data become available to malicious groups or entities. A design-thinking approach could be used to boost innovation and creativity. However, as argued by (Cavoukian, 2009), privacy norms should be embedded in this design thinking in order to prevent these privacy and security issues.

Factors that could increase the EV drivers' acceptance towards privacy and security obstacles encountered by V2G could be explored through the lens of technology acceptance theories. Alabdulkarim, Lukszo, & Fens (2012) investigated the Dutch consumers' perceptions towards smart metering using the Unified Theory of Acceptance and Usage of Technology (UTAUT) and the Innovation Diffusion Theory (IDT). In particular, the UTAUT theory could be an interesting lens for policymakers, as this theory originates from the IT domain and was used to study the individual's acceptance towards newly implemented technologies within organizations (Venkatesh, Morris, Davis, & Davis, 2003). The theory can be used to understand the EV drivers' behaviour towards V2G programmes.

#### **6.3.2.3 Incentive schemes for EV drivers**

An increased market share for EVs corresponds to a larger V2G market. Therefore, current incentive schemes should be maintained by the Dutch government. In Norway, as an illustration, EVs correspond to more than half of the newly sold vehicles. This is mainly driven by the incentives that EV drivers benefit from, such as free parking, access to bus lanes and an extensive charging infrastructure (Ofgem, 2018). In Hong Kong, EVs have quickly been adopted, due to the many financial and non-financial incentives provided by the government. However, after the government had decided to phase out these incentives, the EV market in Hong Kong almost vanished. As the Dutch government plans to reduce the tax incentives on EVs, the EV sales in the Netherlands could stagnate as well (Automobiel Management,

2019). Policymakers should keep in mind the extra functionality of V2G brought about by EVs. Therefore, it is highly recommended to stick to the current incentive schemes in order to increase the share of EVs on the road – and in order to increase the potential V2G capacity for ancillary services.

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## **Appendices**

All appendices are shown in this section.

### **Appendix A: Academic paper**

The academic paper that has to be written alongside the MSc thesis is attached to this Appendix from the next page.

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# Dutch electric vehicle drivers' preferences regarding vehicle-to-grid contracts – a context-dependent stated choice experiment considering the EV recharging speed

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## Abstract

Vehicle-to-grid (V2G) could turn an electric vehicle (EV) into a potential source of flexibility, in order to deal with the variability and uncertainty in electricity supply brought about by renewable energy sources and the load increase caused by the adoption of EVs. However, only a few studies have focussed on the complexity of EV drivers' motivations towards V2G contracts. The main objective of this paper was to address this lack of empirical evidence in the V2G literature by conducting a stated choice experiment among Dutch EV drivers' to obtain their preferences regarding participating in V2G contracts with an aggregator, an intermediary party that would bundle the batteries of the EVs virtually. These preferences were measured from the perspective of an increased recharging speed of EVs. Therefore, the impact of an increased recharging speed on the potential success of V2G was also measured. In particular, the effect of an increased recharging speed on the guaranteed minimum battery level, one of the contract attributes used in both former as well as in this research, was quantified. A total of 1,332 choice observations was gathered and used to estimate a Multinomial Logit (MNL) model. The results showed that Dutch EV drivers based their decisions to choose for a particular V2G contract on a required plug-in time, a financial compensation, a number of discharging cycles and a guaranteed minimum battery level. However, the relative importance of these contract attributes depended on the recharging speed of the EVs. In fact, Dutch EV drivers valued the guaranteed minimum battery level half as important within the context of a fast recharging speed, relative to recharging speed of their current EVs. The results are compared to the few previously conducted stated choice experiment on V2G contracts, indicating that the demanded financial compensation for the significant contract attributes seems to decrease. This paper concludes with recommendations for further scientific research.

## Keywords

Vehicle-to-grid, V2G, stated choice, stated preference, electric vehicle, EV, recharging speed, consumer preferences, V2G contract

## Graduation committee

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## 1. Introduction

There is a growing body of literature that recognises the major trends that transform today's electricity supply and transport landscape. Among these trends, two developments cause huge challenges on the electricity grid. Firstly, centralised conventional power plants are gradually replaced by small-scale decentralised renewable sources and

secondly, the electric vehicle (EV) is becoming popular and is starting to disrupt the mobility sector (Bayindir, Colak, Fulli, & Demirtas, 2016; Huda, Aziz, & Tokimatsu, 2018). The intermittent character of renewable energy sources asks for intelligent electricity storage, particularly as the adoption of EVs will increase the load. Without electricity storage, capacity problems on the grid and misalignments between electricity supply and demand will arise (Ellabban, Abu-Rub, & Blaabjerg, 2014).

In an effort to use EVs as an intelligent source of electricity storage, Kempton & Letendre (1997) introduced the concept of using car batteries as a new source of power, termed vehicle-to-grid (V2G). With this technology, an EV could become an electricity storage device when being parked and plugged in. This makes an EV a potential source of flexibility, which can be defined as the ability to deal with variability and uncertainty in electricity supply and demand (Holtinen et al., 2013). Given that EVs are not in use for driving for about 90% of the time (Hoogvliet, Litjens, & van Sark, 2017), EVs provide a high potential of electricity storage without the need for major reinforcements on the electricity grid. The use of EV batteries could therefore be an intelligent alternative to stationary storage (Tarroja, Zhang, Wifvat, Shaffer, & Samuelsen, 2016). However, as one single EV does not have enough capacity to make an impact on the grid, the role of an ‘aggregator’ is introduced (USEF, 2015). An aggregator gathers information and capacity from many different car batteries to aggregate them into a large source of electricity storage (Guille & Gross, 2009). The degree to which an aggregator could manage the car battery of an EV driver could be specified in a contractual relationship (Guille & Gross, 2009).

Even though V2G is a technically mature system that could offer many benefits (Geske & Schumann, 2018), a number of socio-technical dimensions are currently understudied. Firstly, only a few studies have focussed on the complexity of EV drivers’ motivations towards V2G systems (Sovacool, Axsen, & Kempton, 2017). For this reason, empirical insights on specific requirements of V2G programmes are not yet widely available in V2G literature. Without these insights, future scenarios of the true potential of V2G remain unrealistic. In particular, social elements such as EV drivers, attitudes, perceptions and driving behaviour are mainly neglected in previous studies. Secondly, only four studies have empirically analysed the willingness to participate in V2G contracts (Geske & Schumann, 2018; Kubli, Loock, & Wüstenhagen, 2018; Parsons, Hidrue, Kempton, & Gardner, 2014; Zonneveld, 2019). These insights could be rather valuable for all actors in the transport and electricity supply sector. Moreover, these insights could be particularly interesting for aggregators, as they have to design their V2G contracts carefully in order to attract EV drivers that are most valuable to them (Broneske & Wozabal, 2017). In addition to these neglected socio-technical dimensions, the ongoing technological process regarding the battery development of EVs should be considered in V2G research. Parsons et al. (2014) argued that the recharging speed of an EV could have a potential influence on the overall success of V2G. In particular, the guaranteed minimum battery level, one of the contract attributes used in both former as well as in this research, could be affected by the recharging speed.

The main objective of this paper was to obtain Dutch EV drivers’ preferences regarding participating in V2G contracts with aggregators. As outcomes of a stated choice experiment in the Netherlands were analysed, this research further builds on previously conducted stated choice experiments (Geske & Schumann, 2018; Kubli et al., 2018; Parsons et al., 2014; Zonneveld, 2019). The second objective was to measure the impact of the recharging speed of EVs on the potential success of V2G. In particular, the influence of an improving recharging speed on the guaranteed minimum battery level was measured.

The data collection was gathered by administering both an online and offline survey with stated choice experiment among Dutch EV drivers. In total, 148 Dutch EV drivers completed the survey. In this survey, respondents had to choose multiple times between three options, namely two hypothetical V2G contracts and one option to opt out and stick to their conventional way of charging. Subsequently, the respondents’ choices were analysed with a Multinomial Logit (MNL) model in order to estimate parameters expressing the importance of the contract attributes and context variable.

This paper contributes to the empirical literature on V2G in several ways. To start with, this is the first research that investigates the relationship between a particular EV attribute with a V2G contract attribute. Specifically, the potential moderation effect of the speed of recharging on the importance of guaranteed minimum battery level is quantified. This stresses the importance of EV developments regarding the potential of V2G. Furthermore, this paper belongs to the select few studies that quantifies the relative importance of several V2G contract attributes (Geske & Schumann, 2018; Kubli et al., 2018; Parsons et al., 2014; Zonneveld, 2019). Therefore, supportive and contradicting findings compared to previous research are added to the empirical knowledge base on V2G contracts. On top of the

reproduction, the effect of two newly proposed contract attributes on the overall willingness to participate in a particular V2G contract has been measured. Finally, with respect to the collection of the data, this is the first paper that directly approached EV drivers at public fast-charging locations for their cooperation in the V2G survey.

## 2. Conceptual model

This section concentrates on the relevant, previously conducted stated choice experiments on V2G to obtain the most important factors that influence EV drivers in their participation in V2G contracts. These factors are conceptualized in the conceptual model in **Figure 1**.

### 2.1. Contract attributes

An aggregator should be able to control sufficient battery capacity in order to provide enough flexibility. In order to improve the predictability of storage capacity for the aggregator, an attribute for plug-in duration is part of a V2G contract. Plug-in time can be defined as average plug-in duration over a specific period. Parsons et al. (2014) and Geske & Schumann (2018) based this period on days, varying respectively from 5 to 20 and 0 to 14 hours a day. In this study, the plug-in time was restricted to 5, 10 and 15 hours per day. As plug-in times constraint the EV drivers' freedom, a negative effect on the perceived utility was expected from this contract attribute ( $H_3$  in **Figure 1**).

Guaranteed minimum battery level can be defined as a minimum battery state of charge below which power aggregators will not draw power from the battery. Therefore, this attribute guarantees the EV driver will not be faced with an uncharged vehicle for unexpected trips. Parsons et al. (2014), Geske & Schumann (2018), Kubli et al. (2018) and Zonneveld (2019) all expressed this attribute in a driving-distance-equivalent charge. In this thesis, it was assumed that the lowest level of the guaranteed minimum driving range almost equalled the average daily driving range as in Geske & Schumann (2018). Assuming the aggregator does not always draw the battery down to its minimum level, this implies that EV drivers would, on average, be able to drive the average daily driving distance. Furthermore, it was chosen to express this range in percentages, as in Kubli et al. (2018), rather than in kilometres. Showing the attribute levels in kilometres could be confusing as to whether this corresponds to the theoretical or the practical distance that is left in the battery. By showing percentages, an EV driver would be able to recognise the practical distance the EV would be able to travel. Therefore, the minimum level was set to 10%, corresponding to the average daily driving distance. The maximum level was set to 50%, corresponding to half the capacity. The middle level was set to 30% in order to preserve attribute level equidistance. As a higher battery level corresponds to a longer driving range, a positive effect on the perceived utility was expected ( $H_4$  in **Figure 1**).

In V2G contracts, EV drivers are to a certain extent obliged to have their EVs plugged in. This creates discomfort, which has to be compensated. Therefore, remuneration can be defined as any form of compensation for the cost of discomfort experienced by EV drivers with a V2G contract (Kubli et al., 2018). In previous stated choice experiments, remuneration was mainly based on frequent fixed payments. However, Parsons et al. (2014) proposed several other strategies to the strict cash-back-contract approach. One of them is a pay-as-you-go contract, which requires no plug-in obligations. EV owners would be paid for power capacity on an hourly basis. In Lee et al. (2018), these contracts were defined as control-based contracts. It would be interesting to investigate how EV drivers would value another remuneration approach. Next to the fixed periodically payments based on the plug-in time, a variable extra remuneration could be provided for every extra hour an EV is plugged in on top of the pre-specified plug-in time. This would both result in a backup capacity for the aggregators secured by the plug-in time, as well as an incentive for EV drivers to plug-in their EVs more often. Therefore, in this research, remuneration was based on these two components. The first component included a fixed monthly payment, as being used in the previous studies. On top of that, a variable extra remuneration component was added as a contract attribute for which a separate parameter was estimated. Both remuneration components made up the hybrid remuneration structure, which was defined as a fixed as well as a variable monthly payment. This variable monthly payment was based on an hourly rate, multiplied by the number of hours an EV was plugged in per month above the required plug-in time. The attribute levels of the remuneration in this research have been chosen to be less than those in the research of Zonneveld (2019), as extra variable remuneration could be obtained by being plugged in for more hours than the EV driver is obliged to. Therefore, the levels of fixed remuneration were set to €20, €60 and €100 per month and the levels for variable extra remuneration to €0.00, €0.15 and €0.30 per extra hour outside of the plug-in time obligations. An average extra plug-in time of five hours a day would thus correspond to respectively €0, €23 and €45 variable extra remuneration per month. Both fixed and variable extra remuneration were expected to have a positive effect on the perceived utility ( $H_1$  and  $H_2$  in **Figure 1**).

Even though the true impact of V2G on battery degradation has not yet determined (Wang, Coignard, Zeng, Zhang, & Saxena, 2016), EV drivers could base their decisions to choose for a particular V2G contract on this aspect. Kubli et al. (2018) introduced a flexibility attribute, implying the level of flexibility a prosumer could create. Next to the guaranteed minimum driving range, this flexibility attribute also included a unit for battery degradation. This degradation was defined in terms of number of discharging cycles per day. Therefore, the flexibility attribute indicated the number of times an aggregator used the battery discharging in a day, varying from 1 to unlimited numbers a day. This attribute level range is, in fact, infinite. Zonneveld (2019) narrowed this range down to three attribute levels of 1, 4 and 7 discharging cycles per session, implying a barely, moderate or large effect on the batteries' longevity. In this paper, it was assumed that one V2G session corresponded to one day. As not many new insights were obtained in literature regarding battery degradation, the same attribute level range as in Zonneveld (2019) were used in this research. Furthermore, it was expected that a higher number of discharger cycles resulted in a lower perceived utility. Therefore, a negative effect was expected ( $H_6$  in **Figure 1**).

The contract duration was included as a contract attribute in the studies of Kubli et al. (2018) and Zonneveld (2019). It can be defined as the length of the contract between the aggregator and EV owner. Kubli et al. (2018) varied the attribute levels from 0 month – implying that a contract could be cancelled anytime – to 48 months. Zonneveld (2019) based these levels on the contract duration of phone subscriptions, resulting in contract durations of one month, one year or two years. As it might be the case that an aggregator will pay for the V2G charger, a contract of one month is rather short. Therefore, the one-month contract from Zonneveld (2019) was replaced by a six-month contract in this research. This results in attribute levels of 6, 12 and 24 months. It was expected that EV drivers preferred a short contract over a long contract. Therefore, a negative effect of contract duration on the perceived utility was expected ( $H_5$  in **Figure 1**).

## 2.2. Recharging speed

Recharging speed has always been an important attribute for the adoption of EVs. The same barriers regarding the complexity of EV drivers' preferences towards EV attributes now apply for V2G attributes. Various studies have been performed on preferences and trade-offs of EV attributes. In fact, Hackbarth & Madlener (2016) and Hidrue, Parsons, Kempton, & Gardner (2011) both conducted a stated choice experiment to calculate the willingness-to-pay for EV attributes. Parsons et al. (2014) built on the research of Hidrue et al. (2011) by adding V2G attributes. However, as the preference for EV attributes were estimated in a separate experiment and were kept constant in the experiment with V2G attributes, no information about trade-offs between EV attributes and V2G attributes could be observed. In particular, Parsons et al. (2014) expressed the need for a carefully examined trade-off between the EV attribute of recharging time and the V2G attribute of guaranteed minimum driving range. The relative importance of guaranteed minimum driving range might be lower when it takes less time to recharge the EV. This was also expressed by a survey distributed in 2012, which found that respondents had a larger concern about the battery range than the costs of an EV (Egbue & Long, 2012).

Currently, many research and development departments are trying to develop batteries with a faster recharging speed (Kottasova, 2018), some arguing to be able to fully recharge an EV within five minutes in the near future (StoreDot, n.d.). As the development of batteries is an ongoing process, the speed of recharging could be of influence on the willingness to participate in V2G programmes. In particular, as proposed by Parsons et al. (2014), it would be interesting to measure the importance of the guaranteed minimum battery level in a hypothetical future scenario in which the speed of recharging of EVs approximates the recharging speed proposed by (Kottasova, 2018; StoreDot, n.d.). Therefore, recharging speed was added as a context variable to the conceptual model. This variable consisted of two levels. In the first level, the respondents were made to imagine that the EV recharges according to current recharging speeds. In the second level, a hypothetical future scenario was created, in which the respondents were made to imagine that the EV was able to fully recharge within five minutes at every charging point. Even though this would probably never be the case in real life, the effect of an increasing recharging speed (or decreasing recharging time) on the sensitivity of guaranteed minimum battery level could be measured. In order to increase the variance, it was chosen to randomly assign one context per choice set. The respondents' annoyance regarding the varying contexts within the survey remained limited, as only two contexts existed. Therefore, one respondent received choice sets in the first as well as in the second context. It was expected that EV drivers were less sensitive to guaranteed minimum battery level if the EV recharging speed was fast ( $H_7$  in **Figure 1**).



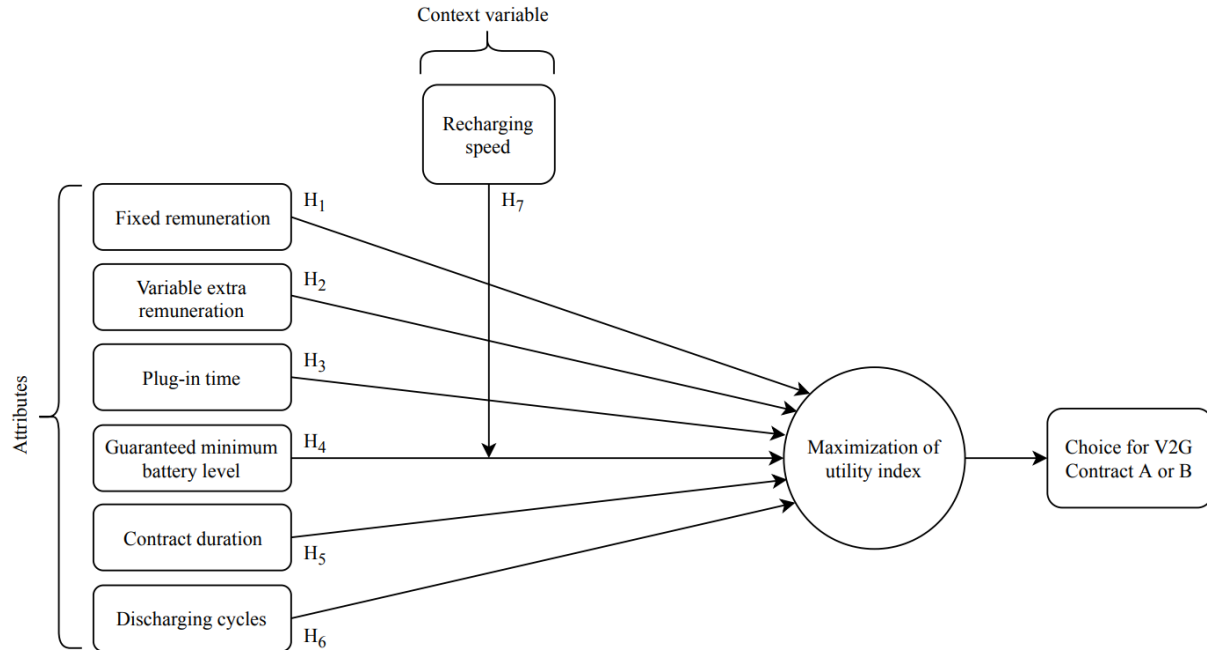


Figure 1: Conceptual model

### 3. Survey and stated choice experiment design

In this section, the design of the survey and the stated choice experiment is described, as well as the process of distributing the survey.

#### 3.1. Survey design

After conducting a small pilot (N=31) in order to correct for errors and unexpected bias, to test the comprehensibility of the survey and to obtain prior parameters for the efficient design of the final survey, both an online and offline survey with stated choice experiment among Dutch EV drivers was conducted from 28 May to 4 July 2019. In total, 148 Dutch EV drivers completed the final survey. Socio-demographic characteristics of the sample are displayed in Appendix A. The final survey was composed of an introduction and informed consent page, an explanation section with video clip, nine choice sets and additional questions on socio-demographics and other EV driver characteristics.

In the introduction section, the topic as well as the experiment was explained. Two simple questions that were related to the topic were asked. First, as a respondent would only qualify if he or she drove a full EV, a multiple choice question asked whether the respondent had a full EV, a plug-in hybrid EV or something else. In addition to this question, the respondent was asked if he had ever heard of V2G. In 2013, only 1% of the German vehicle users indicated that they had heard of V2G and that they knew something about it (Geske & Schumann, 2018). As part of the introduction, an informed consent page was added. Subsequently, information about V2G and the experiment was given in the explanation section. As respondents are generally not willing to read long texts of information, a short video clip was created in PowToon and uploaded on YouTube. The clip was embedded in the online pilot survey and could be viewed directly. It explained the concept of V2G and what was expected from the respondents in the experiment. In the video the contract attributes were explained. For convenience, these were written out in the survey as well. Finally, in the experimental stage of the survey, the respondents were asked to choose between three contracts nine times in a row. Two out of three alternatives consisted of a V2G contract – V2G Contracts A and B. The third option was a ‘no V2G at all’ alternative. In order to be able to still gather information on trade-offs between options A and B, the respondents were asked two questions for every choice set. In the first question, the respondents had a choice between all three alternatives. In the second question, though, the respondents had to choose between one of the two contracts. The ‘no V2G contract’ alternative was not an option in the second question. The respondents were made to answer each question, which resulted in less uncompleted surveys. An example choice set from the survey is shown in Appendix B.

### 3.2. Stated choice experiment

In a stated choice experiment, respondents are asked to make a choice out of hypothetical alternatives, which makes it a data collection method based on an experimental design constructed by the researcher. The attributes defined in the conceptual model in **Figure 1** were included in the choice sets of the stated choice experiment. All attributes with corresponding attribute levels are shown in **Table 1**.

**Table 1:** Attributes and attribute levels used in the stated choice experiment

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

### 3.3. Distribution of the final survey

The final survey was distributed online as well as offline. The online survey was distributed by use of an anonymous link. For the offline distribution, another sampling approach was executed. Several public charging points were visited. In order to be able to sample as efficiently as possible, the charging points had to meet four requirements. First, the locations should include fast chargers. Second, they should show characteristics of a ‘charge-and-ride’ location, which maximizes the probability of EV drivers waiting in their vehicles during the charging process. Third, they should be easily accessible. Fourth, they should have a large capacity and therefore be busy. Three locations had been chosen: one Fastned location (Den Ruygen Hoek-West) and two Tesla Superchargers (Schiphol and Zwolle).

## 4. Model specification

The discrete choice data obtained from the stated choice experiment could be analysed with a Random Utility Maximization (RUM) model. In particular, an MNL model was used to estimate the parameters.

### 4.1. Random Utility Maximization

First, RUM theory assumes that the decision maker sums up the multiplication of all attribute levels with the corresponding weights (or importance) of each alternative to obtain the utility per alternative. Second, the decision maker compares the utility levels of the alternatives. RUM theory assumes that only utility levels are compared to each other. Third, the decision maker chooses the alternative that has the highest utility. In the context of this research, the choice sets consisted of three alternatives (V2G Contract A, V2G Contract B and ‘no V2G contract’) and every alternative was described by seven attributes that consisted of three attribute levels each (defined in **Table 4** in Chapter 2).

The total utility consists of both a systematic utility and an error term, from the researcher’s perspective. The systematic utility contains factors that can be observed and measured by the researcher. The error term is based on all other factors that have an influence on the total utility, but cannot be observed and measured by the researcher. This could, for instance, be the case if an important attribute is missing in the choice set. Therefore, based on the RUM theory, the total utility of alternative  $i$  chosen by decision maker  $n$  is expressed in equation (1):

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

In equation (1),  $U_{in}$  denotes the total utility of alternative  $i$ ,  $V_{in}$  denotes the systematic utility and  $\varepsilon_{in}$  denotes the unobserved error. The systematic utility is expressed in equation (2):

$$V_{in} = \sum_m \beta_m \times X_m \quad (2)$$

In equation (2),  $V_{in}$  denotes the systematic utility of alternative  $i$  and  $\beta_m$  denotes the weight parameter associated with attribute  $X_m$ , which represents the importance of the attribute. The  $\beta$ s correspond to the parameters that are to be estimated with a discrete choice model, which is described in section 3.2.2. Furthermore, alternative  $i$  is chosen over alternative  $j$  if  $U_{in}$  has the maximum value. This is expressed in equation (3):

$$\sum_m \beta_m \times X_{im} + \varepsilon_i > \sum_m \beta_m \times X_{jm} + \varepsilon_j, \forall j \neq i \quad (3)$$

#### 4.2. MNL model

The MNL model is an easy-to-use estimation model based on the RUM theory and proposed by Daniel McFadden. This closed form estimation model is one of the most widely used RUM models and is based on the assumption that the error term is independently and identically distributed across all alternatives with a type I extreme-value distribution and are thus drawn independently from distribution with the same variance. The systematic utility  $V_{in}$  is based on attributes with linear parameters. Hence, the linear-additive utility maximization. The choice probability  $P_i$  of alternative  $i$  chosen by the decision maker  $n$  could be found using the formula in equation (4):

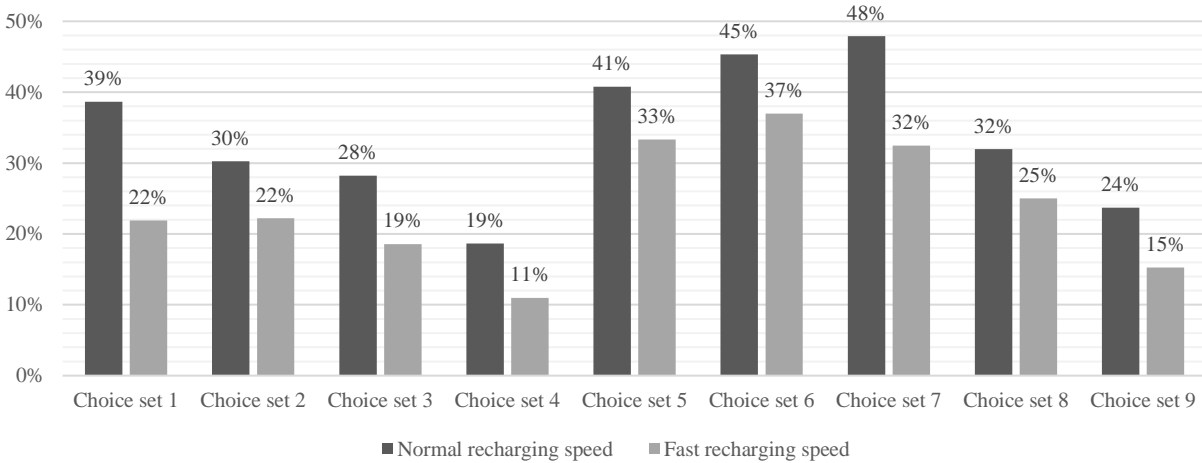
$$P_i = \frac{\exp(V_{in})}{\sum_{j=1..J} \exp(V_{jn})} \quad (4)$$

## 5. Results

This section reports the results of the study. First, the influence of recharging speed on the EV drivers' choice distributions is discussed. Second, the estimations results of the MNL models are presented and interpreted.

### 5.1. Importance of recharging speed

Every choice set contained a particular context. In the first context, the 'status quo', the respondents had to assume a normal EV recharging speed. In the second context, the hypothetical future scenario, the respondents had to assume that their EV could fully recharge within five minutes. Interestingly, as can be deduced from **Figure 2**, the 'no V2G contract' option is less preferred within the context of fast recharging speed. This is so for every choice set. More specifically, the percentage range of the respondents choosing for the 'no V2G contract' option decreased from 48-19% in the context of normal recharging speed to 38-12% with a fast recharging speed, which is on average a reduction from 34% to 24%. In other words, more than one-third of the respondents at the moment does not prefer a V2G contract over conventional charging, while only less than a quarter would not prefer this if the recharging speed was faster. This could indicate that a faster recharging speed of an EV has indeed a positive effect on the willingness to participate in V2G contracts.



**Figure 2:** Share of respondents that have chosen the 'no V2G contract' option for every choice set

## 5.2. Estimation results

As can be seen from **Table 2**, four MNL models have been estimated. In the first MNL model, only linear components were included. Additionally, MNL models A, B and C were extended with a combination of quadratic components for plug-in time and guaranteed minimum battery level, in order to test these contract attributes for non-linearity.

**Table 2:** MNL estimation results. \* corresponds to an insignificant parameter estimate

Parameter name	Linear MNL model		MNL model A		MNL model B		MNL model C	
	Value	p-value	Value	p-value	Value	p-value	Value	p-value
$\beta_{CON}$	-0.0464	0.29*	-0.00782	0.11*	-0.00603	0.18*	-0.00621	0.16*
$\beta_{DIS}$	-0.0485	0.00	-0.0339	0.04	-0.0406	0.00	-0.0449	0.00
$\beta_{EREM}$	-0.243	0.34*	-0.306	0.34*	-0.132	0.61*	-0.156	0.54*
$\beta_{GUAR}$	0.0411	0.00	0.0212	0.37*	0.0429	0.00	0.0439	0.00
$\beta_{GUARQUA}$	–	–	0.000375	0.35*	–	–	–	–
$\beta_{PLUG}$	-0.143	0.00	0.114	0.13*	0.0761	0.22*	–	–
$\beta_{PLUGQUA}$	–	–	-0.0132	0.00	-0.0111	0.00	-0.00753	0.00
$\beta_{REM}$	0.00697	0.00	0.00791	0.00	0.00704	0.00	0.00710	0.00
$\beta_{GUARSPEED}$	-0.0216	0.00	-0.0218	0.00	-0.0218	0.00	-0.0218	0.00
Number of estimated parameters	7		9		8		7	
Number of observations	1,332		1,332		1,332		1,332	
Null log-likelihood	-923.272		-923.272		-923.272		-923.272	
Final log-likelihood	-822.116		-815.188		-815.608		-816.336	
Rho-squared	0.110		0.117		0.117		0.116	

In MNL model A, a quadratic component for both plug-in time as well as for guaranteed minimum battery level were included. However, the estimation of this model resulted in many insignificant parameters. In MNL model B, the quadratic component of guaranteed minimum battery level was excluded. As a significant parameter of the quadratic component of plug-in time was estimated, while the parameter estimate of the linear component of plug-in time was insignificant, MNL model C was estimated, only including a quadratic component for plug-in time. The quadratic component of plug-in time remained significant, implying that the linear effect of this component was explained away by the quadratic component. This demonstrates a quadratic effect of the parameter estimate of plug-in time on the total utility. As can be seen from the two final log-likelihoods from the linear MNL model and MNL model C (-822.1 and -816.3), it can be concluded that MNL model C fitted the data best. Therefore, the estimated parameters from MNL model C were used for the analysis of the results.

### 5.2.1. Relative importance

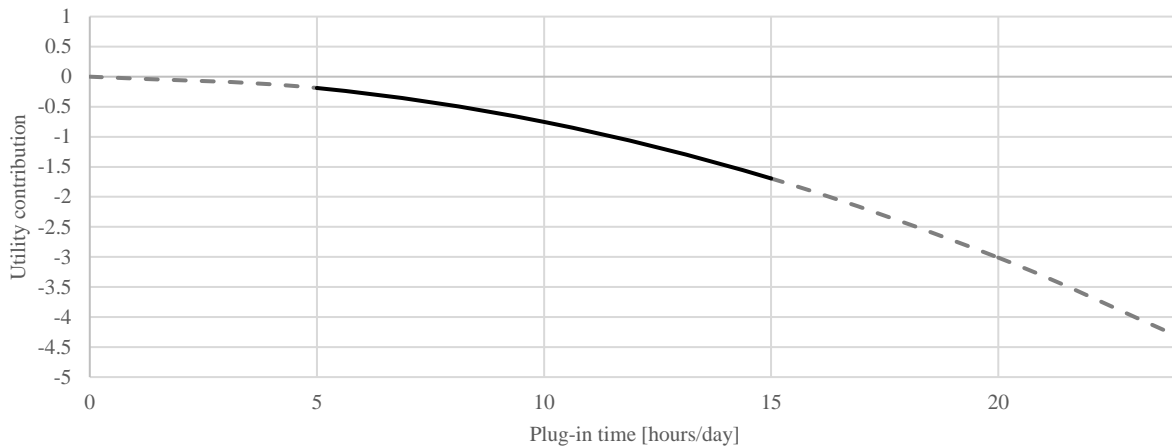
Five out of seven estimated parameters were significant at 1% level (**Table 2**). The relative importance of the contract attributes could be obtained by calculating the utility contributions, which could be calculated by multiplying the weights of the parameter estimates with the total attribute level range. For both contexts, discharging cycles was the least important contract attribute, followed by the fixed remuneration. When a context of normal recharging speed was assumed by the respondents, the guaranteed minimum battery level was the most important contract attribute.

Furthermore, plug-in time was the second most important factor for EV drivers' decision making regarding V2G contracts. When a context of fast recharging speed was assumed by the respondents, an interesting observation could be made. The weight of the interaction effect of recharging speed on the guaranteed minimum battery level was -0.0218 (Table 2). Consequently, the calculated weight of the guaranteed minimum battery level was moderated by the context variable from 0.0429 to 0.0211 (0.0429 minus 0.0218). Therefore, the guaranteed minimum battery level became half as important in the context of fast recharging speed, relative to the normal recharging speed. Consequently, plug-in time became the most important attribute in the context of fast recharging speed.

### 5.2.2. Implicit prices

To start with, the weight of the parameter estimate of fixed remuneration had a positive effect on the total utility. This is fully in line with previous studies and expectations. The effect is linear, implying that the marginal utility increase – or in other words, the direction coefficient of the utility function of fixed remuneration – is constant. In order to compare the significant parameter estimates of plug-in time, guaranteed minimum battery level and discharging cycles in monetary terms, implicit prices were calculated. The implicit prices were calculated by dividing the parameter estimates of the particular contract attribute by the parameter estimate of the fixed remuneration. Consequently, the monthly willingness-to-pay (positive sign) or monthly demanded financial compensation (negative sign) for a one-unit increase of a particular contract attribute was calculated.

It was observed that respondents experienced a large inconvenience for plug-in time. Therefore, this attribute had a negative effect on the perceived utility. The utility function of this attribute shows a quadratic effect, implying a utility contribution with an increasing rate. This effect is graphically shown in Figure 3. This quadratic component is in line with the findings in Parsons et al. (2014). Here, increasing the plug-in time from 5 to 10 hours a day, would have to be financially compensated with €79.54 per month. Further increasing the required plug-in hours from 10 to 15 hours, would correspond to a demanded financial compensation of €132.57. This implies a required per-hour incremental financial compensation of €15.19 (5-10h) and €26.51 (10-15h) per month.



**Figure 3:** Quadratic utility contribution of the plug-in time attribute. The grey dashed line is an extrapolation of the results.

The contract attribute of guaranteed minimum battery level had a positive effect on the total utility. Therefore, increasing the level of this attribute resulted in a higher probability that a particular contract will be preferred. When considering the context of normal recharging speed, this attribute was valued as most important to the respondents. Interestingly, when assuming a fast recharging speed, the weight of this parameter estimate became half as important. It is calculated that a 1%-increase in guaranteed minimum battery level was worth €6.04 per month to the respondents in a battery level range of 10-50%. This reduced to €2.97 per month in the context of fast recharging speed. As the average range of a full EV battery in this study's sample equalled approximately 360 km, this range corresponded to 36-180km. Moreover, this means that an increase in one kilometre is valued at €1.68 per month. Interestingly, this valuation reduces to €0.83 in the context of fast recharging speed. The lower the specified guaranteed minimum battery level in a V2G contract, the higher the value for an aggregator is. Therefore, the development of battery recharging speed could influence the social acceptance of V2G contracts in a positive way.

As was expected, the attribute of discharging cycles had a negative effect on the perceived utility. Even though an effect of discharging cycles existed, it was the least important factor of the significant parameters. One extra discharging cycle would have to be financially compensated with €6.32 per month in order to be accepted by the respondents.

### 5.2.3. Reflection on conceptual model

When the weights of the estimated parameters that were statistically significant were substituted in the utility functions, the following systematic utility function for a V2G contract was found:

$$V_{V2G \text{ Contract}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429 - 0.0218 \cdot SPEED) \cdot GUAR - 0.0449 \cdot DIS$$

The weight of the guaranteed minimum battery level depended on the context variable. Therefore, by substituting the two variables for *SPEED* (0 or 1), the following two systematic utility functions for both normal recharging speed as well as for fast recharging speed arose:

$$V_{V2G \text{ Contract, Normal Recharging Speed}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429) \cdot GUAR - 0.0449 \cdot DIS$$

$$V_{V2G \text{ Contract, Fast Recharging Speed}} = 0.00710 \cdot REM - 0.00753 \cdot PLUG^2 + (0.0429 - 0.0218) \cdot GUAR - 0.0449 \cdot DIS$$

As shown by the two utility functions, the weight for the guaranteed minimum battery level depends on the recharging speed. Note that the terms for variable extra remuneration as well as for contract duration were excluded from the utility function, as their parameter estimates were statistically insignificant. Fixed remuneration, plug-in time, guaranteed minimum battery level, discharging cycles and the interaction effect of recharging speed were correctly hypothesized.

## 6. Conclusions

To the knowledge of the researcher, this is the first research that has empirically analysed the effect of an improving recharging speed on V2G contracts. In fact, a significant moderation effect of the EV recharging speed on the guaranteed minimum battery level was found. The respondents in this sample valued the guaranteed minimum battery level – relative to the ‘status quo’, or normal recharging speed – half as important if the EV would be able to fully recharge within five minutes. Even though this hypothetical recharging speed is not yet feasible and perhaps a little overdone, this confirms that interesting trade-offs between EV and V2G attributes provide valuable insights. Moreover, it has been determined that, on average, 34% of the respondents did not prefer a V2G contract over conventional charging in the ‘status quo’ scenario, against only 24% in a fast recharging speed context. Therefore, the development of the battery recharging speed could have a beneficial influence on the adoption of V2G contracts.

Furthermore, four out of seven contract attributes had a significant effect on the total perceived utility for a V2G contract and were correctly hypothesized, according to the parameter estimations. Interestingly, the order of relative importance of the significant contract attributes differed per context. Within the context of normal recharging speed, guaranteed minimum battery range had the largest utility contribution. However, due to the interaction effect of recharging speed on the guaranteed minimum battery level, plug-in time became the most important contract attribute within the context of fast recharging speed. In particular, due to the quadratic function, plug-in time became the constraining contract attribute with levels above 10 hours per day.

In order to increase the tangibility of the results, implicit prices for every significant contract attribute were calculated. Compared to previous studies, these implicit prices seemed to decrease. This could imply that EV drivers slowly start to recognize the need for such flexibility solutions. In fact, a one-kilometre increase in guaranteed minimum battery level is worth €1.68 per month assuming the current speed of recharging. This reduces to €0.83 per month when the speed of recharging reduces to five minutes. Furthermore, one extra discharging cycle per V2G session should be compensated with €6.32 per month. Finally, a one-hour increase in plug-in time in the range of 5 to 10 hours per day should be financially compensated with €15.91 per month. Due to the quadratic utility function for plug-in time, this required financial compensation increases to €26.51 per month for every one-hour increase in the range of 10 to 15 hours.

## 7. Discussion

This final section compares the obtained findings with previous findings in the V2G literature. Furthermore, scientific recommendations for further research are provided.

### 7.1. Comparison with previous stated choice experiments on V2G

The weight of the fixed remuneration is in line with the findings of Geske & Schumann (2018), as remuneration is apparently not the most important contract attribute. This is in contrast with the estimation results of Kubli et al. (2018) and Parsons et al. (2014). An explanation for this could lie in the relatively high income levels of the sample in this study. High income individuals might be less sensitive to financial incentives.

This study found relatively low implicit prices for plug-in times compared to the study in Parsons et al. (2014). These were estimated at €247.96 (5-10h) and €534.61 (10-15h) per year, respectively €20.66 and €44.55 per month. As an average vehicle is parked for around 95% of the day, Parsons et al. (2014) argued that these incremental costs were surprisingly high. Apparently, respondents did not treat plug-in time as a potential of increasing the productivity of their parked vehicles. Instead, they only focussed on the inconveniences a high plug-in time would cause. In this study, the respondents did seem to see more potential for their parked vehicles, as they demanded less financial compensation for an increase in plug-in time. This could partly be explained by the fact that the survey in Parsons et al. (2014) was distributed as early as 2009, even before EVs were widely adopted. Another explanation could be that the sample in this study only consisted of EV drivers, while the sample in Parsons et al. (2014) also included conventional vehicle drivers in their sample. The reduction in demanded financial compensation for plug-in time has a beneficial as well as a disadvantageous implication for the aggregator. On the one side, the potential inconveniences respondents see with plug-in times seem to be reduced, allowing an aggregator to increase its predictability of available battery capacity for ancillary services. On the other side, increasing the number of required plug-in hours to above 10 hours per day would result in a relatively high demanded financial compensation.

This study also found relatively low implicit prices for the guaranteed minimum battery level. The average per-kilometre incremental willingness-to-pay from a range of 10-50km was calculated at €5.13 per month by Geske & Schumann (2018). Parsons et al. (2014) found the utility contributions to behave as a quadratic function. An increase in the range of 40-120km would be worth €4.01 per month for every one-kilometre increase. Furthermore, these valuations reduced to €3.19 and as little as €0.46 in respectively the ranges of 120-200km and 200-280km.

An explanation for the relatively low importance of the number of discharging cycles could be that a large part of this sample (64.9%) leases an EV. They might be less concerned about battery degradation, as they do not own the vehicles themselves. However, this does introduce an implication for the leasing companies, as they own the vehicles and could be more concerned about potential damage to the batteries.

Finally, regarding the offline data collection method, the offline sampling approach turned out to be an excellent sampling strategy to increase the number of respondents. As many EV drivers wait in their EVs for at least twenty minutes while charging, practically every single one of the approached EV drivers reacted friendly on approach, were willing to fill in the survey and were genuinely interested in the research. As offline distribution might have increased the sample variance in terms of socio-demographic factors, the validity of the research increased as well. For further research on V2G contracts, an offline sampling approach at public fast chargers would definitely be recommended.

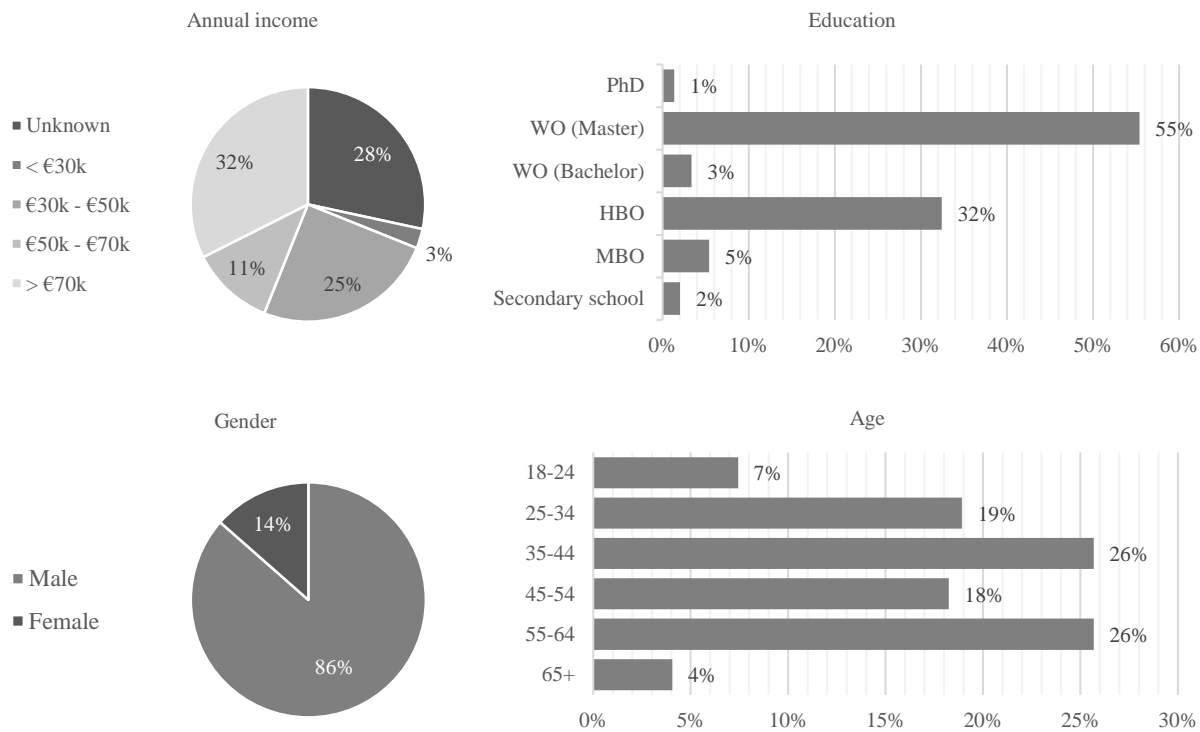
### 7.2. Recommendations for further scientific research

Two interesting contract attributes that have not been measured yet can be proposed. First, free parking as an alternative remuneration method could be explored. Instead of a financial compensation, citizens would be able to take advantage of free parking initiatives in exchange for V2G services. It would be interesting to quantify how EV drivers would value such remuneration schemes compared to rather straightforward remuneration schemes from previous studies. Secondly, Geske & Schumann (2018) measured the importance of an on-board computer in which EV drivers could specify their trips. In this way, they could plan trips in advance. This would increase the reliability of plug-in times for the aggregator. In Geske & Schumann (2018), the relative importance of an on-board computer was higher than plug-in time as well as remuneration. Even though this parameter would increase the complexity of the survey for the respondents, a stated choice experiment could be designed that would measure this contract attribute in particular.

Furthermore, this research only included one context variable. Two additional context variables that would also be interesting to research are the type of parking and the ownership of a second car. First, the difference in short-term and long-term parking could be investigated. This study did not make an explicit distinction between these two types of parking. It would be interesting to measure V2G's potential from the perspective of long-term parking relative to short-term parking. It would, for instance, be interesting to find out whether V2G contracts would be valued differently than was the case in this research if the EV driver was not using the EV for an extended period, during for instance a holiday by plane. If so, exploiters of parking spaces at airports could investigate new business models. Secondly, several respondents mentioned having a second car and argued to be in favour of V2G programmes due to the ownership of this second car. The potential positive effect on the willingness to participate in V2G contract because of being able to use a second car could also be quantified by using a context variable. In fact, having a second vehicle would take away much of the discomfort experienced by long plug-in time requirements or low battery levels. This would give the aggregator an indication on whether to target more heavily on EV drivers that own more than one vehicle or not.

Noted must be, however, that if the number of the to be estimated parameters increases by enlarging the number of either contract attributes or context variables, more respondents will be needed to be able to estimate statistically significant parameters.

### Appendix A: Socio-demographic characteristics



**Figure 4:** Socio-demographic characteristics of the sample population (n=148). Note that the offline respondents did not fill in their income. Therefore, this income distribution is only based on the 106 online respondents.



## Appendix B: Survey

### Keuzeset 2 van de 9

Vergelijk onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	€20 per maand + €0,30 per extra uur bovenop minimale inpluigtijd	€100 per maand + €0,00 per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	5 uur per dag	10 uur per dag	
Gegarandeerd batterij level	10 %	30 %	
Ontlaad frequentie	7 X per dag	1 X per dag	
Contract lengte	24 maanden	6 maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

- V2G Contract A
- V2G Contract B
- Geen V2G Contract

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

- V2G Contract A
- V2G Contract B

**Figure 5:** Example choice set from the final survey

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## Appendix B: Ngene output of efficient design

This Appendix shows the properties of the efficient design, constructed by the software programme Ngene.

### Appendix B.I: MNL efficiency measures

<b>D error</b>	0.010814
<b>A error</b>	1.446414
<b>B estimate</b>	83.728056
<b>S estimate</b>	46.017889

<b>Prior</b>	<b>b1</b>	<b>b2</b>	<b>b3</b>	<b>b4</b>	<b>b5</b>	<b>b6</b>
<b>Fixed prior value</b>	0.00586	0.847	-0.251	0.0328	-0.0754	-0.0181
<b>SP estimates</b>	15.207327	46.017889	3.292211	4.23304	18.010793	32.742235
<b>SP t-ratios</b>	0.502608	0.28893	1.08022	0.952642	0.461838	0.342533

### Appendix B.II: Design

<b>Choice situation</b>	<b>alt1.a</b>	<b>alt1.b</b>	<b>alt1.c</b>	<b>alt1.d</b>	<b>alt1.e</b>	<b>alt1.f</b>	<b>alt2.a</b>	<b>alt2.b</b>	<b>alt2.c</b>	<b>alt2.d</b>	<b>alt2.e</b>	<b>alt2.f</b>
<b>1</b>	100	0.00	5	30	7	24	20	0.30	5	10	1	6
<b>2</b>	20	0.30	5	10	7	24	100	0.00	10	30	1	6
<b>3</b>	60	0.00	5	10	4	6	60	0.30	10	50	4	24
<b>4</b>	60	0.15	10	30	4	6	60	0.15	5	50	4	24
<b>5</b>	100	0.30	15	50	1	12	20	0.00	10	10	7	12
<b>6</b>	100	0.30	10	10	4	12	20	0.00	15	50	4	12
<b>7</b>	20	0.15	15	50	7	6	100	0.15	15	10	1	24
<b>8</b>	20	0.00	10	30	1	24	100	0.30	15	30	7	6
<b>9</b>	60	0.15	15	50	1	12	60	0.15	5	30	7	12

### Appendix B.III: MNL probabilities

<b>Choice situation</b>	<b>alt1</b>	<b>alt2</b>
<b>1</b>	0.523109	0.476891
<b>2</b>	0.402779	0.597221
<b>3</b>	0.503675	0.496325
<b>4</b>	0.17006	0.82994
<b>5</b>	0.774221	0.225779
<b>6</b>	0.660584	0.339416
<b>7</b>	0.671858	0.328142
<b>8</b>	0.658968	0.341032
<b>9</b>	0.197562	0.802438

## Appendix C: Survey designs

This Appendix displays an example choice set from the pilot survey as well as the full online version of the final survey.

### Appendix C.I: Example choice set from the pilot survey

#### Keuzeset 8 van de 12

Vergelijk onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Vergoeding	€60 per maand	€100 per maand	
Extra vergoeding	€0.15 per extra uur ingeplugd buiten contract	€0.00 per extra uur ingeplugd buiten contract	
Inpluigtijd	15 uur per dag	15 uur per dag	
Gegarandeerd batterij level	30%	50%	
Ontlading tot gegarandeerd batterij level	4X per maand	10X per maand	
Ontlaad cycli	1X per dag	4X per dag	
Contract lengte	24 maanden	12 maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A

V2G Contract B

Geen V2G Contract

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A

V2G Contract B

Vorige

Volgende

## Appendix C.II: Final survey design

### Introductie

Allereerst, dank voor uw deelname. Mijn onderzoek bestaat uit twee delen. U krijgt eerst negen keuzesets, waarin u een keuze moet maken tussen verschillende contractvormen. Vervolgens krijgt u een aantal meerkeuzevragen. In totaal duurt het invullen van deze enquête ongeveer 10 tot 15 minuten.

Mijn naam is Aart Meijssen en ik ben een Complex Systems Engineering and Management student. Ik schrijf momenteel mijn masterscriptie en voor het verzamelen van mijn data heb ik u als elektrische auto-eigenaar nodig. In mijn onderzoek wil ik de bereidheid van Nederlanders met een elektrische auto in kaart brengen, met betrekking tot een nieuwe vorm van opladen van uw elektrische auto. Deze techniek heet 'vehicle-to-grid' – ook wel V2G – en komt erop neer dat de batterij van uw elektrische auto gebruikt kan worden om elektriciteit in op te slaan, maar ook om weer terug te leveren aan uw huis, uw burelen, of zelfs het elektriciteitsnet. Potentiële contractvormen tussen u en een aggregator – een tussenpartij die de batterij van uw elektrische auto kan gaan beheren – zullen in de nabije toekomst een rol kunnen gaan spelen en staan daarom centraal in deze enquête.

U blijft volledig anoniem en er zal vertrouwelijk met uw gegevens worden omgegaan. Bij vragen of andere opmerkingen kunt u mij bereiken via [agmeijssen@hotmail.com](mailto:agmeijssen@hotmail.com).

Volgende

## Toestemming

Als onderzoeker vraag ik uw toestemming om deel te nemen aan dit onderzoek. Bij vragen kunt u mij bereiken op mijn e-mailadres.

Ik heb de intentie van dit onderzoek gelezen en begrepen en ik heb vragen kunnen stellen over dit onderzoek.

Ik neem vrijwillig deel aan dit onderzoek en begrijp dat ik vragen kan weigeren. Ik begrijp ook dat ik mezelf zonder reden kan terugtrekken van deelname aan dit onderzoek.

Ik begrijp dat deelname aan dit onderzoek inhoudt dat ik vragen zal beantwoorden die in deze enquête staan.

Ik begrijp dat resultaten van dit onderzoek in een rapport op de website van de TU Delft komen te staan, in anonieme vorm.

Ik begrijp dat persoonlijke informatie, die over mij is verzameld en mij zou kunnen identificeren, nooit zal worden gedeeld.

Ik geef toestemming om de gegevens die ik hier invul op te slaan in de TU Delft Survey database, zodat toekomstige wetenschappers meer onderzoek kunnen doen en hiervan kunnen leren.

Vorige

Volgende

Beantwoord de onderstaande twee vragen.

Wat voor soort elektrische auto heeft u?

Volledig elektrisch	<input type="radio"/>
Plug-in hybride	<input type="radio"/>
Anders, namelijk:	<input type="radio"/>
<input type="text"/>	

Heeft u ooit gehoord van het 'vehicle-to-grid' concept en/of bi-directioneel laden?

Ja, en ik weet wat het concept inhoudt	<input type="radio"/>
Ja, maar ik weet niet precies wat het concept inhoudt	<input type="radio"/>
Nee	<input type="radio"/>

Klik op 'Volgende' om uitleg over dit experiment te krijgen!

Vorige

Volgende

## Keuze experiment

Bekijk eerst het onderstaande filmpje met uitleg over dit experiment. Als het filmpje niet zichtbaar is, kunt u hem ook bekijken via onderstaande link.

Link: <https://www.youtube.com/watch?v=XozI7LzIGIw>



De V2G contractelementen en contexten staan hieronder nogmaals uitgelegd. Als alles duidelijk is, kunt u de negen keuzesets beantwoorden. Let op, de waarden van de contractelementen verschillen!

**Financiële vergoeding:** Dit is een financiële compensatie voor het feit dat de aggregator uw batterij kan gebruiken en dat u niet altijd een 100% opgeladen elektrische auto heeft. Dit wordt per maand aan u uitbetaald en bestaat uit twee delen. U krijgt namelijk een vast bedrag, plus een extra vergoeding voor elk uur dat u extra ingeplugd staat bovenop uw minimale inpluigtijd. Het wordt dus beloond om vaker ingeplugd te staan!

**Minimale inpluigtijd:** Het minimale aantal uur per dag dat uw elektrische auto ingeplugd moet staan. Dit is een gemiddelde over een periode van een jaar, dus u kunt altijd in noodgevallen gebruik maken van uw elektrische auto, zolang u aan het eind van het jaar het gemiddelde haalt.

**Gegarandeerd batterij level:** Een bepaald batterij percentage waaronder een aggregator geen elektriciteit meer uit uw batterij mag halen. Hierdoor zult u uw elektrische auto nooit met een lege batterij aantreffen. Het gegeven percentage is gebaseerd op uw huidige elektrische auto.

**Ontlaad frequentie:** Het aantal keer dat de aggregator wisselt tussen opladen en ontladen. Een hogere ontlad frequentie kan slechter voor uw batterij zijn.

**Contract lengte:** De periode die u afsluit voor uw V2G contract.



Context

**Context:** De context is gegeven in het rood boven elke keuzeset – zie bovenstaande kader. Kijk hier dus goed naar, want dit verschilt per keuzeset! Bij het beantwoorden van de vraag moet u beredeneren vanuit een van de twee onderstaande contexten:

- Uw elektrische auto **laadt even snel** als uw huidige elektrische auto
- Uw elektrische auto kan overal **volledig opladen in 5 minuten** – ook aan uw thuislader!

Klik op 'Volgende' om naar de keuzesets te gaan!

Vorige

Volgende

### Keuzeset 1 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Context	Uw elektrische auto <b>laadt even snel</b> als uw huidige elektrische auto!		
Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€100</b> per maand + <b>€0.00</b> per extra uur bovenop minimale inpluigtijd	<b>€20</b> per maand + <b>€0.30</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>5</b> uur per dag	<b>5</b> uur per dag	
Gegarandeerd batterij level	<b>30 %</b>	<b>10 %</b>	
Ontlaad frequentie	<b>7 X</b> per dag	<b>1 X</b> per dag	
Contract lengte	<b>24</b> maanden	<b>6</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

## Keuzeset 2 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Context	Uw elektrische auto <b>laadt even snel</b> als uw huidige elektrische auto!		
Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€20</b> per maand + <b>€0.30</b> per extra uur bovenop minimale inpluigtijd	<b>€100</b> per maand + <b>€0.00</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>5</b> uur per dag	<b>10</b> uur per dag	
Gegarandeerd batterij level	<b>10 %</b>	<b>30 %</b>	
Ontlaad frequentie	<b>7 X</b> per dag	<b>1 X</b> per dag	
Contract lengte	<b>24</b> maanden	<b>6</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

### Keuzeset 3 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

<b>Context</b>	Uw elektrische auto kan overal <b>volledig opladen in 5 minuten</b> – ook aan uw thuislader!
----------------	--

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	€60 per maand + €0.00 per extra uur bovenop minimale inpluigtijd	€60 per maand + €0.30 per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	5 uur per dag	10 uur per dag	
Gegarandeerd batterij level	10 %	50 %	
Ontlaad frequentie	4 X per dag	4 X per dag	
Contract lengte	6 maanden	24 maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

#### Keuzeset 4 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

<b>Context</b>	Uw elektrische auto kan overal <b>volledig opladen in 5 minuten</b> – ook aan uw thuislader!
----------------	--

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€60</b> per maand + <b>€0.15</b> per extra uur bovenop minimale inpluigtijd	<b>€60</b> per maand + <b>€0.15</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>10</b> uur per dag	<b>5</b> uur per dag	
Gegarandeerd batterij level	<b>30 %</b>	<b>50 %</b>	
Ontlaad frequentie	<b>4 X</b> per dag	<b>4 X</b> per dag	
Contract lengte	<b>6</b> maanden	<b>24</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

### Keuzeset 5 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

<b>Context</b>	Uw elektrische auto kan overal <b>volledig opladen in 5 minuten</b> – ook aan uw thuislader!
----------------	--

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€100</b> per maand + <b>€0.30</b> per extra uur bovenop minimale inpluigtijd	<b>€20</b> per maand + <b>€0.00</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>15</b> uur per dag	<b>10</b> uur per dag	
Gegarandeerd batterij level	<b>50 %</b>	<b>10 %</b>	
Ontlaad frequentie	<b>1 X</b> per dag	<b>7 X</b> per dag	
Contract lengte	<b>12</b> maanden	<b>12</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

### Keuzeset 6 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

<b>Context</b>	Uw elektrische auto kan overal <b>volledig opladen in 5 minuten</b> – ook aan uw thuislader!
----------------	--

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€100</b> per maand + <b>€0,30</b> per extra uur bovenop minimale inpluigtijd	<b>€20</b> per maand + <b>€0,00</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>10</b> uur per dag	<b>15</b> uur per dag	
Gegarandeerd batterij level	<b>10 %</b>	<b>50 %</b>	
Ontlaad frequentie	<b>4 X</b> per dag	<b>4 X</b> per dag	
Contract lengte	<b>12</b> maanden	<b>12</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

### Keuzeset 7 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	€20 per maand + €0.15 per extra uur bovenop minimale inpluigtijd	€100 per maand + €0.15 per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	15 uur per dag	15 uur per dag	
Gegarandeerd batterij level	50 %	10 %	
Ontlaad frequentie	7 X per dag	1 X per dag	
Contract lengte	6 maanden	24 maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende



### Keuzeset 8 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

<b>Context</b>	Uw elektrische auto <b>laadt even snel</b> als uw huidige elektrische auto!
----------------	---

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	<b>€20</b> per maand + <b>€0.00</b> per extra uur bovenop minimale inpluigtijd	<b>€100</b> per maand + <b>€0.30</b> per extra uur bovenop minimale inpluigtijd	
Minimale inpluigtijd	<b>10</b> uur per dag	<b>15</b> uur per dag	
Gegarandeerd batterij level	<b>30 %</b>	<b>30 %</b>	
Ontlaad frequentie	<b>1 X</b> per dag	<b>7 X</b> per dag	
Contract lengte	<b>24</b> maanden	<b>6</b> maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

### Keuzeset 9 van de 9

Bekijk de context. Vergelijk vervolgens onderstaande V2G contracten en beantwoord de twee corresponderende vragen.

Contract Attributen	V2G Contract A	V2G Contract B	Geen V2G Contract
Financiële vergoeding	€60 per maand + €0.15 per extra uur bovenop minimale inplugtijd	€60 per maand + €0.15 per extra uur bovenop minimale inplugtijd	
Minimale inplugtijd	15 uur per dag	5 uur per dag	
Gegarandeerd batterij level	50 %	30 %	
Ontlaad frequentie	1 X per dag	7 X per dag	
Contract lengte	12 maanden	12 maanden	

Als ik tussen alle drie de opties zou kunnen kiezen, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>
Geen V2G Contract	<input type="radio"/>

Als 'Geen V2G Contract' geen optie is, gaat mijn voorkeur uit naar:

V2G Contract A	<input type="radio"/>
V2G Contract B	<input type="radio"/>

Volgende

## Eigenschappen en demografie

Beantwoord de onderstaande meerkeuzevragen.

1. Wat is uw geslacht?

Man

Vrouw

2. Wat is uw geboortjaar?

Ik ben geboren in:

3. Wat is uw hoogst behaalde diploma?

MBO

HBO

WO Bachelor

WO Master

PhD (Doctor)

Anders, namelijk:

4. Wat is uw bruto inkomen op jaarbasis?

Minder dan €30,000

€30,000 – €50,000

€50,000 – €70,000

Meer dan €70,000

5. Geef aan wat voor u van toepassing is:

Ik lease een elektrische auto

Ik heb een elektrische auto gekocht

Anders, namelijk:

6. Hoeveel rijdt u gemiddeld met uw elektrische auto per jaar?

Minder dan 10,000 km

10,000 km - 20,000 km

20,000 km - 40,000 km

Meer dan 40,000 km

7. Hoelang rijdt u al in een elektrische auto?

Korter dan 3 maanden

Tussen 3 maanden en een jaar

Tussen een jaar en 3 jaar

Langer dan 3 jaar

8. Wat is de **theoretische** actieradius van uw elektrische auto als deze volledig is opgeladen?

9. Wat is **in de praktijk** de actieradius van uw elektrische auto als deze volledig is opgeladen?

Vorige

Volgende

Bedankt voor uw tijd om aan deze enquête deel te nemen.  
Uw antwoord is geregistreerd.

## Appendix D: Recruitment of respondents

Different recruitment strategies that are applied are shown in this Appendix.

### Appendix D.I: Flyer design

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#### **Ik heb uw hulp nodig!** **Onderzoek naar slim laden van uw elektrische auto**

---

Voor mijn afstudeerscriptie onderzoek ik de bereidheid van Nederlanders met een elektrische auto om deel te nemen aan slimme manieren van opladen. Wilt u mij helpen? Het kost u maar 10 minuten en u bent weer volledig up-to-date van de ontwikkelingen rondom elektrisch rijden!

Bedankt voor uw hulp!

De enquête is te vinden via onderstaande QR-code en/of link:

[bit.ly/2Q2RWht](https://bit.ly/2Q2RWht)



## Appendix D.II: NU.nl discussion

AG\_1994 1 dag geleden

Gave technologie... de auto kan dus naast een transport functie ook een opslag functie leveren. Gegeven dat auto's het grootste deel van de dag stilstaan, kan dit - mits voldoende laadpalen worden bijgebouwd - interessant zijn!

Ik ben begonnen met een onderzoek om de bereidheid tot deelneming van Nederlanders met een elektrische auto tegenover V2G technologie te peilen. Heeft u een elektrische auto en bent u geïnteresseerd, dan kunt u uw mening geven via onderstaande link! [https://rug.eu.qualtrics.com/jfe/form/SV\\_aWt5g91dIWAjKER](https://rug.eu.qualtrics.com/jfe/form/SV_aWt5g91dIWAjKER)

Respect 3  Reageer 

Deel  Rapporteer 

Ramana 21 uren geleden

De grootste denkfout die hierbij wordt gemaakt is dat a) nachts geen sprake is van een piekbelasting en b) op momenten van piekbelasting de kans op autogebruik groot is en c) op momenten van rust (overdag als baasje M/V aan het werk is) de accu weer moet bijgeladen voor de thuisreis.

Respect 3  Reageer 

Deel  Rapporteer 

momus 15 uren geleden

Ik denk dat de denkfout juist is dat een 'smart grid' dus ook gewoon regelt dat er helemaal geen sprake is van piek of dalbelasting. Een smartgrid weet en voorspelt wat de vraag is/wordt en regelt adhv de vraag de productie.

Respect 1  Reageer 

Deel  Rapporteer 

AlfredJkwak 13 uren geleden

Juist omdat er in de nacht een dal in de afname is en windmolens gewoon doordraaien is het interessant om dan de accu's op te laden en deze energie op een ander moment te gebruiken. De praktijk zal zijn dat je vaak niet meer dan de helft van de energie uit de accu gebruikt per dag

Respect  Reageer 

Deel  Rapporteer 

## Appendix D.III: Facebook post

 **Aart Meijssen** ▸ Vereniging Elektrische Rijders (VER) ...  
Zojiust · 📍

Beste elektrische rijders,

Ik heb een enquête opgesteld om nieuwe vormen van elektrisch laden - 'vehicle-to-grid' - te onderzoeken. Geïnteresseerd in de ontwikkelingen binnen slim laden? Vul dan de enquête in via onderstaande link!

[https://rug.eu.qualtrics.com/jfe/form/SV\\_6Kke2Y4XljEslyR](https://rug.eu.qualtrics.com/jfe/form/SV_6Kke2Y4XljEslyR)

Veel dank!

Groeten,  
Aart Meijssen

RUG.EU.QUALTRICS.COM ⓘ  
**Enquete V2G contracten**  
Qualtrics sophisticated online survey software solutions make creating online surveys easy. Learn more about Research Suite and get a free...

 Leuk  Opmerking

 Schrijf een opmerking...    



#### Appendix D.IV: Offline recruiting

The different fast charging locations that have been visited are displayed below. These are the Tesla Superchargers in Zwolle and Hoofddorp and the Fastned location Den Ruygen Hoek-West.



## Appendix E: MNL models

In total, four MNL models are estimated – one MNL model including only linear components and three MNL models including both linear as well as non-linear components. The MNL codes used to estimate the parameters in Biogeme are shown in this Appendix.

### Appendix E.I: MNL model with linear components

[ModelDescription]

[Choice]

CHOICE2

[Beta]

B_REM	0	-10000	10000	0
B_EREM	0	-10000	10000	0
B_GUAR	0	-10000	10000	0
B_GUAR_SPEED	0	-10000	10000	0
B_DIS	0	-10000	10000	0
B_CON	0	-10000	10000	0
B_PLUG	0	-10000	10000	0

[Utilities]

1 Alt1 one  $B\_REM * REM1 + B\_EREM * EREM1 + B\_PLUG * PLUG1 + B\_GUAR * GUAR1 + B\_GUAR\_SPEED * GUARSPEED1 + B\_DIS * DIS1 + B\_CON * CON1$

2 Alt2 one  $B\_REM * REM2 + B\_EREM * EREM2 + B\_PLUG * PLUG2 + B\_GUAR * GUAR2 + B\_GUAR\_SPEED * GUARSPEED2 + B\_DIS * DIS2 + B\_CON * CON2$

[Expressions]

one = 1

[Model]

\$MNL

## Appendix E.II: MNL model A

[ModelDescription]

[Choice]

CHOICE2

[Beta]

B_REM	0	-10000	10000	0
B_EREM	0	-10000	10000	0
B_GUAR	0	-10000	10000	0
B_GUAR_Q	0	-10000	10000	0
B_GUAR_SPEED	0	-10000	10000	0
B_DIS	0	-10000	10000	0
B_CON	0	-10000	10000	0
B_PLUG	0	-10000	10000	0
B_PLUG_Q	0	-10000	10000	0

[Utilities]

1 Alt1 one  $B\_REM * REM1 + B\_EREM * EREM1 + B\_PLUG * PLUG1 + B\_PLUG\_Q * PLUG1Q + B\_GUAR * GUAR1 + B\_GUAR\_Q * GUAR1Q + B\_GUAR\_SPEED * GUARSPEED1 + B\_DIS * DIS1 + B\_CON * CON1$

2 Alt2 one  $B\_REM * REM2 + B\_EREM * EREM2 + B\_PLUG * PLUG2 + B\_PLUG\_Q * PLUG2Q + B\_GUAR * GUAR2 + B\_GUAR\_Q * GUAR2Q + B\_GUAR\_SPEED * GUARSPEED2 + B\_DIS * DIS2 + B\_CON * CON2$

[Expressions]

one = 1

[Model]

\$MNL

### Appendix E.III: MNL model B

[ModelDescription]

[Choice]

CHOICE2

[Beta]

B_REM	0	-10000	10000	0
B_EREM	0	-10000	10000	0
B_GUAR	0	-10000	10000	0
B_GUAR_SPEED	0	-10000	10000	0
B_DIS	0	-10000	10000	0
B_CON	0	-10000	10000	0
B_PLUG	0	-10000	10000	0
B_PLUG_Q	0	-10000	10000	0

[Utilities]

1 Alt1 one  $B\_REM * REM1 + B\_EREM * EREM1 + B\_PLUG * PLUG1 + B\_PLUG\_Q * PLUG1Q + B\_GUAR * GUAR1 + B\_GUAR\_SPEED * GUARSPEED1 + B\_DIS * DIS1 + B\_CON * CON1$

2 Alt2 one  $B\_REM * REM2 + B\_EREM * EREM2 + B\_PLUG * PLUG2 + B\_PLUG\_Q * PLUG2Q + B\_GUAR * GUAR2 + B\_GUAR\_SPEED * GUARSPEED2 + B\_DIS * DIS2 + B\_CON * CON2$

[Expressions]

one = 1

[Model]

\$MNL

## Appendix E.IV: MNL model C

[ModelDescription]

[Choice]

CHOICE2

[Beta]

B_REM	0	-10000	10000	0
B_EREM	0	-10000	10000	0
B_GUAR	0	-10000	10000	0
B_GUAR_SPEED	0	-10000	10000	0
B_DIS	0	-10000	10000	0
B_CON	0	-10000	10000	0
B_PLUG_Q	0	-10000	10000	0

[Utilities]

1 Alt1 one  $B\_REM * REM1 + B\_EREM * EREM1 + B\_PLUG\_Q * PLUG1Q + B\_GUAR * GUAR1 + B\_GUAR\_SPEED * GUARSPEED1 + B\_DIS * DIS1 + B\_CON * CON1$

2 Alt2 one  $B\_REM * REM2 + B\_EREM * EREM2 + B\_PLUG\_Q * PLUG2Q + B\_GUAR * GUAR2 + B\_GUAR\_SPEED * GUARSPEED2 + B\_DIS * DIS2 + B\_CON * CON2$

[Expressions]

one = 1

[Model]

\$MNL

## Appendix F: MNL model estimation results

In total, four MNL models are estimated – one MNL model including only linear components and three MNL models including both linear as well as non-linear components. All estimations results are shown in the Appendix.

### Appendix F.I: Estimation results of MNL model with linear components

<b>Model</b>	Logit
<b>Number of estimated parameters</b>	7
<b>Number of observations</b>	1332
<b>Number of individuals</b>	1332
<b>Null log likelihood</b>	-923.272
<b>Cte log likelihood</b>	-918.038
<b>Init log likelihood</b>	-923.272
<b>Final log likelihood</b>	-822.116
<b>Likelihood ratio test</b>	202.312
<b>Rho-square</b>	0.110
<b>Adjusted rho-square</b>	0.102
<b>Final gradient norm</b>	+1.890e-004
<b>Diagnostic</b>	Convergence reached...
<b>Iterations</b>	5
<b>Run time</b>	00:00
<b>Variance-covariance</b>	From analytical hessian
<b>Sample file</b>	Greenlight-Data.dat

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
B_CON	-0.00464	0.00444	-1.04	0.30	* 0.00436	-1.06	0.29
B_DIS	-0.0485	0.0137	-3.54	0.00	0.0141	-3.45	0.00
B_EREM	-0.243	0.250	-0.97	0.33	* 0.254	-0.96	0.34
B_GUAR	0.0411	0.00356	11.53	0.00	0.00369	11.14	0.00
B_GUAR_SPEED	-0.0216	0.00399	-5.43	0.00	0.00405	-5.34	0.00
B_PLUG	-0.143	0.0175	-8.16	0.00	0.0175	-8.17	0.00
B_REM	0.00697	0.000979	7.12	0.00	0.000983	7.09	0.00

Id	Name	Availability	Specification
1	Alt1	one	B_REM * REM1 + B_EREM * EREM1 + B_PLUG * PLUG1 + B_GUAR * GUAR1 + B_GUAR_SPEED * GUARSPEED1 + B_DIS * DIS1 + B_CON * CON1
2	Alt2	one	B_REM * REM2 + B_EREM * EREM2 + B_PLUG * PLUG2 + B_GUAR * GUAR2 + B_GUAR_SPEED * GUARSPEED2 + B_DIS * DIS2 + B_CON * CON2

## Appendix F.II: Estimation results of MNL model A

<b>Model</b>	Logit
<b>Number of estimated parameters</b>	9
<b>Number of observations</b>	1332
<b>Number of individuals</b>	1332
<b>Null log likelihood</b>	-923.272
<b>Cte log likelihood</b>	-918.038
<b>Init log likelihood</b>	-923.272
<b>Final log likelihood</b>	-815.188
<b>Likelihood ratio test</b>	216.169
<b>Rho-square</b>	0.117
<b>Adjusted rho-square</b>	0.107
<b>Final gradient norm</b>	+8.092e-004
<b>Diagnostic</b>	Convergence reached...
<b>Iterations</b>	10
<b>Run time</b>	00:01
<b>Variance-covariance</b>	From analytical hessian
<b>Sample file</b>	Greenlight-Data.dat

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
B_CON	-0.00782	0.00497	-1.757	0.12	* 0.00494	-1.58	0.11
B_DIS	-0.0339	0.0157	-2.16	0.03	0.0162	-2.09	0.04
B_EREM	-0.306	0.318	-0.96	0.34	* 0.320	-0.96	0.34
B_GUAR	0.0212	0.0239	0.89	0.38	* 0.236	0.90	0.37
B_GUAR_Q	0.000375	0.000410	0.92	0.36	* 0.000401	0.93	0.35
B_GUAR_SPEED	-0.0218	0.00401	-5.44	0.00	0.00406	-5.37	0.00
B_PLUG	0.114	0.0755	1.51	0.13	* 0.0761	1.50	0.23
B_PLUG_Q	-0.0132	0.00385	-3.43	0.00	0.00387	-3.42	0.00
B_REM	0.00791	0.00138	5.73	0.00	0.00135	5.85	0.00

Id	Name	Availability	Specification
1	Alt1	one	B_REM * REM1 + B_EREM * EREM1 + B_PLUG * PLUG1 + B_PLUG_Q * PLUG1Q + B_GUAR * GUAR1 + B_GUAR_Q * GUAR1Q + B_GUAR_SPEED * GUARSPEED1 + B_DIS * DIS1 + B_CON * CON1
2	Alt2	one	B_REM * REM2 + B_EREM * EREM2 + B_PLUG * PLUG2 + B_PLUG_Q * PLUG2Q + B_GUAR * GUAR2 + B_GUAR_Q * GUAR2Q + B_GUAR_SPEED * GUARSPEED2 + B_DIS * DIS2 + B_CON * CON2

### Appendix F.III: Estimation results of MNL model B

<b>Model</b>	Logit
<b>Number of estimated parameters</b>	8
<b>Number of observations</b>	1332
<b>Number of individuals</b>	1332
<b>Null log likelihood</b>	-923.272
<b>Cte log likelihood</b>	-918.038
<b>Init log likelihood</b>	-923.272
<b>Final log likelihood</b>	-815.608
<b>Likelihood ratio test</b>	215.328
<b>Rho-square</b>	0.117
<b>Adjusted rho-square</b>	0.108
<b>Final gradient norm</b>	+5.413e-003
<b>Diagnostic</b>	Convergence reached...
<b>Iterations</b>	6
<b>Run time</b>	00:00
<b>Variance-covariance</b>	From analytical hessian
<b>Sample file</b>	Greenlight-Data.dat

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value	
B_CON	-0.00603	0.00456	-1.32	0.19	* 0.00452	-1.33	0.18	*
B_DIS	-0.0406	0.0139	-2.92	0.01	0.0143	-2.84	0.01	
B_EREM	-0.132	0.256	-0.52	0.61	* 0.259	-0.51	0.61	*
B_GUAR	0.0429	0.00360	11.92	0.00	0.00366	11.73	0.00	
B_GUAR_SPEED	-0.0218	0.00401	-5.43	0.00	0.00406	-5.36	0.00	
B_PLUG	0.0761	0.0630	01.21	0.23	* 0.0626	1.22	0.22	*
B_PLUG_Q	-0.0111	0.00310	-3.59	0.00	0.00308	-3.61	0.00	
B_REM	0.00704	0.000990	7.11	0.00	0.000994	7.08	0.00	

Id	Name	Availability	Specification
1	Alt1	one	B_REM * REM1 + B_EREM * EREM1 + B_PLUG * PLUG1 + B_PLUG_Q * PLUG1Q + B_GUAR * GUAR1 + B_GUAR_SPEED * GUARSPEED1 + B_DIS * DIS1 + B_CON * CON1
2	Alt2	one	B_REM * REM2 + B_EREM * EREM2 + B_PLUG * PLUG2 + B_PLUG_Q * PLUG2Q + B_GUAR * GUAR2 + B_GUAR_SPEED * GUARSPEED2 + B_DIS * DIS2 + B_CON * CON2



## Appendix F.IV: Estimation results of MNL model C

<b>Model</b>	Logit
<b>Number of estimated parameters</b>	7
<b>Number of observations</b>	1332
<b>Number of individuals</b>	1332
<b>Null log likelihood</b>	-923.272
<b>Cte log likelihood</b>	-918.038
<b>Init log likelihood</b>	-923.272
<b>Final log likelihood</b>	-816.336
<b>Likelihood ratio test</b>	-213.872
<b>Rho-square</b>	0.116
<b>Adjusted rho-square</b>	0.108
<b>Final gradient norm</b>	+3.639e-005
<b>Diagnostic</b>	Convergence reached...
<b>Iterations</b>	5
<b>Run time</b>	00:00
<b>Variance-covariance</b>	From analytical hessian
<b>Sample file</b>	Greenlight-Data.dat

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
B_CON	-0.00621	0.00453	-1.37	0.17	* 0.00445	-1.39	0.16
B_DIS	-0.0449	0.0134	-3.35	0.00	0.0137	-3.28	0.00
B_EREM	-0.156	0.253	-0.62	0.54	* 0.256	-0.61	0.54
B_GUAR	0.0429	0.00360	11.91	0.00	0.00367	11.69	0.00
B_GUAR_SPEED	-0.0218	0.00400	-5.44	0.00	0.00406	-5.36	0.00
B_PLUG_Q	-0.00753	0.000853	-8.83	0.00	0.000842	-8.94	0.00
B_REM	0.00710	0.000985	7.21	0.00	0.000985	7.20	0.00

Id	Name	Availability	Specification
1	Alt1	one	B_REM * REM1 + B_EREM * EREM1 + B_PLUG_Q * PLUG1Q + B_GUAR * GUAR1 + B_GUAR_SPEED * GUARSPEED1 + B_DIS * DIS1 + B_CON * CON1
2	Alt2	one	B_REM * REM2 + B_EREM * EREM2 + B_PLUG_Q * PLUG2Q + B_GUAR * GUAR2 + B_GUAR_SPEED * GUARSPEED2 + B_DIS * DIS2 + B_CON * CON2

## Appendix G: Calculations

The exchange rate of USD/EUR of 30 June 2019 is used for the calculations: 1.00 USD = 0.8793 EUR. Furthermore, the following conversion from miles to kilometres is used: 1.00 mile = 1.6093 km.

### G.I: Plug-in time

$\$282/\text{h per year} = (\$282/(1.00/0.8793))/\text{h per year} = \text{€}247.96/\text{h per year} = (\text{€}247.96/12)/\text{h per month} = \text{€}22.66/\text{h per month}$  (Parsons et al., 2014)

$\$608/\text{h per year} = (\$608/(1.00/0.8793))/\text{h per year} = \text{€}534.61/\text{h per year} = (\text{€}534.61/12)/\text{h per month} = \text{€}44.55/\text{h per month}$  (Parsons et al., 2014)

### G.II: Guaranteed minimum battery level

$\$88/\text{mile per year} = (\$88/(1.00/0.8793))/\text{mile per year} = \text{€}77.38/\text{mile per year} = \text{€}77.38/(1.6093 \text{ km}) \text{ per year} = \text{€}48.08/\text{km per year} = (\text{€}48.08/12)/\text{km per month} = \text{€}4.01/\text{km per year}$  (Parsons et al., 2014)

$\$70/\text{mile per year} = (\$70/(1.00/0.8793))/\text{mile per year} = \text{€}61.55/\text{mile per year} = \text{€}61.55/(1.6093 \text{ km}) \text{ per year} = \text{€}38.25/\text{km per year} = (\text{€}38.25/12)/\text{km per month} = \text{€}3.19/\text{km per year}$  (Parsons et al., 2014)

$\$10/\text{mile per year} = (\$10/(1.00/0.8793))/\text{mile per year} = \text{€}8.79/\text{mile per year} = \text{€}8.79/(1.6093 \text{ km}) \text{ per year} = \text{€}5.46/\text{km per year} = (\text{€}5.46/12)/\text{km per month} = \text{€}0.46/\text{km per year}$  (Parsons et al., 2014)

$((\text{€}6.45 + \text{€}5.07 + \text{€}3.88)/3)/\text{km per month} = \text{€}5.13/\text{km per month}$  (Geske & Schumann, 2018)