
Increasing participation in V2G through contract elements

*Examining the preferences of Dutch EV users regarding V2G contracts using a stated
choice experiment*



Increasing participation in V2G through contract elements

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Preface

Since my start at the Delft University of Technology I have been intrigued with solving complex problems in the Transport & Logistics domain. During summer holidays I've read a news article about the potential of storing electricity in the batteries of Electric Vehicles. This provided the opportunity to combine the Transport & Logistics domain with the Energy and Industry domain and sparked my interest and I decided to turn this into my thesis topic.

This master thesis is written in fulfilment of my master's degree in Complex Systems Engineering and Management at the Delft University of Technology. This thesis is my final product which I proudly have been working on for the past six months. This report is intended for those who are interested in the design of Electric Vehicle charging systems or user behaviour research.

I would like to take this opportunity to thank those, who helped me during this process.

First of all, I would like to thank my committee members Caspar Chorus, Maarten Kroesen, Emile Chapin and Rick Wolbertus for their critical feedback and overall guidance throughout the process of this thesis. Thank you for everything you have done for me.

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Thirdly, I would like to thank all my friends and family for believing in me during the process. At moments when I did not seem to see a light at the end of the tunnel, they did. Special thanks to my parents and my girlfriend for keeping my head up.

Lastly, I would like to thank everyone who participated in the survey such that I could analyse the obtained data and special thanks to Mr. Sovacool, Lance Noel and Johannes Kester, for providing the data of their study regarding Electric Vehicle users in the Nordic countries such that these results can be put in perspective.

*Jip Zonneveld
Schiedam, March 2019*

Executive summary

Introduction

Due to increased awareness regarding environmental effects of fossil fuels an upsurge of renewable energy sources and technologies is occurring (Marell, 2014). With this regard, there are currently two trends observable: the usage of Electric Vehicles (EV) is growing exponentially and the usage of Renewable Energy Source (RES) is increasing (EV outlook, 2018; IEA, 2018). Contrary to the positive effects, challenges for the electricity grid are expected. The exponential growth of EV's may cause voltage deviations, quality of supply degradation, increase of power losses and infrastructure overloads. In addition, the increased usage of Renewable Energy Sources causes issues regarding the balancing of the grid due to its fluctuating nature. For the Netherlands, these issues are even more critical as the Dutch government aims to phase out the production and usage of gas by the year of 2050. Therefore, the Dutch Distribution System Operators face a trade-off:

- 1) Invest in expanding the grid
- 2) Decrease/evade peak moments

Flexibility services can contribute to the latter and prevent high investment costs for grid expansion. Flexibility is the ability of a system to deal with variability and uncertainty regarding the demand and supply of electricity. One flexibility option is using the batteries of the EV to store electricity and feed back electricity to the grid when necessary. This concept is known as Vehicle to Grid (V2G). However, the user of an EV experiences discomfort as the vehicle may not be fully charged and the longevity of its battery will be reduced. Therefore users would like to be compensated for the usage of V2G which can be done via a contract. Prior research on V2G has focused on the technology itself yet more research on user behaviour is desired. It is currently unknown how users of EV respond to V2G contracts. The main research question of this thesis is therefore: ***“To what extent do different contract elements influence the willingness to use V2G among EV users in the Netherlands?”***

Research approach

Based on the Universal Smart Energy Framework (USEF, 2018) the adoption of flexibility services to the electricity market is analysed. It is observed that adoption of V2G requires a new party: the aggregator. This party aggregates the electricity from the users. Therefore, the relation between the aggregator and EV user is explored in this thesis. Most likely a contractual relationship enfolds. The aggregator proposes a contract, with certain elements, to the EV user. To define the elements that might be present in such contracts demand response programs are used as inspiration. It is observed that price- and volume-based contracts are used. However, extension toward V2G requires adoptions to accommodate for the differences between demand response and V2G. Using the price- and volume-based contract, Park Lee (2018) proposes V2G contracts for fuel cell EV's. These contract elements are developed for fuel cell EV's and require adjustments to accommodate for battery EV's which are the main focus of this thesis. Based on the latest literature on V2G contracts, the contracts of Park Lee (2018) are extended and made compatible for battery V2G. In this thesis five contract elements are considered: guaranteed energy, remuneration, discharging cycles, contract duration and plug-in duration. These five contract elements are hypothesized and visualised in a conceptual model.

Method

To identify the preferences of EV users regarding these contract elements, random utility theory is applied. According to this theory, each contract element has a contribution to the total utility of an alternative. The alternative that maximises utility, is the preferred alternative. A distinction is made between a price- and volume-based contracts and the conventional way of charging (plug-in and

immediately start charging) as alternatives. In addition, characteristics of the EV users and the impact these might have on the utility contribution are evaluated as well. To analyse the influence of contract elements on utility, the multinomial logit model is used. To obtain data, a stated choice experiment is conducted by distributing a web survey among the Dutch EV users, as EV users are more familiar with concept and more reliable results are expected.

Results

In total, 96 respondents fully completed the survey. The estimations of the multinomial logit model result in seven out of eight significant parameters at 0.05 level and one parameter being significant at 0.1 level. This includes four contract elements that significantly contribute to the decision to participate in vehicle to grid programs. The rejection of the null hypotheses is shown in Table 1.

Table 1: Hypotheses

Hypotheses	Sign	Nul hypothesis rejected?
H1: guaranteed energy has a positive effect on the perceived utility	Positive	Yes***
H2: remuneration has a positive effect on the perceived utility	Positive	Yes***
H3: battery degradation has a negative effect on the perceived utility	Negative	Yes***
H4: contract duration has a negative effect on the perceived utility	Positive	No***
H5: plug-in duration has a negative effect on the perceived utility	Negative	Yes *

Significance *=0.1 level, **=0.05 level, ***=0.01 level

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

Based on the estimations, the relative importance of the five contract elements can be calculated. This results in the following ranking order, from high importance to low importance:

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

In addition, a constant for V2G is estimated to determine the overall preference regarding V2G. The results (V2G constant = -2.29) have shown that EV users do not prefer V2G against conventional charging per se, but they are willing to accept some level of discomfort in return for higher utility gains through other contract elements i.e. high remuneration (€10.00/10 hour) or high guaranteed energy (90 km). Remuneration and guaranteed energy contribute for 55% of the perceived utility. In addition, plug-in duration only contributes for 5% of the perceived utility, while this contract element is seen as a key difference between the price- and volume-based contract.

It is shown that three contract elements can increase the expected demand for V2G to percentages in which V2G option is preferred by at least 50%. However, caution should be given to the sample that is used to obtain these results, only nine females were present in this sample. In reality, it may thus be expected that more female EV users are present which may decrease demand for V2G as females are more sensitive for “range anxiety” and the guaranteed energy element becomes more important. Another result of the survey is that EV users with high income levels perceive less utility regarding V2G than EV users with a low income. The demand for V2G, in the “base” scenario, decreases with 13% and 10% for price-based and volume-based contracts respectively. No significant influence of the charging location on utility was observed.

In comparison with earlier studies, this thesis provides three important insights:

- 1) the number of discharging cycles have a considerable effect on the decision whether or not to participate in V2G programs and should be taken in consideration when designing V2G contracts
- 2) guaranteed energy is still considered as an important contract element, however, the costs for an increase in guaranteed energy have dropped considerably. This can also be concluded for plug-in duration
- 3) plug-in duration is not considered that important for EV users when participating in V2G programs while this contract element can stimulate the predictability of V2G

Conclusion

The results show that V2G programs are acceptable when EV users are compensated for their experienced discomfort. Due to the low relative importance of plug-in duration no significant differences in demand for price- and volume based are expected. There are three contract elements that have a large contribution to the decision of participation in V2G programs: remuneration, guaranteed energy and contract duration. It is observed that it is not necessary to use a combination of these three contract elements to increase demand for vehicle to grid. However, to increase demand by using only one of these contract elements high compensation levels are necessary. Therefore, more value can be created by using a combination of these three contract elements. Based on the results, it is likely that there is some demand for V2G. However, further research is necessary to identify the total costs and benefits of V2G. This requires research in the technological, regulation, user behaviour and business domains.

Recommendations

When comparing the remuneration prices that are used in the base scenario to APX prices, some margin is observed. This implies that room for business models arises. Therefore, some recommendations are proposed to the DSO and regarding policy. Three steps are proposed to the DSO:

- 1) Explore locations where flexibility services are desired and beneficial
- 2) Determine the value that V2G can generate in a certain area
- 3) Co-create a V2G contract with aggregators to optimize the compensation structures

Regarding policy also three recommendations are proposed, which are all focused on European level:

- 1) Standardization in V2G mechanisms is required but this is not per se a task for the government in the early phases, as standardization withholds innovative solutions
- 2) Privacy and security regarding V2G are not captured by the market, a role for the ACM is present to ensure privacy and security regulations
- 3) Stimulation of low price EV's such that low-income classes can benefit from V2G as well

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List of abbreviations

EV	Electric Vehicle
RES	Renewable Energy Sources
V2G	Vehicle-to-Grid
GHG	Greenhouse gasses
DSO	Distribution system operator
TSO	Transmission system operator
CPO	Charging point operator
USEF	Universal Smart Energy Framework
WTP	Willingness-to-pay
MNL	Multinomial Logit model
VER	Vereniging Elektrische Rijders (Community for Elektric Drivers)
GDPR	General Data Protection Regulation

1. Introduction

Structure

This chapter introduces the topic of this thesis and its problem statement, followed by the research approach. The starting point is the increased usage of Electric Vehicles (EV's), Renewable Energy Sources and specifically for the Netherlands, the transition of gas to electricity. In section 1.1, the challenges from three key trends regarding the electricity grid are introduced, followed by a proposed flexibility solution in which EV's are used as electricity storage and feed electricity back to the electricity grid. In section 1.2, the willingness of EV users to use their EV for this concept is discussed. In section 1.3, the backbone of this thesis is proposed: the conceptual model. Followed by, the research questions, scope and objective. Thereafter the research approach is explained. In section 1.4 the scientific and societal contribution is discussed. Section 1.5 provides an outline for this thesis.

1.1 Background

Due to increased awareness regarding environmental effects of fossil fuels an upsurge of renewable energy sources and technologies is occurring (Marell, 2014). The increased environmental recognition entails issues regarding fossil fuel scarcity and the increased sustainability (Egner & Trovik, 2018).

Currently, conventional vehicles accommodate for at least 20% of the total CO2 emissions in Europe (EU, 2018). Electric Vehicles (EV's) are seen as a solution to reduce the use of fossil fuels and additional Greenhouse gases (GHG), EV's do not use liquid fuels and exhaust zero emissions (Egbue & Long, 2012). Besides the reduction of GHG, EV's show potential to reduce other harmful emissions as well, including NOx, PM and SOx and thereby contribute to better air quality (Razeghi et al., 2016). Several governments are stimulating the usage of EV's due to these reasoning. For example, in Norway the adoption of EV's is stimulated by price incentives such as reducing taxes, providing free parking opportunities and no road tolls for EV users. Stimulating the use of EV's results in an increased market share of EV's. According to the EV outlook (2018) the EV's in use worldwide is growing exponentially which is depicted in Figure 1.

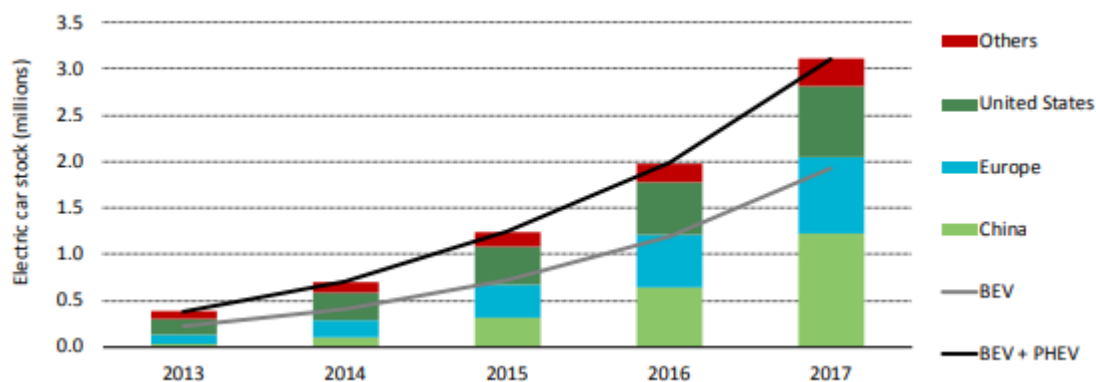


Figure 1: Uptake of EV's worldwide (EV outlook, 2018)

The exponential growth of EV usage will not only have a positive impact on the environment, but will also have a significant impact on the electricity grid (further denoted as: grid) and its operations. The charging of a large amount of EV's could result in complications for the grid. EV users will have to charge their EV when they are not using them. For day job commuters this entails that the charging of the EV will occur when they either arrive at work in the morning or arrive at home in the evening. This is in line with the already existing electricity demand peaks that will thus then also increase when EV's are charging. This is shown in Figure 2. Consequently, this results in complications that consists of: voltage deviations, quality of supply degradation, increase of power losses and infrastructure overloads (Pillai, Bak-Jensen, 2010; Foley, Tyther & Calnan et al., 2013; Putrus, Suwanapingkarl & Johnston et al., 2009).

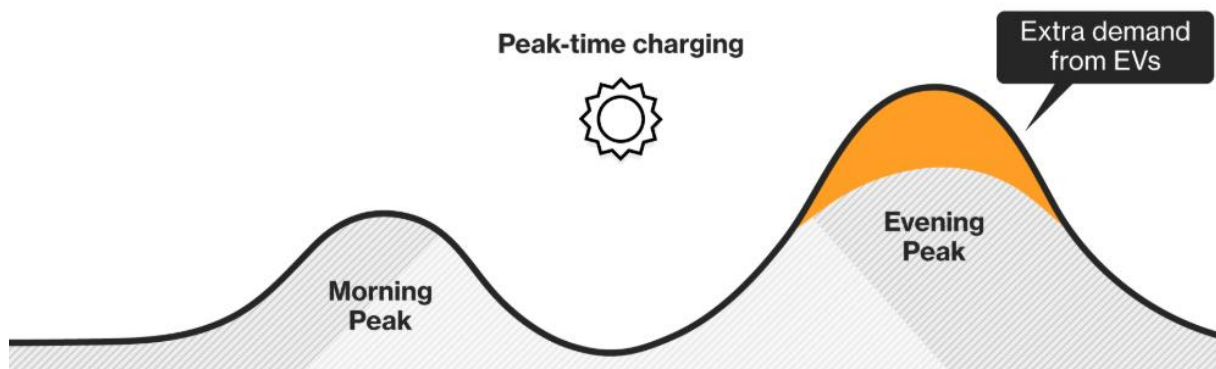


Figure 2: Electricity demand (Bloomberg, 2018)

In addition, the share of Renewable Energy Sources (further: RES) in the electricity mix is rapidly increasing: from 24% in 2017 towards 30% in 2023 (IEA, 2018). Due to the fluctuating nature of RES, the increased usage of RES causes issues regarding the balancing of demand and supply on the grid (Romer, Reichhart, Kranz & Picot, 2012). This can result in grid instabilities.

Specifically for the Netherlands, another trend is accelerating the grid instabilities. The government aims to phase out the production and usage of gas by the end of the year 2050 (Ministerie van EZ, 2018). This is causing an extra demand for electricity at peak moments (NetbeheerNederland, 2017).

In summary, three main trends are observable in the Netherlands:

- 1) The increased usage of EV's
- 2) Increased usage of RES
- 3) The transition of Gas towards electricity

The three trends cause challenges for grid operators, i.e. Transmission System Operator (TSO) and Distribution System Operator (DSO). The TSO is responsible for the transportation of electricity at the high voltage level. Their main objective is to safely provide reliable electricity. Then, Dutch DSO's are responsible for the distribution network of electricity on low and middle voltage level. Hereby maintaining a reliable, stable and affordable network is the main objective of the DSO. Both TSO's and DSO's are therefore searching for solutions regarding the three challenges. For TSO's the balancing capacity needs to increase on national level and find solutions in national balancing markets. However, for DSO's the three trends cause local grid capacity problems which may arise on

the short term and cannot be solved using national balancing markets (Kempton, 2005). Therefore, the Dutch DSO's are therefore forced to make a decision between either:

- 1) Increase grid capacity by investing in new infrastructure, which is expensive (Amin, 2018) or,
- 2) Decrease/evade peak demand by flexibility services, which is difficult

Flexibility services can help to stabilise the electricity grid without the high investment costs of new infrastructure. This contributes to the maximisation of the network utilisation and optimisation of the grid capacity. Therefore, the Dutch DSO's aim to develop new flexibility services to minimize grid expansions (Enexis, 2018).

Flexibility is defined as “the ability of a system to deal with variability and uncertainty regarding the demand and supply of electricity”, so the fluctuated nature of RES and increased demand of EV's can be coped with (Denholm & Hand, 2011). To make use of flexibility, electricity storage is required, which is seen as a key challenge (Lazkano et al., 2017). Flexibility can be provided in numerous ways, i.e. hydrogen production or demand side management.

Another important source of grid flexibility can be provided by EV's, as EV's can store electricity in their battery and can also feed their stored electricity back to the grid. EV users that charge at home are on average 15.3h connected to the grid (Wolbertus, Kroesen, Hoed & Chorus, 2018). This provides opportunities to use the battery of EV's for flexibility services. The concept of loading and unloading electricity from EV's is known as Vehicle to Grid (further denoted as V2G) (Huang et al., 2014). The concept of V2G is depicted in Figure 3, in which the production of electricity is shown, combined with the distribution of electricity. By integrating V2G up and downward streams of electricity arise. Here, households are using the EV both for transportation and as electricity source.

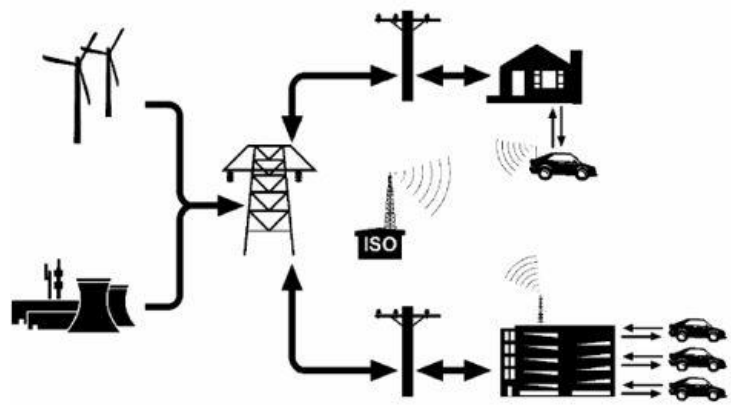


Figure 3: Vehicle to Grid (Sovacool, 2018)

Providing flexibility via EV's creates synergy as it has two benefits:

- 1) Contributing to managing the increasing demand for electricity due to the increased usage of EV's and transition from gas to electricity, by peak shaving and valley filling (Zhenpo & Shuo, 2013)
- 2) Contributing to the balancing of the electricity grid that is necessary due to the increase of RES. EV's can store electricity when RES produces more electricity than forecasted and feed in electricity to the grid when RES fall short on the forecasted amount of electricity (Hoarau & Perez, 2018)

To provide flexibility via V2G a minimum of 1MW of electricity is required to trade on the electricity market (Tennet, 2018). Since the capacity of an EV varies between 15 kWh and 95 kWh a single EV user cannot participate solely in the electricity market. Therefore, a new party is required that aggregates the electricity provided via V2G, in literature this party is denoted as the aggregator (USEF, 2018). The aggregator accumulates flexibility from the V2G users and sells it on the electricity market. The role and responsibilities of the aggregator are not yet incorporated in current legislation, resulting in an uncertain future (PWC, 2017).

In addition, the main function of an EV is to provide transport for the EV users. Configuring to V2G, the EV now has the function of providing transportation and providing flexibility.

The main priority of EV users', however, is transportation. As V2G requires the EV to be plugged in to the electricity grid the two functions cannot be executed simultaneously and thus requires the participation of EV users. Since it is unknown how EV users respond to V2G contracts and thus the value that is provided via V2G is unknown as well, DSO's cannot make a cost benefit analysis whether to use V2G as a flexibility solution or invest in new infrastructure.

The focus of this thesis is to investigate the desires and needs of the current Dutch EV users to participate in V2G programs such that the potential value of V2G as flexibility service for grid operators is investigated. To determine the desires and needs of EV users, different contract types found in literature are proposed to EV users and from their choices, preferences are inferred. Due to the fact that V2G is a new, non-existing concept, a stated choice experiment will be conducted.

1.2 Problem description

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

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

It is in the DSO's interest to use more V2G as this increases their ability to match supply and demand and cope with congestion management. However, this creates more discomfort for the EV user resulting in opposing interests between DSO's and EV users regarding V2G.

EV users would like to be compensated for the discomfort they experience and might differ in their preferences (Kubli et al., 2018).

In the Universal Smart Energy Framework (USEF) the addition of flexibility services, such as V2G, to the electricity market are described. Both the USEF framework and literature mention that a contract can be used to establish the newly formed relationship between the aggregator and EV user. Then, the contract can be provided with incentives to compensate for the discomfort the EV users experience.

To exploit the potential of V2G, the contract should be designed towards the EV users desires and needs (Geske & Schumann, 2018). However, the participant behaviour still requires a detailed study as it is unknown how much compensation EV users are willing to get (Sovacool, Axsen & Kempton, 2017; Hoarau & Perez, 2018).

There are currently 50 pilot projects active on V2G programs worldwide. EV Consult (2018) conducted a research into all project activities and found that the technical feasibility of V2G is

extensively tested in the pilot projects while the consumer side of V2G is not yet given much attention. Given that the value of V2G depends on the amount of user participating, more research is necessary.

Three studies have examined EV users’ desires and needs concerning V2G contracts using Stated Preferences Studies methodology (Parsons et al., 2014; Kubli, Loock & Wustenhagen, 2018; Geske & Schumann, 2018). But, these studies do not provide complete information regarding the experienced discomfort by EV users as the wear and tear of the battery is not considered which is seen as a key barrier to widespread adoption of V2G (Dubarry, Devie & McKenzie, 2017). The neglect of this key barrier in the three studies result in an incomplete estimation of the potential value of V2G. A more complete estimation can be given when battery effects are included, thus additional research is required. In addition, more limitations will be described in section 2.3. It is expected that EV users are not homogenous regarding their preferences, therefore differences in EV users’ characteristics will be explored as well.

For the DSO’s in the Netherlands, a deeper understanding on the required compensation for the experienced discomfort is required as this is limited studied. Providing this to the DSO will contribute to the decision they face as insights are provided into the required compensation and value of flexibility.

1.3 Conceptual model

Summarizing the introduction, the following problem statement is proposed:

“Due to the experienced discomfort in V2G programs by EV users, there is a lack of knowledge about the participation in V2G programs by Dutch EV users. Compensation for the experienced discomfort can be provided via contract elements, but it is unknown how Dutch EV users respond to different V2G contract elements which consequently results in inadequate knowledge regarding the value of V2G and whether the usage of V2G can minimize grid expansions.”

Given the problem statement, it is desired to know how much compensation Dutch EV users would like to receive in return for providing V2G services. The compensation is incorporated in the contract elements. Here, it is also expected that different types of EV users will respond differently to these contracts. This is schematically depicted in Figure 4.

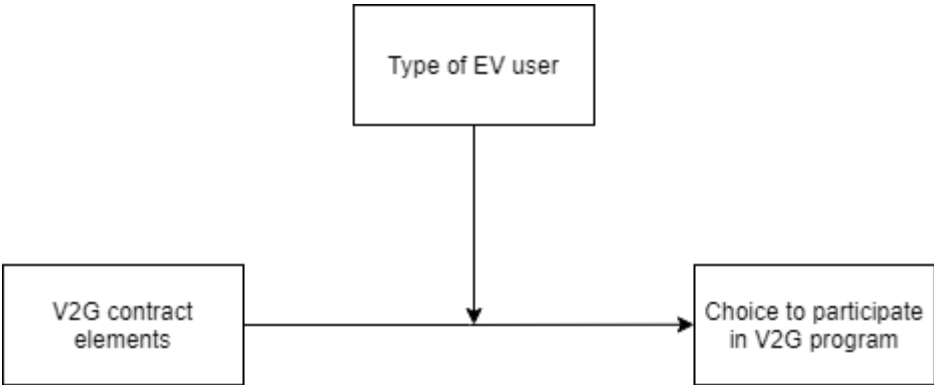


Figure 4: Conceptual model

Research questions

To provide structure in the report and to ensure all subjects are included in the thesis, two research questions are established. The research questions focus on the relationship between the participation in V2G by Dutch EV users and how different contract types affect this participation.

This thesis aims to provide an answer to the main research question:

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

To answer the main research question, two sub-questions are developed:

- 1) *According to the current developments, what type of V2G contracts are feasible for implementation?*
- 2) *What is the expected usage of V2G by current EV users under different V2G contracts?*

Objective

Currently, it is unknown how Dutch EV users respond to different V2G contract elements. In addition, it is assumed that different type of EV users exist and differentiating in their preferences regarding V2G contracts. This thesis aims to fill this knowledge gap. It will focus on different type of contract elements built in V2G contracts and the effect this has on the usage of V2G among the current Dutch EV users. It is chosen to use Stated Choice Experiment to test this. A Stated Choice Experiment systematically and qualitatively assesses the preferences of Dutch EV users regarding V2G contracts. The preferences of Dutch EV users will be elicited by estimating a Multinomial Logit Model.

Scope

For this thesis Full Battery EV's will be considered. Fuel cell EV's and Hybrid EV's are thereby excluded from this thesis. Since the perspective of this thesis comes from a Dutch DSO point of view, the Netherlands is chosen as a system boundary. Therefore, only Dutch EV users will be considered in this thesis. It is expected that the results can be extended towards similar countries, however caution should be given to different laws, regulation and perceptions regarding driving.

Research phases

This thesis exhibits two research phases. The first phase involves the literature study and development of a conceptual model. The second phase consists of the survey development, distribution and analysis followed by a conclusion. This is depicted in Figure 5.

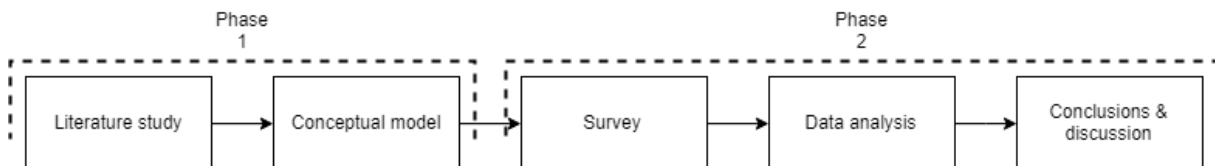


Figure 5: Research phases

Phase 1

In phase one, an answer will be provided to the first sub question. The main objective of phase 1 is identifying different contract elements that are relevant for the DSO. This will be done by literature research.

The literature research will use the USEF framework to identify how V2G is implemented in the

electricity market. Then, literature is sought for on V2G contracts and will provide insights in the state of the art of the literature on V2G contracts. This way, feasible contract elements will be identified. The contract elements that are relevant for the DSO are taken in consideration in the experiment.

Based on the findings in the literature research, a set of contract elements is proposed including the potential effects and hypothesis of these effects. The contract elements form the conceptual model which will be tested with the help of the Stated Choice Experiment in phase 2.

Phase 2:

In phase two, an answer to sub-question 2 will be provided.

Based on the literature research, the Stated Choice Experiment will be designed. During this phase, the variables that will be investigated will be defined and thereafter the levels of the elements that will be proposed to the respondents will be chosen.

Next, is the execution of the Stated Choice Experiment. This will focus on getting insights in participation in V2G programs under different contract types with incentives. The Stated Choice Experiment will be executed in three parts. Firstly, an online survey will be held among a small group of respondents to determine if the survey is clear and understandable for the respondents. When this is the case, step two can be executed. Sending the survey towards a large group of Dutch EV users (the respondents). When enough respondents have filled in the survey, step three can be executed. This is the final analysis, which consists of inferring preferences of the choices that respondents made in the survey. Here a MNL will be estimated. The description of the method of the choice experiment and data analysis will be elaborated upon more in detail later in the report. This is shown in Figure 6.

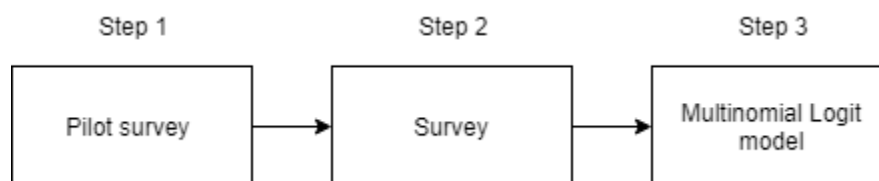


Figure 6: Steps of stated choice experiment

In phase 1 and 2, the two sub-question are answered. The outcomes of these phases will be synthesized into conclusions and provide input for the recommendations for the main problem owner, the Dutch DSO's. Here, also the limitations of the thesis and potential implications that arise from this thesis will be discussed upon.

1.4 Scientific and Societal contribution

This thesis aims to provide new insights in to the research domain of V2G. Many subjects are studied but user behaviour is often neglected while the concept of V2G is dependent on the EV users. Three studies stated preferences studies have been conducted on EV user participation in V2G programs. These studies do not provide a complete answer as will be described in chapter 2.4. By combining the proposed contract set from Park Lee (2018) with these three studies, it is aimed to provide new insights in terms of contract elements that are acknowledged by EV users. It is aimed in this thesis to contribute to the knowledge in this research domain and providing new directions for further research to better understand the desires and needs of EV users regarding V2G.

The social relevance of this thesis is that the results can provide information on the preferences of Dutch EV users regarding V2G. Then, organisations (i.e. DSO's, TSO's, aggregators) can design V2G programs such that it is designed to the users' needs and preferences. Furthermore, the outcomes of this thesis can help the DSO in their decision-making process of investing in the electricity grid or investing in the use of flexibility by V2G. This, as the value of V2G can be calculated by using the obtained choice probabilities for V2G demand based on the contracts used in this thesis.

1.5 Link Complex Systems Engineering and Management

This research aligns with the master "Complex Systems Engineering and Management" due to analysis of a socio-technical system. V2G is a concept that requires a new party to enter the electricity market. This brings along new relationships and new responsibilities. The relationship will most likely take a contractual form. Currently, multiple stakeholders are trying to identify how the contract should be formalized such that it accommodates to their interests and generates user participation. This thesis considers different contract elements to identify the preferences of EV users. Doing so, this thesis identifies the impact of contract elements on the choice to participate in V2G programs. This provides value for the party that will fulfil the role of the aggregator. In addition, more research is necessary as this thesis does not provide a standardized solution for the aggregator.

1.6 Thesis outline

The structure of this thesis is as follows. The next chapter provides theoretical and practical background on V2G contract elements that are feasible for implementation. The V2G contract elements are conceptualised and hypothesised. These are the variables that are going to be tested in this thesis. Thereafter, the research methodology is described, followed by the survey design and how data is going to be collected. The fourth chapter revolves around the empirical analysis and findings. This thesis ends with a conclusion, recommendations, a discussion on the limitations of this thesis and directions for future research are proposed.

2. Theoretical framework

Structure

This chapter aims to answer the first sub-question:

According to the current developments, what type of V2G contracts are feasible for implementation?

This will be done by answering the following questions:

- a) How does V2G fit in the current electricity market? → section 2.1
- b) What contract elements are being used in comparable flexibility solutions? → section 2.2
- c) What contract elements are being used in the most recent V2G literature? → section 2.3
- d) Is the importance of a contract element affected by moderating variables? → section 2.1 & section 2.2

In section 2.1, an exploration is taken into the USEF framework. This framework illustrates the role of the aggregator and the relationship that enfolds with the EV user. In section 2.2, a comparison is made with Demand Response programs, which forms the basis for V2G contract elements. In section 2.3, the contract elements that are found in Demand Response programs are extended towards V2G contracts. In section 2.4, the conceptual model with its hypotheses is introduced. In section 2.5, the chapter ends with a conclusion.

2.1 Universal Smart Energy Framework

The Universal Smart Energy Framework (USEF) framework is developed to fluently add flexibility processes to the traditional electricity market. This framework will therefore serve as a guide to the analysis of V2G implementation in the electricity market. In this section the USEF framework will be discussed.

USEF explanation

To integrate flexibility services into the current electricity market the USEF has been developed (USEF, 2018). This framework delivers one common standard to build smart energy products and services. It enhances the opportunity to use flexibility as a trading commodity by providing structure to the market. Hereby the current existing processes function as a starting point, so the integration of new market models fluently integrates to the existing market models. USEF is developed by ABB, Alliander, DNV GL, IBM, ICT, Stedin and Essent. These parties are part of the Smart Energy Collective (SEC), which is a Dutch multi-partner (20 parties) collaboration that focusses on developing and testing new pilot projects that will provide smart energy services. Integrating EV's into the electricity grid, V2G, is one of these smart energy services.

USEF describes the roles and responsibilities between market parties, the operation regimes and proposes a Market Control Mechanism (MCM) with the corresponding phases and thereby sets the rules that are required for the incorporation of flexibility services, see Appendix 1 for detailed description of the MCM. The framework is therefore valuable for the connection of projects to the current electricity market.

To present a complete overview of the current electricity market and the impact V2G has on this market, the involved actors, the market interactions between the EV user and the uncertain role of the aggregator will be discussed in the next paragraphs.

Actors in USEF

USEF defines all actors that are actively involved in the electricity market, including their roles and responsibilities. Special attention is given to the roles and responsibilities of the actors in the mobility sector, since V2G requires interaction between those sections. Table 2 shows the actors that are relevant for this thesis.

Table 2: Actors in electricity market (USEF,2018)

Actor	Responsibilities	Perception V2G
Prosumer	A prosumer is defined as an entity that consumes energy and produces energy. Examples are households with PV systems or large industries.	Party that maintains a relationship with the aggregator.
Aggregator	Aggregator is the party that is aggregating flexibility from the prosumers. This party is responsible for the monetization of the provided flexibility by the prosumer and guaranteeing EV availability for V2G. The aggregator can trade with different parties in the electricity market.	New party that enters the electricity market, seeking for opportunities to maximize profits. Maximizing their client base to guarantee EV availability.
DSO	As mentioned earlier in this thesis, the Distribution System Operator (DSO) is responsible for the supply of electricity in the distribution grid. Hereby maintaining an affordable, reliable and stable distribution grid in a given region is their main objective.	Faces decision: invest in grid expansion or making use of flexibility services, such as V2G. V2G can improve grid usage and reduce investment costs.
EV user	The user of an EV that requires charging the vehicle at any point in time.	Experience discomfort when providing flexibility via V2G. Requires a charging point, has already contract with Charging Point Operator or E-mobility service provider.
Charging Point Operator	A Charging Point Operator (CPO) is a party that operates the charging infrastructure for EV's and thereby monitors, controls and maintains the infrastructure.	Seeking for opportunities to maximize client base. Due to large client base, CPO is able to fulfil the role of the aggregator (see Appendix 1).
E-mobility service provider	The E-mobility service provider sells services to the EV user. An example of these services is providing access to charging points that are operated by different CPO's. These services can be bundled with other services and can include the supply of energy.	Seeking for opportunities to maximize client base. Due to large client base, E-mobility service provider is able to fulfil the role of the aggregator (see appendix 1).

The actors described in Table 2 interact with other parties that operate in the electricity market. These parties mainly encompass producers, suppliers and balance responsible parties whom are responsible for producing, supplying and balancing the electricity in the Netherlands respectively.

Market interactions in USEF

As mentioned above, the relationships between the actors in the electricity market are also elaborated on in USEF. In the framework, interactions between the current market and the flexibility market are prescribed. In Figure 7, USEF depicted all the interactions between the involved parties. The blue arrows depict the current electricity market relations between parties, the orange arrows depict the new interactions that arise when flexibility services are adopted.

The most notable change due to flexibility services, is the rise of the role of the aggregator. This results in a new relationship between the prosumer and the aggregator. Since the role of the aggregator is a new role, the party that fulfils the role of the aggregator has yet to be defined. This thesis focusses on the new relationship between the aggregator and the prosumer, in this case the EV user.

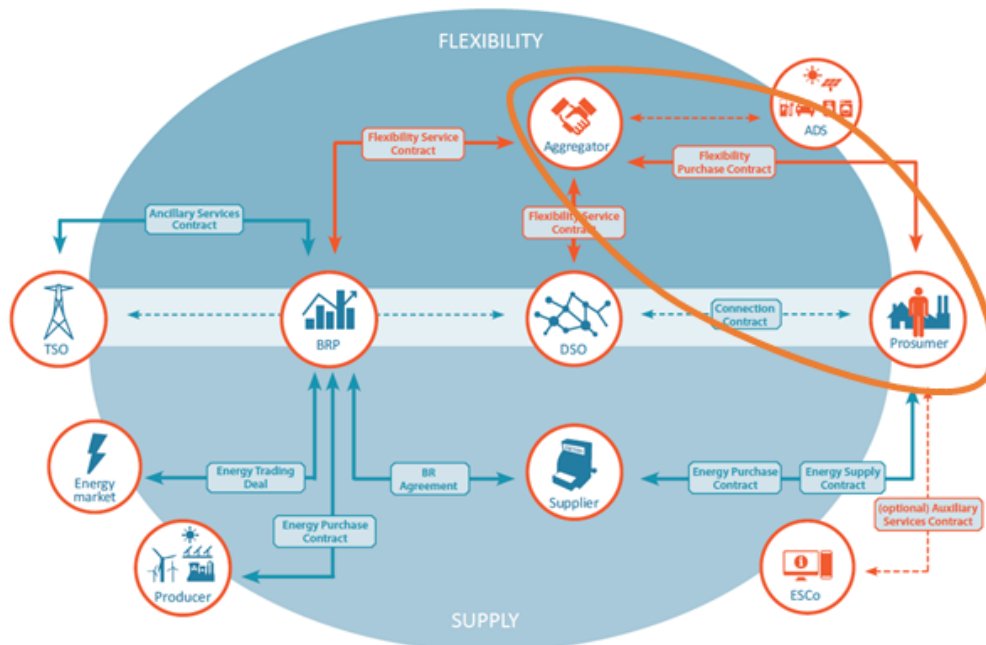


Figure 7: Market interactions (USEF, 2018)

Contractual relationship

The relationship between the EV user and the aggregator enfold due to a transfer of ownership regarding the EV. The aggregator takes control of the EV when plugged-in for V2G services and the EV user uses the vehicle for mobility services. The ownership of the EV transfers each time the EV is plugged-in or plugged-out, affecting the property rights of the EV (Hart & Moore, 1990). Property rights are defined as:

- The right to use the product
- The right to earn income via the product
- The right to transfer the product
- The right to enforce the property rights

In the case of V2G, the electricity in the EV refers to the product.

In Coase (1960) the importance of clear division of property rights is explained. Clear division of property rights will result in an economic efficient outcome regarding externalities. V2G possess externalities in the sense of improving grid efficiency. For V2G services it is important to allocate the property rights well, a contract can provide this. In addition, USEF (2018) proposes a contractual relationship as well between the aggregator and the EV user. Contracts serve as a set of rules or institutions that define the behaviour among the involved actors.

The importance of having a contract between the aggregator and the prosumer is also noted in V2G literature (Guille & Gross, 2009; He et al., 2013; Parsons et al., 2014). In Parsons et al. (2014) two ways of getting participation are proposed: a yearly based contract or a non-contractual way in which V2G is integrated into a pay-as-you-go system. The non-contractual way holds as main advantage that consumers decide whether they are willing to participate and offer flexibility. Thereby the choice lies with the consumer, but at the same time it withholds the potential of achieving the maximum benefits of V2G for the distributed flexibility system as the DSO's then cannot, at any desired moment, control the number of EV's that are available to provide V2G (Kubli, Loock & Wustenhagen, 2018). This may result in having not enough EV's available to provide flexibility.

In addition, contracts are an effective way to coordinate EV users in the participation of V2G (Guille & Gross, 2009). Contracts are then used to get the commitment of the EV users. This commitment is either rewarded or penalized when failing to comply to this commitment. The rewards compensate for the discomfort that is experienced by EV users when providing V2G services, while the penalizations can take the form of higher prices for electricity or lower remuneration.

In these contracts the daily V2G behaviour is specified. In this thesis the perceived costs and benefits for the involved actors are defined by contract elements. The contract elements refer to the change from mobility to V2G and vice versa.

It is important to note that participation in V2G programs is dependent on the EV users' perceived costs and benefits associated with V2G (He et al., 2013). Here costs refer to what EV users perceives as discomfort for providing V2G services to the counterparty, in this case the aggregator. Benefits refer to what the EV users perceive as compensation in return for the participation in V2G programs. The contract elements can be formalised such that they compensate for the discomfort EV users experience when providing V2G services.

Whether EV users are willing to accept a contract depends on the elements that are present in a contract and how these are formalized. The contract elements will be defined by the aggregator (USEF, 2018).

[Different aggregator models](#)

The aggregator proposes a contract to the EV users and determines the contract elements that are present in the contract. In the future, the role of the aggregator could be fulfilled by new parties that are able to enter the market. This creates uncertainty for the elements that are used in contracts, as different parties may propose different elements. For example, when a car manufacturer fulfils the role of the aggregator discounts at the purchase of an EV may be present in the contract as compensation for providing V2G services as long as the car is owned. In comparison, when a parking facilitator fulfils the role of the aggregator, parking spaces may be present as contract element and compensation for providing a temporary V2G service instead. Since the fulfilment of the aggregator

role is not yet defined, the contract elements that are incorporated in the contract are variable and may differ depending on the party that fulfils the aggregating role. This may result in different participation rates in V2G programs by EV users.

However, USEF (2018) proposes two logical parties that might take the role of the aggregator in the future. This is as the DSO, which has a logical position to take the role of the aggregator, is not permitted by law to take the role of the aggregator. In addition, the EV user itself cannot become the aggregator as well because of insufficient volume of flexibility (Tennet, 2018). Then, the two logical options are:

- 1) The CPO. Multiple charging stations are managed by the CPO and therefore sufficient flexibility volume is available. This means that the CPO is only active in certain regions, otherwise a monopoly is formed, which would damage economic welfare (Sharkey, 1982). I.e.: Newmotion is a Dutch CPO who is seeking to fulfil the role of the aggregator.
- 2) The E-mobility service provider. Here enough flexibility volume is generated since this party already has multiple contracts with EV users and therefore, the E-mobility service provider can become the aggregator. I.e., Jedlix (a platform that connects EV users with electricity suppliers) is already operating as aggregator in the Netherlands.

Whichever party takes the role of the aggregator, it is likely that the aggregator will propose contract elements to the EV user that compensate for their experienced discomfort such that profits of the aggregator can be maximized.

Aggregator uncertainty and the DSO

For the DSO, the uncertainty regarding the role of the aggregator might have consequences. Here, objectives between the DSO and the party that fulfils the role of the aggregator can be contradicting. The benefits V2G offers to the DSO are location specific. See Figure 8, as V2G offers the following benefits: reduce capacity, reduce congestion and provide voltage control (Lam et., 2014).

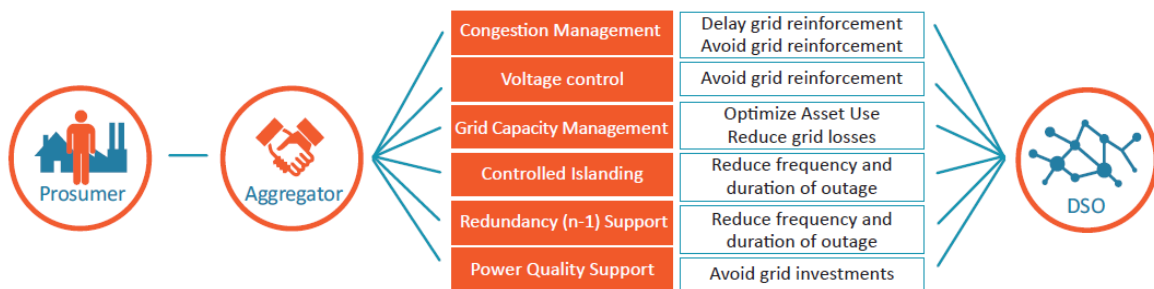


Figure 8: flexibility services for the DSO (USEF, 2018)

For example, when the CPO takes the role of the aggregator, different contract elements may be presented to the EV user than when the DSO would have been allowed to take the role of the aggregator. If the CPO becomes the aggregator there is an incentive for the CPO to optimize the charging infrastructure and utilization of the charging points rather than providing an unlimited number of charging points to provide the required energy and availability (PwC, 2018). This entails that the CPO is able to provide elements in the contract that stimulates EV users to plug-in at a specific location while V2G is desired at another location. More of these contradicting situations may arise when a new party takes the role of the aggregator.

Given the two logical options for the aggregator, the contradicting objectives this may yield and the relation to charging locations, this thesis will take different charging locations into account. It is found desirable to understand if EV users experience more discomfort in V2G contracts at different charging locations. EV's can be charged at three locations:

- 1) Private (i.e. at home)
- 2) Semi-public (i.e. at work)
- 3) Public location (i.e. at Fastned)

Private charging refers to charging at home or another private environment (office). Here the flexibility that is provided can be used to reduce local grid capacity. Also, this type of flexibility can be used to create revenue through commodity optimization and grid congestion management.

Semi-public charging locations can be found in parking garages and offices. The building tenant operates the charging stations to be used for its employees or guests. This type of flexibility can be used for capacity management and managing grid congestion.

In public charging locations, a CPO operates a set of charging stations in the public environment, i.e. Fastned on the Dutch highways. Here EV users have an agreement with the E-mobility service provider to gain access to the charging stations.

These three locations will be further used in this thesis. In appendix 1 this is described in more detail.

Conclusion USEF

By adding V2G to the traditional electricity market, new roles and responsibilities originate. The most notable role is the rise of the aggregator. This party is not yet defined but will have a relationship with the EV user. This new relationship will most likely take a contractual form. The contract contains elements that compensate for the discomfort EV users experience when offering V2G services. The elements that are present in a contract are dependent on the party that fulfils the role of the aggregator.

In addition, two logical options for the aggregating role are given. This may result in opposing interests between the aggregator and the DSO regarding the charging location of EV users. Therefore, in this thesis the impact of charging location on contract elements will be considered.

2.2 Demand response contracts

In literature, the focus lies on providing grid stability via V2G such that RES can be incorporated in the grid. The consequences that V2G bring along for the EV users via contracts is rather limited researched (Sovacool et al., 2018). Therefore, to start off with an exploration of V2G contracts in the literature, a comparison is made with the already existing Demand Response programs in which EV's participate.

Demand Response and V2G are both flexibility services, with expected similarities. Some of the issues regarding V2G coordination are indeed comparable to demand response programs e.g. activation criteria and remuneration scheme (Holtinen et al., 2013). Moreover, Demand Response is already being used in the charging of EV's: smart charging (Vandebroun, 2018). Smart charging is a form of Demand Response and applied to EV's such that charging EV's occurs such that electricity demand peaks are reduced.

Demand Response description

Demand Response is considered a mechanism that better balances the supply and demand of electricity by keeping demand bounded by the supply of electricity (Yan et al., 2018). According to the US Federal Energy Regulation Commission demand response is defined as: “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” (Balijepalli et al., 2011).

There are semi-automated demand response activities and automated demand response services. Semi-automated refers to the involvement of a person to activate demand response, while automated demand response is initiated by an external communication signal. The most known applications of demand response are those of heating, ventilation, air condition, washing machine, dryer or the charging of an EV.

Demand response contracts

In demand response programs a distinction is made between “explicit” and “implicit” mechanisms (Smart Energy Europe, 2018). Explicit demand response entails a pre-arranged contract with a customer for a determined amount of volume (incentive-driven). End users participate voluntarily in these explicit demand response programs, but a penalty is usually given to those not meeting their contracted volume (Bossart & Giordano, 2012; Braithwait & Eakin, 2002).

Implicit demand response entails a pre-arranged contract with a customer for a determined price (price-driven). The end users are incentivised to reduce electricity according to the actual value of electricity in the market. Consumers participating in such programs can save money by reacting to price-based signals (Bossart & Giordano, 2012; Braithwait & Eakin, 2002; Masiello et al., 2013). The two distinctions are depicted in Figure 9.

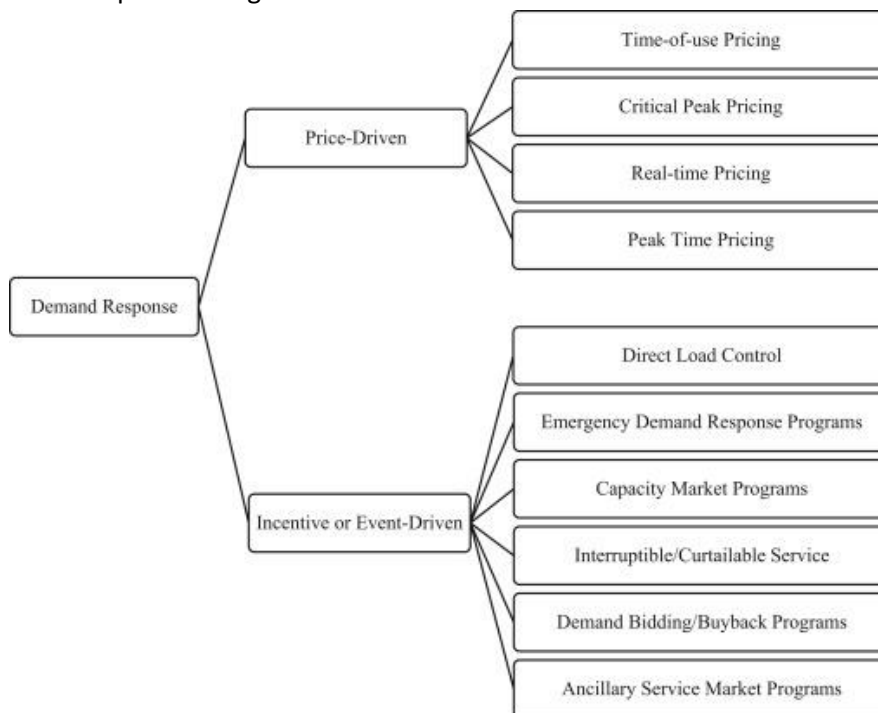


Figure 9: Demand Response programs (Yan et al., 2018)

For the price-based demand response programs there are four different ways to operationalize it (Yan et al., 2018).

- 1) Time of Use (TOU) pricing program: uses a static pricing scheme that is founded in the price values. These are easy to follow and therefore easy for consumers to participate in.
- 2) Critical peak pricing program: uses high electricity prices as trigger for participation in the program. Consumers receive an incentive if they reduce peak consumption. This type of program does not occur on daily basis, since it is based on an event.
- 3) Real time pricing program: electricity prices vary as they continuously do in the wholesale market. These prices are made available to the customer who are able to adjust their electricity consumption to the financial benefits provided by real time prices. This is a dynamic pricing scheme.
- 4) Peak Time Pricing: consumers pay additional fee for the use of electricity during peak moments.

The incentive or “volume” based demand response program consists of six different incentives or events that trigger demand response (Yan et al., 2018):

- 1) Direct load: refers to remotely shifting control from the end user to the utility. Incentives are provided to users that participate in these programs.
- 2) Emergency response programs: entail incentives in exchange for voluntary load reduction during special events.
- 3) Capacity market programs: these are mandatory programs, which will penalize consumers if they do not comply with the agreement. Load reduction is pre-specified.
- 4) Interruptible/curtailable services: mandatory programs, which will penalize consumers if they do not comply with the agreement.
- 5) Demand bidding/buyback programs provides large energy consumption parties the possibility to negotiate the value for load reduction.
- 6) Ancillary service market programs: prices are used where back-up electricity for the grid is provided.

Willingness to use Demand Response

Some of the concepts of demand response programs are studied using stated preference methods to measure the willingness to participate in these programs (Cappers et al., 2010; Torriti et al., 2010; Annala, 2015; Gamma, 2016). The studies stress three important conclusions: Firstly, high financial incentives are required for users to participate in demand response programs, but the amount differs for different appliances. For example, consumers tend to value their usage of TV and laptop more than the time of use of their washing machine. Secondly, consumers are not willing to adjust their behaviour, for example shifting the use of certain appliances to low energy peak times. For example, consumers want to watch TV when they reach home after work, not during midnight. It could be stated that users require high financial incentives to adjust their behavior. Thirdly, Joskow & Wolfram (2011) find that demand response users with a low income are more responsive to dynamic pricing schemes than high income groups. It is expected that this behaviour will also likely occur in V2G programs. Therefore, income is seen as an important factor that defines participation in V2G programs.

Conclusion Demand Response

The concepts that are used in demand response programs can be applied to V2G. For example, price and volume-based activation triggers can be used. It is also expected that the observed behaviour can somewhat be extended to V2G. It is expected that income of a EV users will influence the preferences regarding V2G contracts and is therefore considered in this thesis.

2.3 Contract types for V2G

As observed from the literature on demand response, price- and volume-based contracts can be used in V2G programs as well but require adjustments to accommodate to V2G. However, there are some differences between V2G and demand response.

Differences Demand Response and V2G

Despite the similarities between Demand Response and V2G, there are also fundamental differences that should be considered when constructing V2G contracts. In the case of Demand Response, flexibility is provided by slightly adjusting the normal consumption pattern: the EV charges not directly but only when electricity is available. V2G differs in multiple ways i.e.:

- The EV becomes a distributed resource and therefore has impact on behaviour
- V2G has an impact on the batteries' longevity due to the multiple discharging cycles
- Due to the discharging of the battery, there is a risk that the battery does not have the required amount of energy at any given point in time

Extending Demand Response to V2G

Park Lee (2018) deducted price- and volume- based contracts from demand response to V2G for fuel cell EV's. This extension includes additional parameters that were required for V2G. Notion should be given to the fact that these contracts are proposed for fuel cell EV's and require adjustments when using Battery EV's, as in this thesis. The parameters differ between the contract types, but they mainly encompass: the availability, activation criteria and remuneration. Besides, to maintain a guaranteed minimum level after the use of V2G and the required amount of electricity available need to be added into a parameter. These parameters are further denoted as contract elements.

The contract types are based on price, volume or control. The contracts of price and volume are extended from the contracts that are being used in Demand Response programs, respectively from the price-driven and incentive-driven contracts. The control-based contract is mainly mentioned in V2G literature. The contract types and the additional contract elements are shown in Figure 10.

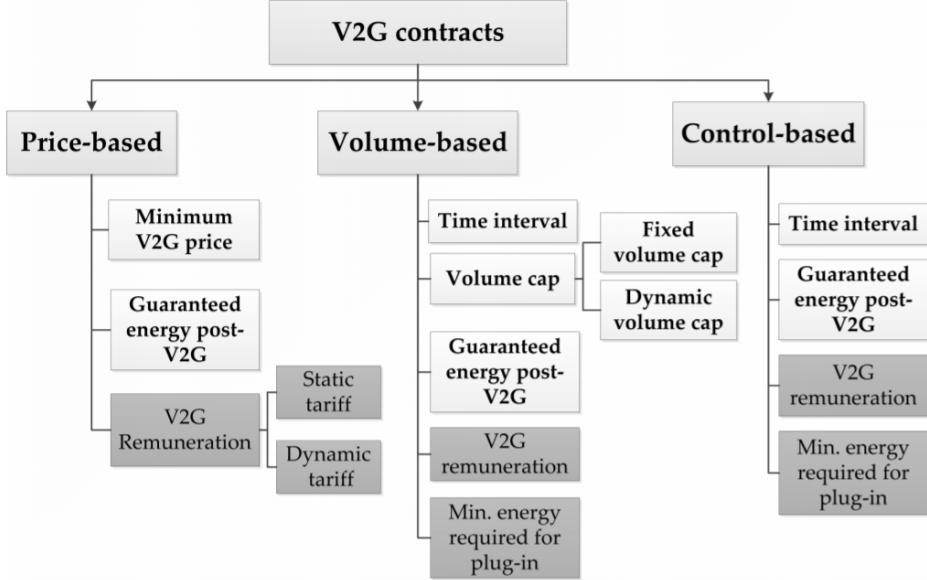


Figure 10: Contracts proposed by Park Lee (2018)

Price

V2G contracts that are price based entail a pre-determined price signal that activates the V2G program. The EV users sets a price that he sees as rewarding for V2G. In this case, the aggregator is only allowed to use the vehicle for V2G when the aggregator is able to provide the defined minimum price. This would be the case if the market price for electricity is higher than the price set by the EV user. Another usage restriction for the aggregator is the amount of electricity available in the vehicle. This cannot exceed the determined guaranteed energy. In this contract form, there are no restrictions on availability or time as the usage of V2G is voluntary. The aggregator can set the contract such that the EV user will get the minimum price and an additional percentage for the extra margin, in case a higher market price than the minimum price set by the EV user. In addition, EV users can be rewarded by receiving additional remuneration for the available time and volume.

Volume

V2G contracts that are based on volume involve commitment to provide a certain amount of electricity within a certain time interval. In this type of contract, the EV user can limit the amount of electricity available for V2G. Due to the pre-settled volume arrangement there is a minimum required volume of electricity required at plug in. As the guaranteed charging level after the use of V2G is defined, the required energy at plug in can be calculated. Volume based contracts are set to be relevant for EV users that have a predictable driving schedule. Due to the predictability, these types of contracts offer grid stability. The remuneration in this contract could therefore be based upon rewarding the commitment, as the commitment is based on time and volume and thereby personal freedom.

Control

V2G contracts that are based on control the EV user controls nor price nor volume. Once the vehicle is plugged in the V2G program, the aggregator has full control over the amount of energy that is depleted and at what price. The activator in this contract is the pre-defined guaranteed energy level post V2G. This shows similarities with the volume contract, however there is no commitment on the maximum volume that is being used. The volume that is being used is thus determined on the guaranteed energy level post V2G and the initial energy level. Remuneration rewards the availability and volume that is provided by the EV user. In this way an incentive is provided to high levels of availability and volume.

V2G contract elements

There are three studies found in literature which aim to gain insights in the willingness of EV users to participate in V2G programs in the future: Parsons et al. (2014), Geske & Schumann (2018) and Kubli et al. (2018). The studies use contracts as basis for the provision of V2G to EV users. How V2G is proposed to EV users in these studies will provide a solid starting point for this thesis. In addition, this thesis will contribute to the limitations of those studies.

To start off, the contract elements that are being used in the stated preferences studies are compared. This is shown in Table 3.

Table 3: Contract elements in literature

Contract elements	Parsons et al. (2014)	Geske & Schumann (2018)	Kubli et al., (2018)
Guaranteed energy	X	X	X
Remuneration	X	X	X
Plug-in duration	X	X	
Contract duration			X
Flexibility (see Table 4)			X
Power mix			X

In Table 4 the definition of flexibility in the Kubli. et al. (2018) study is shown. Flexibility is used as a combination of the state of charge during V2G and battery degradation effects.

Table 4: Operationalization of flexibility

	Super flex	Flex medium	Flex light	No flex
State of Charge after V2G	Guaranteed charging level 40%	Guaranteed charging level 60%	Guaranteed charging level 80%	No access to the battery
Battery Degradation	Unlimited discharging cycles per 24h	Max 3 discharging cycles per 24h	Max 1 discharging cycle per 24h	-

Remuneration

The three studies found that EV users are not per se willing to provide flexibility, but when EV users gain higher utility through other contract elements, they are willing to accept any inconvenience associated with V2G. Parsons et al. (2014) mention that remuneration is required to compensate for the inconvenience that EV user experience during V2G. This is also acknowledged by Kubli et al. (2018).

Guaranteed energy

The three studies found that EV users are cautious with their battery level. Geske & Schumann (2018) found that “range anxiety” negatively influences the participation rates in V2G programs. Range anxiety is defined as: “the fear of fully depleting an EV’s battery in the middle of trip, leaving the driver stranded” (Neubauer & Wood 2014). Therefore, the guaranteed minimum battery level after V2G is considered as an important attribute. Kubli, Loock & Wustenhagen (2018) show that if the minimum guaranteed charging level after V2G drops below 60%, EV users are less likely to participate in V2G programs.

Plug-in duration

The required plug-in time is considered to be important. Parson et al., (2014) noted that the costs for increasing the required plug in time per day were high given the fact that vehicles are idle most time of the day. Geske & Schumann (2018) add that restrictions on connection times do negatively influence the participation in V2G programs.

Battery degradation

A limitation of the Parsons et al. (2014) and Geske & Schumann (2018) study is the omission of battery degradation in the study. Kubli, Loock & Wustenhagen (2018) do consider battery degradation by defining four levels of discharging the battery. However, they measured the willingness to provide flexibility via heat pumps, PV and EV’s and therefore they operationalized flexibility as shown in Table 4. The guaranteed charging level and discharging cycles are consequently put together as one attribute to compare with heat pumps and PV. The battery degradation is therefore not independently measured.

Battery degradation is a topic within V2G that has been researched by many (Marongiue et al., 2015; Saxena et al., 2015; Wang et al., 2016; Hu, et al., 2017). Concluding from the research it could be stated that V2G creates a higher use of the battery and consequently has a negative impact on the lifetime of the battery. Wang et al. (2016) found that the cost for battery degradation per charge are 0.20\$ - 0.45\$. Additional discharging of EV batteries to the grid will consequently result in a deterioration of the batteries performance (Dubarry, Devie & McKenzie, 2017).

There are some contradictions in literature regarding battery degradation, stating that V2G can improve a batteries’ lifetime (Uddin, Dubarry & Glick, 2018). It is concluded that V2G impacts the batteries’ lifetime negatively, but the amount of degradation determines on the frequency of usage, meaning there exists a tradeoff in which the battery not wearied down more than uncontrolled charging. In two recently finished pilot projects, Parker project in Denmark and INVENT project in California, it is observed that V2G does some additional damage to the batteries’ longevity (INVENT, 2018; Parker, 2018). The impact of V2G on the batteries’ longevity depends on the service in which full charging/discharging is the worst for the batteries’ lifetime (INVENT, 2018).

In addition, EV users are reluctant on their battery and therefore battery degradation is considered as a negative aspect of V2G (Hu et al., 2013). Effecting the battery has an influence on “range anxiety” of EV users (Neubauer & Wood, 2014). Therefore, battery degradation is also considered in this thesis.

Contract duration

In Kubli et al. (2018) the importance of contract duration is explained. This is not used in the contract types proposed by Park Lee (2018). Therefore, contract duration will also be considered in this thesis.

In addition, the contract duration contributes to the willingness to participate in certain programs. In Burkhalter et al. (2009) consumers preferences into contract duration is investigated. Burkhalter et al. (2009) found that contract duration does impact the choice of a product, but less than other attributes such as price or service. The length of the contract influences the product choice, is also observed in electricity products (Kaenzig et al., 2013). Moreover, Scarpa & Willis (2010) conducted a choice model considering RES and the contract lengths. They found that the higher the contract length for a RES, the more the utility of the respondent was reduced.

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

- 1) Battery degradation
- 2) Contract duration

These are shown in Figure 11 as green boxes.

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

- 1) Hydrogen volume capacity
- 2) Minimum energy required before plug-in

These contract elements are not compatible for battery EV's and are therefore not considered in this thesis. In Figure 11. These two contract elements are shown in red.

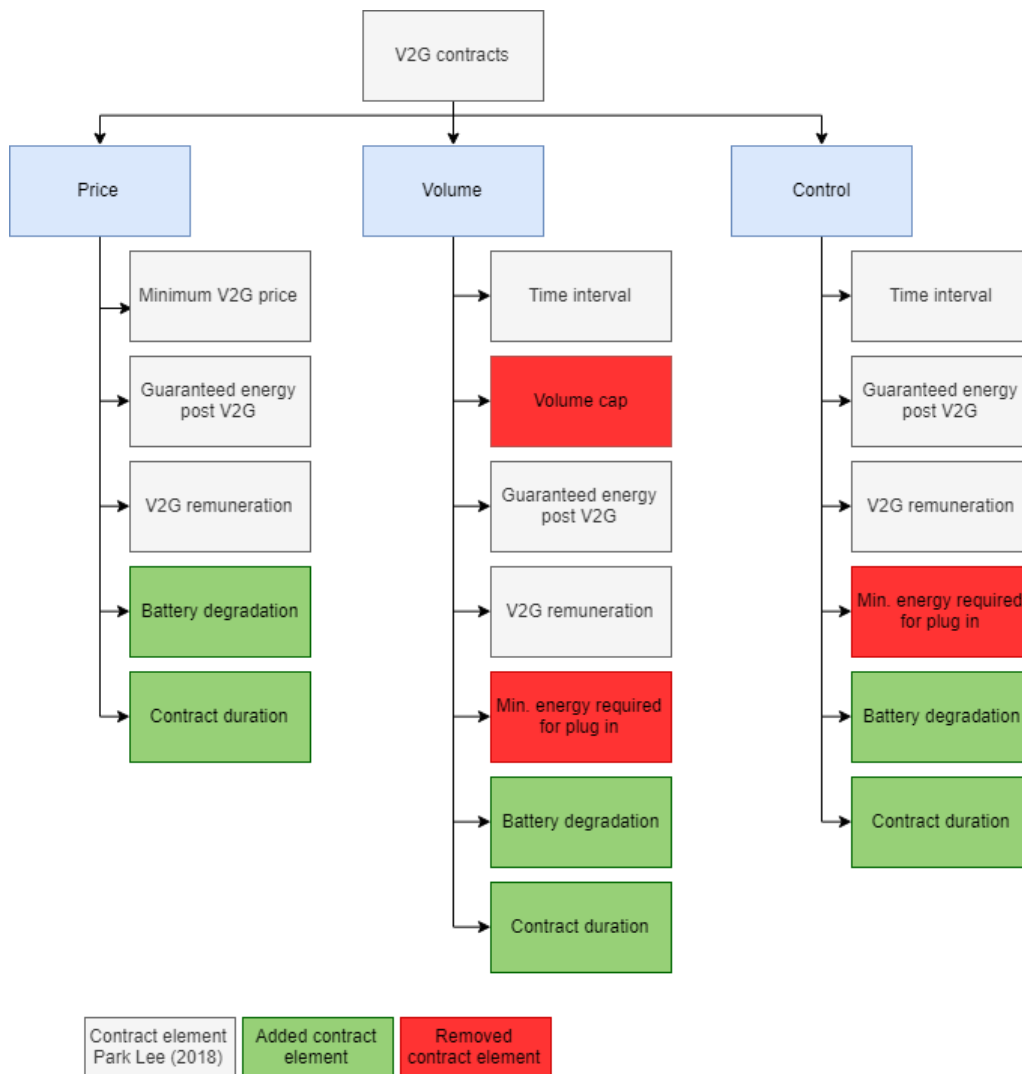


Figure 11: Adjusted contracts

DSO and V2G contracts

The type of contract that is relevant for the DSO depends on the characteristics of the electricity market. As Broneske & Wozabal (2017) conclude in their research on the effect of contract elements on the economics of V2G, the contract should be used to attract the EV user that is most valuable for the market. For example, in electricity markets with low electricity throughput EV users with high availability are most valuable. While for electricity markets with high electricity throughput EV users with high electricity capacity and availability will be valued most.

Due to the characteristics of the electricity market, some contract types offer more value for the DSO than others. As seen in four pilot projects (Parker, Cityzen, Smart Solar Charging and Jumpsmartmaui) the main focus of service for the DSO is congestion management. Congestion refers to an under- or overload of the grid components, which is caused by capacity constraints (USEF, 2018). To cope with this, the DSO's require availability and predictability.

The contracts that are presented have the following functions:

- Control based: not scheduled ahead so no commitment beforehand
- Volume based: providing reserve capacity, requires very predictable behaviour
- Price based: wholesale market, where peak prices are high

Therefore, the contracts of volume- and price-based seem to be most relevant for the DSO's since these contracts provide availability and capacity.

Reflecting on the contract types that are proposed by Park Lee (2018), the contracts that are used in the stated preference studies are all similar and focus on the guaranteed charging level and required plug-in time. This is comparable with the control type contract, proposed by Park Lee (2018). In this type of contract there are no specific arrangements on the volume or price that is required for V2G. This entails that the price and volume-based contracts are still neglected in the literature.

Conclusion V2G contracts

Demand response contracts can be used for V2G programs as well but there are fundamental differences between Demand Response and V2G. To use the mechanisms that are proposed in the demand response literature in V2G programs, adjustments should be made to consider the characteristics related to mobility to stimulate participation among EV users. Park Lee (2018) proposes three contract types that are feasible for V2G usage. The price- and volume-based contracts are deducted from the existing contracts in demand response programs. However, the control-based contract is the most widely used contract form in V2G literature. To provide scientific contribution and provide insights for the DSO two contract types are used in this thesis:

- 1) Price-based contracts
- 2) Volume-based contracts

Examining the current literature on V2G contracts resulted in the identification of a total of five factors that may influence the decision to participate in V2G programs. These are defined as the contract elements and the EV user characteristics. The following contract elements are taken in consideration in this thesis:

- 1) Guaranteed energy during V2G
- 2) V2G remuneration
- 3) Time interval (further denoted as plug-in duration)
- 4) Battery degradation (further denoted as Discharging cycles)
- 5) Contract duration

These five factors are defined as the contract elements.

2.4 Hypotheses & conceptual model

The contract elements and EV user characteristics are defined. Firstly, hypothesis will be constructed. Secondly, the hypotheses are depicted in the conceptual model.

2.4.1 Hypotheses

The following paragraph will elaborate on the contract elements that influence the choice of participating in V2G programs. Hypotheses regarding the previously found contract elements and EV

user characteristics are formed. These are used in different contract types: price- and volume-based. The hypotheses are alternative hypotheses. The null-hypothesis in this regard is defined as:

H0: The parameter value is zero for the population

As shown in Figure 11, price- and volume-based contracts differ in terms of the contract elements they possess. Here, the distinction between the two contracts is the lack of plug-in duration in price-based contracts. The other contract elements remain the same for both contracts.

Guaranteed energy

The guaranteed energy promises the EV user that at any point in time a certain amount of energy is available. This is usually expressed in the minimum driving range (kilometers) (Parsons et al., 2014). The driving range of an EV contributes to the factor “range anxiety. The State of Charge (SOC) of the EV during V2G can be lower than the SOC at the moment of plug in. Hoen & Koetse (2012) found that EV users are willing to pay more for energy in low SOC ranges than in high SOC ranges. In other words, EV users value their minimum range more when the SOC of the EV is low than when the SOC is high. Therefore, it is hypothesized that a lower minimum range results in less utility for participation in V2G programs.

H1: Guaranteed energy has a positive effect on the perceived utility

Remuneration

In return for the provision of electricity a remuneration structure is provided to the participants in V2G programs. EV users participating in V2G programs are found to be willing to provide flexibility services but expect to be compensated for their “discomfort” (Kubli, Loock & Wustenhagen, 2018). Remuneration can take place in different forms (not exclusive): free charging station, greener energy mix, annual payback, upfront payback or monthly remuneration. Either way, it is hypothesized that higher remuneration will result in a higher utility to participate in V2G programs (Carradore & Turri, 2010). In addition, it is expected that the effect of remuneration on the perceived utility is non-linear.

H2: Remuneration has a positive effect on the perceived utility

Battery degradation

Participating in V2G programs will result in a shorter longevity of the EV’s battery. The effect is undisclosed in the literature (see Chapter 2, battery degradation) but in pilot projects effects are measured. As battery degradation results in a less reliable battery, it contributes to “range anxiety”. The more a battery is discharged, the more effect it has on the batteries’ lifetime. Therefore, it is hypothesized that more discharging cycles will result in less utility for participating in V2G programs. In addition, it is expected that the effects of discharging cycles on the perceived utility is non linear.

H3: Battery degradation has a negative effect on the perceived utility

Contract duration

The length of the contract has an impact on the participation in certain programs. In the case of providing RES it is observed that the longer a contract is, the less people participated. Therefore, it is hypothesized that a longer duration for a V2G contract will result in less utility for participating in V2G programs.

H4: Contract duration has a negative effect on the perceived utility

Plug-in duration (only for volume-based contracts)

The plug-in duration represents the availability of the EV user by requiring a certain amount of plug-in duration and start time. This will contribute to a predictable number of participants in V2G programs and enlarge the energy capacity that is available. However, EV users are restricted in their EV usage, as the EV's are required to be plugged in for several hours. Parsons et al. (2014) found that the parameter of the required plug-in time is negative. This entails that EV users perceive plug-in time as a factor that decreases the utility for participation in V2G programs if the plug-in time increases. Therefore, it is hypothesized that the longer the plug-in time, the lower the utility for participation in V2G programs.

H5: Time interval has a negative effect on the perceived utility

As mentioned in the USEF exploration and literature of demand response, there are two factors that are relevant for this thesis as well, these are discussed below. The charging location and income are expected to have an effect on both contracts.

Charging location

As mentioned in the chapter 2, there are roughly three locations of charging the EV: at home, at work or at public infrastructure. According to Wolbertus, Kroesen, Hoed & Chorus (2018), it is observed that EV users who charge their EV at home, have the longest plug-in time (15.3h on average). EV users charging at work, are restricted in their plug-in time by their work schedule. It is therefore expected that EV users who are able to plug-in at home will have different preferences regarding V2G than EV users who are only able to plug-in at public infrastructure. As the home plug-in time is the longest, it is assumed that these type of EV users are less affected by the plug-in requirement of the volume contract. It is therefore hypothesized that EV users with home charging possibilities have a higher utility regarding plug-in duration.

H6: Charging location availability makes EV users less sensitive to guaranteed energy

H7: Charging location availability makes EV users less sensitive to battery degradation

H8: Charging location availability makes EV users less sensitive to plug-in durations

Income of EV user

Since EV's are currently more expensive than conventional vehicles, most of the EV users are therefore in relatively high-income classes. People who have more money are less sensitive to price changes than people who have less income (Petrick, 2005). Since the current EV users might have a higher income, it could be expected that they are less willing to participate in V2G programs or require a higher remuneration to cope with the sense of discomfort. Therefore, it is hypothesized that EV users with a higher income, will require a higher remuneration for participating in V2G programs.

H9: Income makes EV users less sensitive to remuneration

2.4.2 Conceptual model

To test the hypothesis, an assumption is made: Dutch EV users make decisions regarding V2G by maximizing their perceived utility. This paragraph will discuss the relationship between the choice to participate in V2G programs and utility.

Dutch EV users are faced with a choice: participating in V2G programs or not. To deepen the understanding regarding the desires and needs of Dutch EV users in V2G programs, their preferences are modelled. There are several theories available on modelling individual preferences. However, this thesis is based on the “utility theory”. This theory assumes that individuals choose an alternative that has the highest utility (Manski, 1977; Walker & Ben-Akiva, 2002). This is often referred to as “utility maximizing behaviour”. The conceptual model is based on this theory. This is depicted in Figure 12. Here, the attributes are observed variables and utility is the unobserved variable.

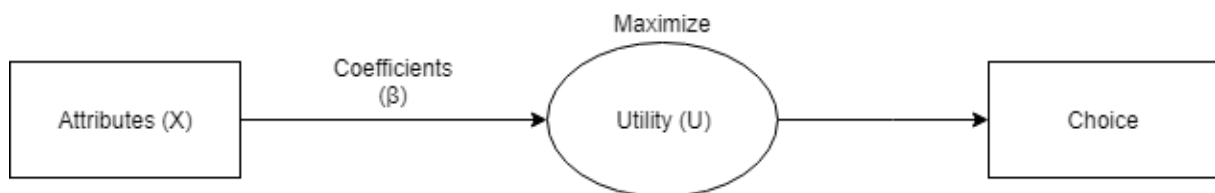


Figure 12: Utility theory

So, an alternative is chosen if the utility is the largest for that alternative. In this thesis the elements in the contract types refer to the attributes and thereby influence the utility of a Dutch EV user. Based on the utility functions estimations can be made on the chance of an individual choosing a particular alternative out of a choice set.

In this thesis the relationship between utility and choosing an alternative will not be discussed, for more information on the causal relationship see: (Thurstone, 1927; McFadden, 1986; Luce, 1959). However, the assumption that people are utility maximizers has been adopted by economics for a long time. In 1912 Taussig stated:

“An object can have no value unless it has utility. No one will give anything for an article unless it yields him satisfaction. Doubtless people are sometimes foolish, and buy things, as children do, to please a moment’s fancy; but at least they think at the moment that there is a wish to be gratified.”

The use of this theory is thus widely adopted. As V2G programs have an effect on the utility EV users perceive, this relationship is adopted.

Conceptual model explanation

This paragraph will elaborate on the contract elements that are included in the conceptual model. The conceptual model is based on the model as proposed by Kroesen (2018) This model is based on the theory of people being utility maximizers. In other words, people choose an alternative that provides them maximum utility.

The conceptual model for this thesis is depicted in Figure 13. The circles represent the contract elements that influence utility and thereby the choice to participate in V2G programs. In choice modelling, these elements are called “attributes”. Hence, the different attributes affect the utility of an EV user which contributes to their choice to participate in V2G or not. The higher utility EV users experiences, the more likely it is that the EV user will participate in V2G.

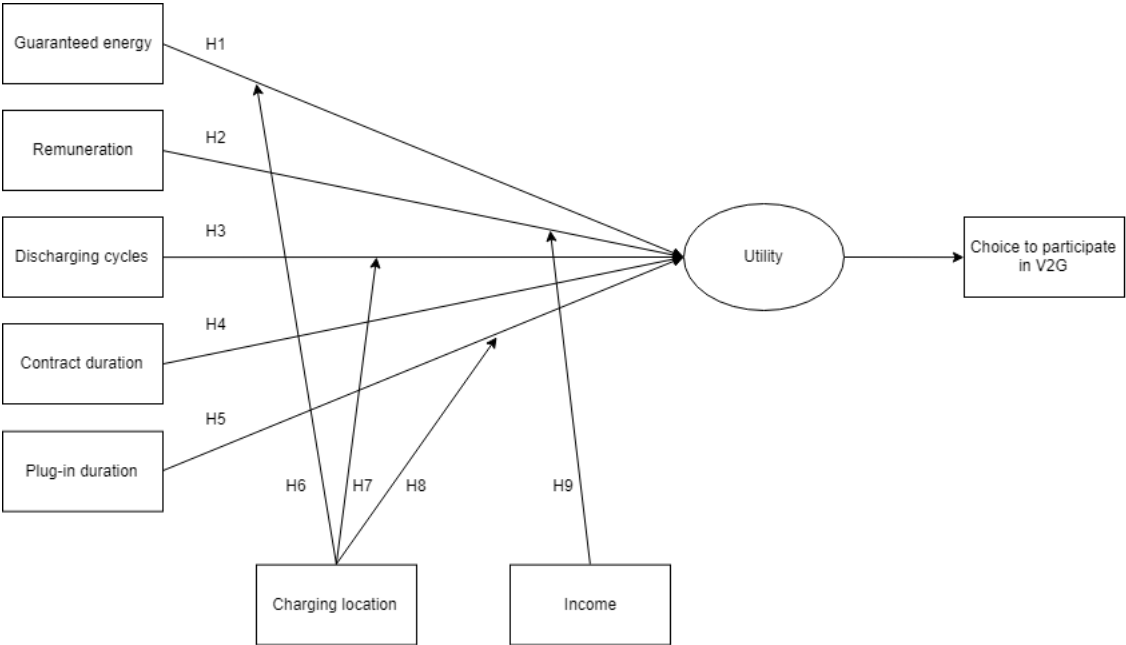


Figure 13: Conceptual model

Based on the literature review and the USEF framework, it is observed that providing flexibility via V2G can affect different market segments. Certain user groups are more relevant for a particular situation than others. It is also observed from literature that different user group characteristics influence the decision to participate in V2G. This is denoted as type of EV user in the conceptual model. In chapter 3 this is further elaborated on.

The decision to participate in V2G programs is also influenced by other factors such as described in earlier in this chapter. However, these are factors that are independent of a contract type. Therefore, the factors are not included in the conceptual model. The effects of these factors that are present in the decision-making process are captured in the model by an error term.

2.5 Conclusion

Adding V2G to the electricity market requires a new party, the aggregator. This party is not yet defined but will have a relationship with the EV user. This relationship most likely takes the form of a contract. In the contract, elements are present that are able to compensate for the discomfort EV users experience during V2G. These contract elements are set by the aggregator. The exploration of the current electricity market via the USEF framework contributed to two important insights for this thesis:

- 1) A contract will settle an agreement between the aggregator and the EV user
- 2) The party that will take on the role of the aggregator in the future is uncertain

Not much literature on V2G contract elements is available, therefore a comparison is made with already existing demand response programs. The price- and volume-based contracts can be extended towards V2G but require some additional elements. Park Lee (2018) proposed three contract types that are extended from the demand response literature: price-, volume- and control-based contracts. Based on the literature that is available on V2G contracts, two missing elements are added to the contract elements of Park Lee (2018). The missing elements are defined as battery degradation and contract duration.

In addition, the current literature focusses only on control-based contracts. Besides, the price- and volume-based contracts provide more value for the DSO's due to the predictability this offers. Therefore, price- and volume-based contracts are considered in this thesis. Here, the difference between the contracts entails the plug-in duration which is required in volume-based contracts while in price-based contracts the EV sets a price that the EV user sees as compensation for V2G services.

Due to the fact that the contract elements are proposed for fuel cell EV's, two contract elements that are only relevant for fuel cell EV's are removed. This leaves five contract elements that are present in price- and volume-based contracts for V2G considering battery EV's:

- 1) Guaranteed energy during V2G
- 2) Remuneration
- 3) Contract duration
- 4) Battery degradation
- 5) Plug-in duration

Besides these contract elements, there are two factors that might have an impact on the perception of EV users on these contract elements. The two factors are:

- 6) Charging location
- 7) Income level of EV user

The five contract elements and two moderating variables are hypothesised on the causal direction. This is shown in the conceptual model.

3. Methodology

Structure

This chapter focusses on the methods and steps that are necessary to test the formulated hypotheses and research questions. First the sample that will be surveyed will be described. Then, the steps of the stated choice experiment study will be explained, providing insights in the development of the questionnaire that is sent to the respondents. This is followed by explaining the process of generating respondents and data collection, which impacts how the gathered data will be used to test the hypothesis as found in chapter 2. The chapter concludes with the explanation of the preparation of data and the analysis of the data.

3.1 Introduction

As concluded in chapter 2, this thesis looks at five contract elements that may influence the utility of EV users and thereby their decision to participate in V2G programs or not, plus the two factors that may influence the sensitivity regarding some of these five contract elements. Nine hypotheses are developed. To test the constructed hypotheses, a quantitative experiment is constructed. Executing a quantitative research enables testing whether people are fundamentally interested in participating in V2G programs. The quantitative experiment is executed by setting up an internet survey.

3.2 Target group

This paragraph explains the sample that is required to test the hypotheses derived from the conceptual model formed in chapter 2.

The target group of this thesis, based upon the problem definition as illustrated in chapter 1, contains all current Dutch EV users in the Netherlands, driving Fully Electric Vehicles only. The population consists of 120.000 EV users as of 21-11-2018 (CBS, 2018). Compared to the three other stated preferences studies; Parsons et al. (2014), Geske & Schumann (2018) and Kubli et al. (2018), also none EV users could participate in the experiment. In this thesis, it is intended that setting the target group at EV users only, more reliable results will be obtained as they already have experience with the charging of an EV (Molin, 2016). In addition, results that are obtained based on this target group provide insights in the value of V2G in the short term as these EV users are able to immediately participate in V2G programs. Thereby accommodating for the problem as described in chapter 1.

To determine the representativeness of the sample, socio-demographic questions are added to the survey. These are divided into the following categories:

- Income level
- Age
- Gender
- Education level

No data is available in terms of the current Dutch EV users regarding socio-demographic characteristics as described above. However, Sovacool et al. (2018) conducted a study in the social demographic characteristics regarding EV usage across five Nordic countries: Denmark, Finland, Iceland, Norway and Sweden. By comparing the sample with the sample in the Nordic regions will provide some indication of the socio-demographic characteristics that are present in the population. This will not result in generalizable results, but when similar socio-demographic characteristics are

obtained it may be expected that the sample is representative to some extent as the EV user base is comparable. The number of EV users in the Nordic regions and the Netherlands is depicted in Table 5.

Table 5: Number of EV users

Country	Number of EV users	Percentage of total vehicles
Netherlands	120.000	6.5%
Denmark	8.746	0.4%
Finland	171.542	3.4%
Iceland	74.103	21.5%
Norway	133.260	38.7%
Sweden	29.333	11.9%

3.3 Data collection

In this paragraph the development of the survey will be described, combined with the strategy to obtain the required data, as well as the effects of the data collection method on the representativeness of the sample and potential distortions this could generate. This section starts with describing the strategy to obtain data and the steps of the design of the experiment. Next, the operationalization of the additional questions will be explained. This section is concluded by specifying the data collection method and its potential complications this has on the representativeness of the data.

3.3.1 Strategy to obtain data

There are numerous ways to infer data regarding people’s preferences via surveys. A distinction can be made between revealed and stated data collection. Revealed data collection contains real market alternatives and thereby reveal what people actually choose when they have to make a decision. For example: the time of the day that EV users charge their EV. Stated data collection contains of hypothetical choice situations presented to the respondents.

Since V2G is a completely new concept, revealed data is not available. Therefore, it is chosen to use the stated data collection method in this thesis. More on the stated and revealed data collection can be found in Appendix 3.

Stated data collection has as an advantage that hypothetical alternatives can be measured, including non-existing alternatives and attributes. In addition, the researcher constructs the choice set thus enough variety in the data is created. Lastly, there is no multi-collinearity between the attributes as the researcher constructs the choice sets. However, it also has its limitations.

Firstly, it is unknown if people actually do what they have said they would do in the hypothetical situation that is proposed to them. Secondly, the consequences of choosing an alternative is not felt. For example: the degradation of the battery’s lifetime will not be experienced while completing the survey. Thirdly, respondents have perfect information regarding their choice alternatives in terms of the costs, time or obligations that are preserved within the alternative. This is not the case in a real-

life situation. Therefore, the alternatives should be made familiar, realistic and fully described to the respondents, which will be explained in the steps of constructing the experiment.

For this stated choice experiment, literature is used to develop the choice alternatives and the attributes, the contract elements, that are incorporated in the contracts. On the other hand, a pilot survey is used to test the length, structure and understandability of the survey.

3.3.2 Choice experiment

The steps of creating a stated choice experiment are described in literature (Hensher et al., 2005; Ryan et al., 2008). It comes down to the following three steps: 1. Identification of relevant attributes and attribute levels → 2. Selection of experimental design and construction of choice sets → 3. Experimental context and Questionnaire development

Hereunder, the steps are elaborated upon.

Step 1: Identification of relevant attributes and attribute levels

The contract elements that are hypothesized are defined as attributes.

In this thesis, five contract elements will function as the attributes which will be presented to the respondents. The attributes are found in chapter 2, however the attribute levels will be discussed in this section. The attribute levels are shown in table Table 6.

Table 6: Attribute levels

Attribute	Attribute levels
Guaranteed minimum range	10 km 50 km 90 km
Battery degradation	7 discharging cycle/charging session 4 discharging cycle/charging session 1 discharging cycle/charging session
Contract duration	1 month 12 months 24 months
Remuneration	2.00 €/10 hour 6.00 €/10 hour 10.00 €/10 hour
Plug in time	0 hour/week 25 hour/week 50 hour/week

1. Guaranteed energy

The guaranteed energy is the amount of energy, translated to the number of kilometers, the vehicle is, *at any moment*, able to overpass. This distance is guaranteed during V2G, to provide the end user the possibility to cancel the program any time without being left with an uncharged vehicle. The absolute minimum is defined as in Kempton & Tomic (2005): an unexpected trip to the hospital should always be possible. Since the maximum distance to a hospital in the Netherlands is 10km, this

distance is chosen as the absolute minimum distance that should be available for the end user see Figure 14.

Afstand tot het dichtstbijzijnde ziekenhuis, 2007

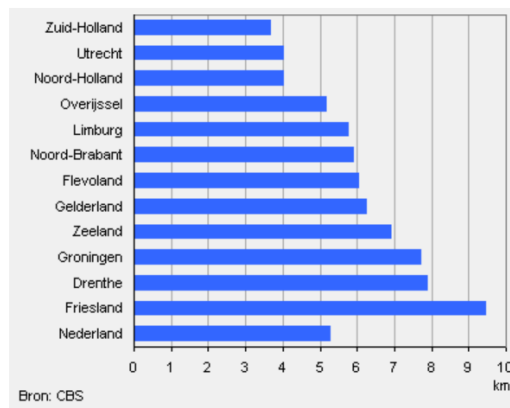


Figure 14: Distance to Hospital per province (CBS, 2018)

The average distance driven by car users in the Netherlands equals 40 km (CBS, 2016). Therefore, it is chosen to add the 40 km to the absolute minimum driving distance for the medium level, resulting in 50 km as minimum driving distance which is always guaranteed. To include all ranges, the highest level of minimum guaranteed range is set at 90 km. This is the range that will cover two days of average travel by car.

2. Remuneration

For supplying electricity back to the grid, EV users will be offered a remuneration. The range for remuneration is based on 10-hour plug-in time and varies between €2.00, €6.00 and €10.00. In England, OVO energy is already providing EV users £0.06 per every Kwh fed back into the grid (OVO Energy, 2018). On average, 5.4kwh can be fed back into the electricity grid, resulting in £0.33 (€0.38 as of December 2018) per hour plug-in time. So, to capture a broader range, it is chosen to go down until €0.20/hour, while around the €0.40/hour is common in England. Furthermore, it is chosen to insert a higher range as well up until average price you pay for charging for 1 hour, equaling €1.00.

3. Battery degradation

It is undisclosed in literature what the effects of V2G on the longevity of the battery are. However, from pilot studies (Parker project and JUMP smart Maui) it is observed that there is an effect. How large this effect is, is dependent on how many discharging cycles are occurring. Therefore, it is chosen to measure this effect in terms of discharging cycles. Since it is unknown how much effect one discharging cycle extra has on the battery, it is chosen to let the respondents deal with this “uncertainty”. Therefore, the discharging cycles varies between 1,4 and 7, which can be seen as barely effect on the battery, moderate effect on battery and large effect on the batteries longevity.

4. Contract duration

The contract duration is the length of the contract that is agreed between the aggregator and the EV user. The levels of the attribute contract duration are set at 1 month—1 year—2 years. This is comparable with the (Dutch) phone subscriptions.

5. Plug-in duration

The plug-in time entails the time that the EV is plugged into the grid. Depending on the contract,

there are requirements regarding the minimum time the EV must be plugged-in. Not complying to the requirement plug-in time will result in a penalty while complying to the agreed plug-in time will result in the corresponding remuneration. In this experiment the plug-in duration varies between zero (no requirements), 25 hours/week and 50 hours/week. The minimum level is chosen to accommodate for price-based contracts, which do not have any obligations regarding the plug-in duration. The maximum level is set at 50 hours per week, which requires the EV users to plug-in every workday for 10 hours. 25 hours is chosen to provide a medium.

Step 2: Selection of experimental design and construction of choice sets

In this experiment the model is specified with two alternatives containing the same attributes, therefore alternative specific parameters are nonexistent. Two alternatives without having alternative specific constants results in the development of unlabeled alternatives, which are defined as contract 1 and contract 2. Each contract consists of five attributes, the contract elements. Furthermore, it is aimed to preserve attribute level balance, resulting in an equal amount of attribute levels for each attribute (ChoiceMetrics, 2018).

As presented above, the attributes vary on three levels. Using the same attribute levels for each alternative is beneficial to limit the number of choice sets that are required. The higher the number of attribute levels and different numbers of attribute levels for each attribute may lead to a higher number of choice sets. This is especially the case if one wants to hold to the attribute level balance property. The attribute level ranges that are used for the design of the experiment are depicted in Table 6.

There are several ways to construct the choice sets as different experimental designs are available. The choice of using a design is based upon the (dis) advantages of the different experimental designs. Firstly, the (dis-) advantages will be described. Secondly, the choice will be reasoned for. The choice will be based upon the following criteria: a design with sufficient variation in the choice situations, estimate reliable parameters, create choice sets that do not exhaust respondents and resemble real world choice situations.

The first design that is examined is the full factorial design. The full factorial design is a design in which all possible combinations of all selected attributes levels are developed. For this thesis, five attributes are present with all three attribute levels. A full factorial design will then result into 243 possible alternatives. So, the full factorial is a simple design, but for this thesis it results into too many alternatives.

Second, to create a design that results in less alternatives, a fraction can be taken of the full factorial design. This is a fractional factorial design. This can be done random, orthogonal or efficient.

- Random: experiment most likely possesses multicollinearity between the attributes. An example would be high remuneration being correlated with low guaranteed minimum range, while it is desired to design the experiment such that the attributes are independent from each other. Therefore, the first logical design that is considered is the orthogonal fractional factorial design.
- Orthogonal: reduction of the number of alternatives, while maintaining zero correlations between the attributes.
- Efficient: results in the estimation of parameters with small standard errors and is therefore especially valuable for studies with a small response group. A disadvantage is the need for prior values of the parameters that are close to the correct parameters. Since the population for this study contains 120.000 EV users a large enough sample can be found to reduce the standard errors. Therefore, there is no necessity to use the efficient design.

Based on aforementioned (dis-) advantages, it is chosen to use an orthogonal fractional factorial design. Using this design, enough variation in the choice sets is created and not too many choice sets are created.

Step 3: Experimental context and questionnaire development

To construct an orthogonal fractional factorial design, the software package Ngene is used. Ngene is developed to generate experimental designs such that choice models can be estimated (ChoiceMetrics, 2018).

Constructing choice sets with the software package Ngene allows the researcher to find a design that fits in the minimum number of choice sets, considering attribute level balance and zero correlations between the attributes. The syntax as depicted hereunder was used, forming the experimental design as depicted in Figure 15.

```
;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]/
U(alt2) = b1*A + b2*B + b3*C + b4*D + b5*E
$
```

Design										
Choice situation	alt1.a	alt1.b	alt1.c	alt1.d	alt1.e	alt2.a	alt2.b	alt2.c	alt2.d	alt2.e
1	1	1	1	2	0	2	2	0	1	0
2	2	1	2	0	2	0	2	2	1	2
3	0	2	2	1	2	0	0	2	1	0
4	0	2	0	0	1	2	1	2	0	0
5	0	0	2	1	0	1	2	1	2	1
6	2	2	0	1	0	0	0	0	0	1
7	1	1	1	2	2	2	0	0	1	2
8	1	2	1	2	1	0	2	0	0	1
9	2	1	2	0	0	1	1	1	2	2
10	0	0	0	0	1	1	1	1	2	0
11	2	0	0	1	2	1	0	1	2	1
12	1	0	1	2	1	2	1	2	0	2

Figure 15: Experimental design

Using the Ngene syntax to construct choice sets, resulted in an experimental design with 12 choice sets for the respondents to complete. It is assumed that respondents find it difficult comparing more than six attributes, more than four or five products/alternatives and more than 20 choices. Therefore, 12 choices with five attributes and two alternatives is already high at the levels described above. Some feedback from respondents included that 12 choice sets are too many. However, using 12 choice sets provides more observations than for example six choice sets, as one choice set is equal to one observation. So, each respondent provides 12 observations in this experiment.

Moreover, the output from Ngene consists of a table of coded attribute levels (0,1,2), which are unclear to the respondents. Therefore, the experimental design must be recoded into a design that consists of the attribute levels as depicted above. Doing so, 12 choice sets are constructed which are presented to the respondents. This is depicted in Table 7.

Table 7: Recoding of attributes

Attribute	Codes	Attribute levels
Guaranteed minimum range	0	10 km
	1	50 km
	2	90 km
Battery degradation	0	7 discharging cycle/charging session 4 discharging cycle/charging session
	1	1 discharging cycle/charging session
	2	
Contract duration	0	1 month
	1	12 months
	2	24 months
Remuneration	0	2.00 €/10 hour
	1	6.00 €/10 hour
	2	10.00 €/10 hour
Plug in time	0	0 hour/week
	1	25 hour/week
	2	50 hour/week

Developing choice sets with Ngene is an iterative process of which each time alternatives are drawn from the full fractional design. Therefore, different choice sets are constructed in each iteration. However, these choice sets can contain dominated alternatives, meaning all attributes from option 1 are at least equal or better than all attributes from option 2. Dominance was found in the constructed choice sets. To exclude dominance in the choice sets, the design was redrawn up until no dominated alternatives were present in the choice sets. This was done manually.

In addition, to estimate the demand of the proposed V2G contracts, an opt-out alternative should be presented to the respondents, so the contracts are comparable to their current way of charging their EV. However, the risk of presenting an opt-out alternative to the respondents involves respondents choosing only the opt-out alternative and thereby not obtaining any information. Instead of the opt-out option an additional question is selected to provide respondents to option whether they are willing to use the selected contract or not. This will provide information regarding the demand of such contracts and if respondents are not willing to use one of the contracts, at least their preference regarding the choice options is obtained. An example of one of the 12 choice sets is depicted in Figure 16.

1. Welk contract heeft uw voorkeur?

Contract 1		Contract 2	
<input type="radio"/>	CONTRACT 1	<input type="radio"/>	CONTRACT 2
VERGOEDING	€6,00 per 10 uur	VERGOEDING	€10,00 per 10 uur
GEGARANDEERD BEREIK	50 km	GEGARANDEERD BEREIK	10 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	7 x per sessie
LENGTE VAN CONTRACT	24 maanden	LENGTE VAN CONTRACT	12 maanden
PLUG-IN TIJD	Geen verplichtingen	PLUG-IN TIJD	50 uur/week

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

Figure 16: Example of choice set 1

Additional questions

Besides the design of the Stated Choice Experiment, additional questions are presented to the respondents to test the hypothesis regarding EV user characteristics and the representativeness of the sample with respect to the population. With the use of multiple-choice questions insights are gathered in the respondents' gender, age, income level and education level. These questions are Mutually Exclusive, Collectively Exhaustive (MECE), which means that respondents always belong to only one of the categories presented to them.

In addition, on May 25, 2018, the new General Data Protection Regulation (GDPR) was put into force. The GDPR is an EU law on data protection and privacy for all individuals within the EU. Therefore, some additional questions that must be completed by the respondents before starting the survey. These additional questions are considered to be the Informed consent for the users. The informed consent is used to ask permission of the respondents to use their data for this thesis. These questions that account for the fact that respondents are voluntarily taking part in the survey and that they can withdraw at any time, can ask the researcher any questions and that their data will remain anonymous.

Survey design

The survey is developed in Dutch since the population consists of Dutch EV users only. The survey starts with a short introduction of the topic and objective of the study. Thereafter, the six questions regarding the informed consent should be validated by the respondent. The survey is then divided into two sections: The Stated Choice Experiment and EV user characteristics questions.

The survey is distributed online and created by using the tool Qualtrics. Qualtrics does not facilitate question randomization, therefore each respondent is faced with the exact same questionnaire. Furthermore, a progress bar is added to the survey to provide respondents with some indication of their progress. Also, a back button is added in the survey, such that respondents are able to adjust their earlier provided answers.

3.3.3 Recruitment of respondents

There are a variety of ways to find a sample of the Dutch EV users. To obtain the most reliable results, a random sample should be sought for. However, this entails that everyone in the population has the same opportunity to enter the survey. Given that there is no “sample frame” available about the population and considering its size, a random sample cannot be found. The survey was set open from December 5, 2018 up until December 20, 2018. Due to the fact that no data is available about the population systematic and stratified sampling is also not possible. Therefore, the survey is distributed in three different ways, aiming to obtain different respondents.

First, a selected approach in finding respondents is used. To find a sample of Dutch EV users, the questionnaire was sent to members of the VER (Vereniging Elektrisch Rijders) which has a user base of more than 1100 EV users. This is done via an online link posted on the Facebook page of the VER. However, distributing the survey to the Facebook page of the VER may lead to biased results as the members of the Facebook page are EV enthusiastic and may therefore be more positive regarding V2G than the “average” EV user.

Second, employers of Accenture Netherlands who drive an EV have been asked to fill in the questionnaire. There are 108 EV users from Accenture in the Netherlands. However, distributing the survey to Accenture employees may influence the results as well. As Accenture employees work at clients’ offices’, the employees travel a lot. This may bias the results as they require more electricity in their battery compared to the “average” EV user. Also, Accenture employees are expected to have a higher income compared to the “average” EV user, making it likely that they are less sensitive to price incentives.

Third, the snowballing method is used to distribute the survey. Here, family members are asked to distribute the survey to EV users in the Netherlands. The receivers of the survey are also asked to distribute the survey to EV users they know and so forth. The snowballing method is used in the area of Rotterdam, so this may influence the results as well as these respondents most likely live in the Randstad, living close to Charging Points.

When interpreting the results, caution should be given to above mentioned potential bias in the results.

3.4 Measures

As described above, the survey consists of two parts: A Stated Choice Experiment and some additional questions regarding the EV user characteristics. The Stated Choice Experiment is used to test the

hypothesis considering the attributes as defined in Figure 17. This will be done using the Multinomial Logit Model (MNL), which is a widely applied method for eliciting consumer preferences (Louviere et al, 2010). The method is mostly used in the transport domain, but also finds its applications in Health, Marketing, Political Sciences and Economics (Train, 2009). The main advantage to use this method is the user friendliness of the method. The easiness of use of this RUM-MNL model stimulates the popularity of the method. The method is widely applied in research and practice resulting in solid foundation.

The additional questions serve as input for testing the other hypotheses regarding EV user characteristics. Here, interaction effects will be used to measure the effects of EV user characteristics on the contract elements.

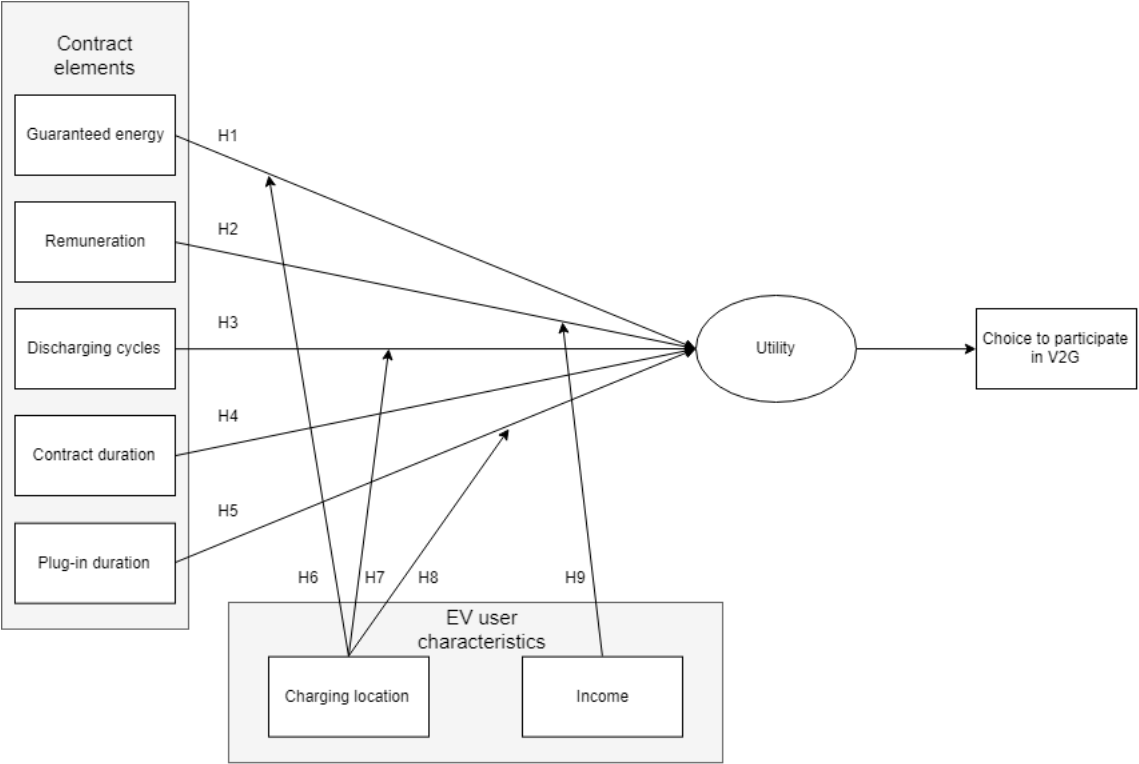


Figure 17: Adjusted conceptual model

Contract elements

Testing the influence of V2G contract elements on the perceived utility by EV users will be done by estimating a MNL model. Each respondent is faced with 12 choice sets, in which the respondent has to choose from two contracting alternatives. Here, the respondents compare the contracts on the elements it possesses and chooses the option that creates the most utility for the respondent. Hence, each choice counts as one observation. After choosing the contract, the respondent is faced with the question whether they are willing to use their chosen option over their usual charging strategy. This will provide insights in the demand for the V2G contract, as their preference is shown, and an indication is given whether they are willing to use the V2G option over their usual charging strategy.

Random Utility Maximization Model

Random Utility Maximization models (RUM-models) are based on the assumption that decision makers perceive some kind of value (utility) to the alternatives in a choice set and then choose the alternatives with the highest utility (Lancaster, 1966; Train, 2009).

Utility exists of observed utility and unobserved utility, which mean systematic utility and an error term respectively. The observed utility is measured by the researcher, given the choice set that is constructed and the attributes that are incorporated in the choice set. However, there are also other factors that are not measured by the researcher, which might have an influence on the utility. The RUM models assume that decision makers are perfect rationalizers when making choices. However, the analyst does not have all the information of the decision-making process of the respondent. Since the analyst determines which attributes are incorporated in the choice set, some of the attributes that are important for the decision maker can be missing. Also, non-observed characteristics of the decision maker or measurement errors are not incorporated in the experiment. Therefore, an error term is added to the systematic utility, to consider this lack of information given by the experiment. So, the certain part of the utility is measured by the experiment and the uncertain part of utility is captured by the error term. In other words, even if the systematic utility is the highest for an alternative, another alternative can still be chosen. So, only probabilities can be predicted of an alternative to be chosen. The higher the utility, the higher the choice probability for a certain alternative.

The systematic utility function for alternative i is depicted in the following formula:

$$V_i = \sum_m \beta_m X_{im}$$

The total utility associated with alternative i then adds an error term:

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

An alternative is then chosen if:

$$U_i > U_j \text{ and } i \neq j$$

Where: i represents an alternative (contract X)

m represents an attribute (contract elements)

β_m represents the tastes of an attribute (these are going to be estimated by the model)

X_{im} is the value of an attribute (amount of remuneration for example)

ε represents the error term (this is the unobserved utility)

j represents an alternative (contract Y)

For each alternative that is present in this study, the utility can be computed by multiplying the decision weights; the estimated parameters B_m with their corresponding attribute levels that belongs to the corresponding alternative (X_{im}). For each alternative the utility can be determined combining the tastes of an attribute B_m with the corresponding attribute-values. Then, choices can be derived by selecting the alternative with the highest utility.

Multinomial Logit Model

In this thesis, three alternatives are being compared by the respondents in each sample question.

The reason for the models' popularity is the closed form formula which can be used to obtain choice probabilities of decision makers, making the model easy to use (Train, 2009). The formula of the RUM-MNL has the following form:

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

Where:

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

EV User characteristics

As mentioned in the conceptual model, it is expected that certain type of EV users have different preferences regarding V2G. Therefore, it is necessary to measure if EV users' characteristics that have an influence on the sensitivity regarding certain contract elements. These effects can only be measured if information regarding these different user types is obtained. The groups that will be measured are: income and charging location. Income is measured by providing four categories to choose from to the respondents, resulting in four categories of income. The charging location is measured by asking respondents to fill in a percentage of moment of charging for each location that exists. The different EV user types are then clustered into groups. These characteristics are then used as interaction variables in the model.

3.5 Data preparation

The survey is distributed among the respondents via the tool "Qualtrics". Since the data that will be exported from Qualtrics is constructed such that each row represents a respondent, data preparation is necessary. The data should be constructed such that each choice is represented by a row, meaning 12 rows per respondent. The responses, other than the choice sets, remain the same for all 12 rows. This data preparation is required for the use of Biogeme, which is a software tool that is used for the estimation of logit models and choice models in particular. This requires adoptions from the output file of Qualtrics.

In addition, the variables that are gathered via Qualtrics need to be recoded. The questions regarding the contracts are coded into "1", "2" and "3" for contract 1, 2 and "none of the contracts option" respectively.

To measure the EV user characteristics, data regarding income and charging location has to be recoded such that the two variables can be incorporated in the utility functions. Here, dummy coding is used. Dummy coding is a pre-specified coding scheme to measure differences between variables. This is shown in Table 8.

Table 8: Dummy coding

Attributes & level	Codes		Indicator	Coefficients
	V1	V2		
Income	High	1 -	Ink	B_ink
	Low	0 -	-	-
Charging location	Home	1 0	Home	B_home
	Work	0 1	Work	B_work
	Other	0 0	-	-

To measure non-linearity effects of contract elements, the contract elements are coded in a similar way. However, the contract elements do not have a zero alternative, thus effect coding is used. An example is given of the contract variable remuneration, see Table 9. This is done for every contract element.

Table 9: Effect coding

Attributes & level	Codes		Indicator	Coefficients
	V1	V2		
Remuneration	10	1 0	R1d	B_RE1
	6	0 1	R2d	B_RE2
	2	-1 -1	-R1d-R2d	-B_RE1-B_RE2

Other data preparation consists of withdrawing outliers of the dataset. It is not expected that the choice experiment nor the additional questions will generate outliers, with the exception of the question regarding the charging duration. Here, respondents are expected to fill in a realistic number of hours charging time, however, due to typos or unserious behaviour, respondents may fill in an answer that is not realistic. As mentioned, for the other questions no outliers are expected as these are all multiple choices (MECE) and requires no preparation.

3.6 Conclusion

The target group of the experiment are the Dutch EV users and approximately consists of 120.000 EV users. No data is available on the user characteristics of the Dutch EV users, so the sample cannot be tested for representativeness. To give an indication, a comparison is made with a study conducted in the five Nordic countries. To obtain data, a stated choice experiment is constructed. Here, the contract elements are defined with their corresponding levels. As both the alternatives contain the same five contract elements, no alternative specific constant was necessary in the development of choice sets. Based on the (dis-) advantages of experimental designs, an orthogonal design is chosen as most suitable. This resulted in a choice experiment that consists of 12 choice sets for the respondent to compare. The survey is sent to the VER, employees of Accenture and via snowballing. To analyse the data, a MNL model will be estimated and expected demand will be calculated based on the binary logit model.

4. Results

Structure

This chapter is part of phase 2 and focuses on the data analysis. Hereby an answer will be provided to the second sub question:

What is the expected usage of V2G by current EV users under different V2G contracts?

This question will be answered by providing an answer to the following questions:

- a) What contract elements have the most impact on the Dutch EV users? → section 4.3
- b) What are the costs of discomfort created by making use of V2G? → section 4.3
- c) How do preferences differ among the Dutch EV users? → section 4.4

In section 4.1 descriptive statistics regarding the experiment will be discussed, including the representativeness of the sample. This is followed by the estimated results of the first MNL model in section 2. Thereafter, in section 4.3 calculations regarding the estimated results will provide insights in the relative importance and costs of certain contract elements. In section 4.4, the results of including EV users' characteristics in a MNL model will be discussed. Finally, in section 4.5 the chapter concludes by providing an answer to the sub question.

4.1 Descriptive results

Response & attrition

The total amount of received responses is 144. After removing incomplete responses, the number of completed responses is 96. An interesting observation here is the fact that the first question is completed by all 144 respondents while the last question is completed by only 96 respondents. A small drop in responses is observed during the General Data Protection Regulation (GDPR) questions at the beginning of the survey (144 to 128). Respondents were not able to continue when not agreeing to one of the six GDPR questions. In addition, a second large drop is observed after the questions regarding EV ownership and the short videoclip of the explanation of the experiment (117 to 102). Besides the positive feedback on the videoclip, two respondents mentioned that the videoclip was not initially shown. It is possible that this occurred to more respondents, resulting in abandoning the survey. Another cause for the large drop of respondents might be the length of the survey combined with the required focus of the respondents. Two choices with five contract elements that are completely new for respondents, might be too much.

Representativeness

In chapter 3 the relevant socio-demographic variables to evaluate the representativeness of the sample are presented. As previously mentioned, no conclusions can be drawn from the level of representativeness of the sample, as no data is available regarding Dutch EV users socio-demographic characteristics. However, the socio-demographic characteristics of the sample are compared to a study conducted in the Nordic region (Sovacool et al., 2018). This study is further denoted as the Nordic study. The Nordic study has a higher response, 367 respondents compared to 96 in this sample, and is more likely to be representative for the population. The comparison is presented in Table 10.

An interesting observation regarding the sample that is obtained, is the difference between the amount of male EV users and female EV users, which is 91% to 9% respectively. In comparison with the Nordic study (Sovacool et al., 2018), high male participation is observed as well (67% to 33%

respectively) but not as extensive as in this sample. Comparing the distribution of income levels in the sample, shows that both samples are quite similar. High income levels are present in both samples. This is in line with the estimations of the Rijksdienst Voor Ondernemend Nederland (RVO, 2018). In addition, most respondents of this survey are between the 45 and 54 years old while the age in the Nordic study is more evenly distributed. Three out of six age categories have a difference larger than 15%. Comparing the education level of the respondents, a similar distribution is observed containing relatively small differences.

Table 10: Representativeness compared to Sovacool et al. (2018)

Socio-demographic characteristics		This Survey		Nordic countries	Difference
		Frequency	Percentage	Percentage	
Gender	Male	90	91%	67%	24%
	Female	9	9%	33%	-24%
Income	<20.000	4	4%	10%	-6%
	20.000-35.000	15	16%	16%	-1%
	35.000-70.000	40	42%	44%	-2%
	>70.000	37	39%	29%	9%
Age	<25	2	2%	20%	-18%
	25-34	9	9%	25%	-16%
	35-44	21	22%	24%	-2%
	45-54	36	38%	18%	19%
	55-64	17	18%	8%	10%
	>65	11	11%	5%	7%
Education	No education	0	0%	0%	0%
	VMBO/MAVO	2	2%	5%	-3%
	MBO	13	14%	6%	8%
	HAVO/VWO	6	6%	6%	1%
	HBO	37	39%	31%	7%
	WO	38	40%	52%	-12%

The Nordic study did not provide any data regarding the ownership of the EV. The distribution of private/lease/other ownership is depicted in Figure 18.

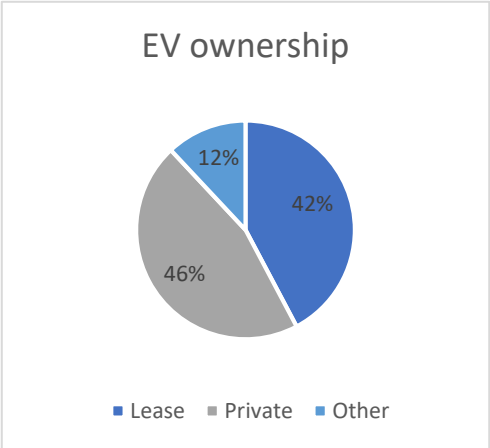


Figure 18: EV ownership

It is observed that the share of private versus lease is somewhat equally distributed. In comparison with the current division of private and leased EV's in the Netherlands, only 20% of the Dutch EV users owns an EV privately (RAI, 2018).

The obtained sample is not entirely comparable with the Nordic countries and most likely not for the Netherlands as well. No conclusions can be drawn about the representativeness of this sample. However, it is not likely that this sample is representative due to some extreme values (91% male, 38% between 44-55) and differences compared with the Nordic study. As mentioned in chapter 3, the survey was distributed in three ways that can explain the non-representativeness of the data. Therefore, conclusions regarding the results of this study should be taken with caution and cannot be generalized to the population as defined in chapter 3.

Charging behaviour

In the sample, home charging occurs more often and provides longer connection times to the grid see Figure 19. There is also a share of respondents that charge their EV at work. However, this is less frequent and connection times are shorter. Other locational charging usually takes no longer than one hour, as this mostly applies to Fastned charging stations along the highways in the Netherlands.

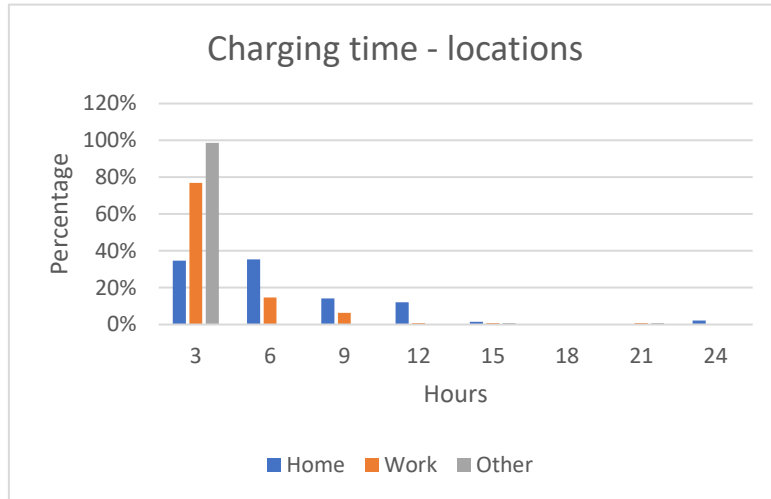


Figure 19: Charging location

Choice sets

In each choice set, respondents had to make a choice between two contracts, each containing variable contract elements followed by a question whether they would choose this option in real life (see chapter 3).

In Figure 20, the distributions of the responses regarding the 12 choices sets are presented. Here the orange and blue parts refer to the choice respondents made regarding their preferred contract and the yellow and grey bars represent whether the respondents would actually choose the corresponding contract over their conventional charging method. One choice set has a dominating response, in choice set 6 contract 1 is dominating contract 2. The other choices are all below 90%. In addition, none of the choices are evenly split (50%-50%) although choice set 8 and 9 came close.

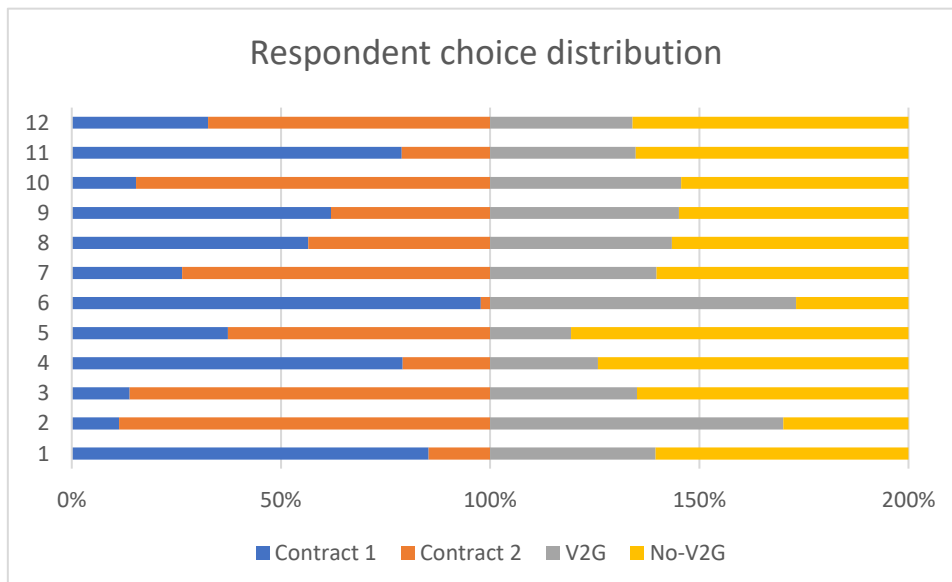


Figure 20: Choice distribution

In Figure 21, the data regarding contract preferences and no V2G are combined. Interesting to note is that only in choice set 2 and choice set 6 contracts are chosen with a higher percentage (70% and 63% respectively) than the no-V2G option. This is most likely due to the fact that the highest range of remuneration and highest guaranteed energy is provided in these contracts. Contrary to this, choice sets 4 and 5 shows high percentages (>74%) of no V2G option. These contracts both have low guaranteed energy and low remuneration structures which most likely adds to these results. The choice model will quantify this claim.

In addition, the no-V2G option is highly preferred over V2G charging. There are eight contracts with a percentage higher than 25%. This shows that there is some interest in certain V2G contracts.

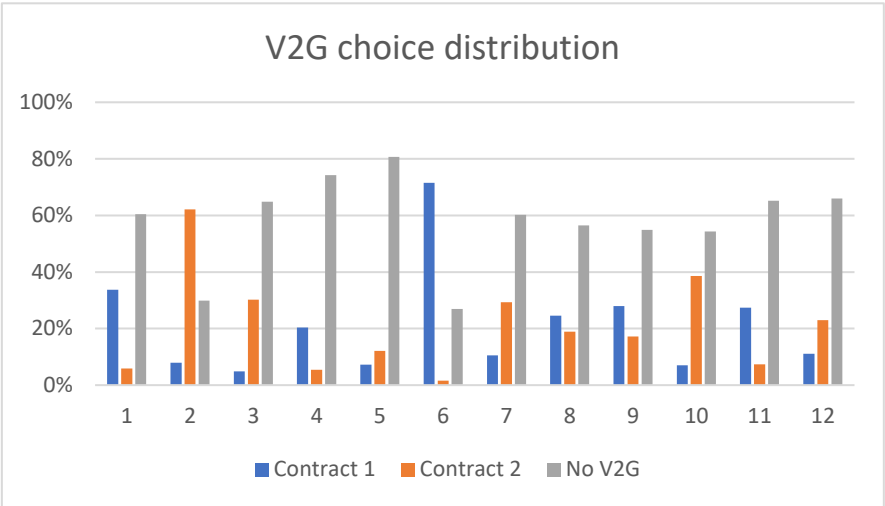


Figure 21: Combined choice distribution

4.2 Estimation of results

In Table 11, the results of the estimation of the parameters are presented, in appendix 5 the full estimations are provided. The survey was constructed such that respondents had to make a choice between two contracts, followed by a question whether they would choose this over their conventional way of charging. Therefore, two models are estimated:

- 1) A model excluding data regarding the extra question providing insights in the preferences regarding the two contracts (model without V2G constant)
- 2) A model including data regarding the extra question which provides insights in the demand for V2G as a constant for V2G is estimated (model with V2G constant)

The number of parameters that are estimated for the MNL model are based upon 1152 observations, resulting from 96 responses that were gathered from the Stated Choice Experiment. The utility functions for the MNL model are depicted in appendix 5, here one example is given:

$$V2 = BETA_ASC + GE2 * BETA_GE + RE2 * BETA_RE + DI2 * BETA_DI + CD2 * BETA_CD + PI2 * BETA_PI$$

After estimation, both MNL models did converge. The null-log likelihood of both models is -1265.6 and the final-log likelihood is -1048.3 for the model excluding V2G constant and -1030.8 for the model including a V2G constant. This results in a McFadden’s rho square (ρ^2) of 0.164 and 0.185

respectively indicating that the model fits the data reasonable¹. The ρ^2 (i.e. $1 - \frac{LL(\hat{\beta})}{LL(0)}$) provides an indication how good the model fits the data better than a model without estimated parameters, or with parameters set to zero. Comparing both models, no major changes are observed in terms of parameter values and robust t-values. The model fit of the model including a V2G constant is improved, which is expected when adding an extra parameter to the model. However, as the model with V2G constant provides opportunities for a more in-depth analysis, this model is further used.

In addition, to test for non-linearity for remuneration and discharging cycles, the model with V2G constant requires extension.

After extending the model to account for non-linearity the utility function will take the following form:

$$V1 = \text{BETA_ASC} + \text{GE1} * \text{BETA_GE} + \text{R1d} * \text{BETA_RE1} + \text{R2d} * \text{BETA_RE2} + \text{D1d} * \text{BETA_DI1} + \text{D2d} * \text{BETA_DI2} + \text{CD1} * \text{BETA_CD} + \text{PI1} * \text{BETA_PI}$$

After estimating the extended model, the MNL model did converge. The null-log likelihood remains -1265.6 and the final-log likelihood is improved to -1017.7, resulting in an improved ρ^2 of 0.196 indicating that the model fits the data reasonably good. All model estimations are shown in Table 11.

Table 11: MNL estimations

Parameter	MNL model without V2G constant				MNL model with V2G constant				MNL non-linearity					
	Value	Robust std error	Robust t-value	P-value	Parameter	Value	Robust std error	Robust t-value	P-value	Parameter	Value	Robust std error	Robust t-value	P-value
Guaranteed energy	0.0228	0.00184	12.43	0.00	Guaranteed energy	0.0182	0.00177	10.26	0.00	Guaranteed energy	0.0159	0.00217	7.34	0.00
Remuneration	0.128	0.0194	6.60	0.00	Remuneration	0.146	0.0193	7.57	0.00	Remuneration1	1.14	0.147	7.75	0.00
										Remuneration2	0.654	0.229	2.86	0.00
Discharging cycles	-0.0754	0.0182	-4.15	0.00	Discharging cycles	-0.0932	0.0222	-4.20	0.00	Discharging cycles 1	-0.421	0.166	-2.54	0.01
										Discharging cycles 2	-1.48	0.355	-4.18	0.00
Contract duration	0.00376	0.00617	0.61	0.54	Contract duration	-0.00703	0.00542	-1.30	0.20	Contract duration	0.0489	0.0155	3.15	0.00
Plug-in duration	0.00730	0.00292	2.50	0.01	Plug-in duration	0.00443	0.00262	-1.69	0.09	Plug-in duration	0.00483	0.00254	-1.90	0.06
V2G constant	-				V2G constant	-2.29	0.245	-9.35	0.00	V2G constant	-2.33	0.237	-9.84	0.00
Number of observations	1152					1152					1152			
Parameters	5					6					8			
Final Log-Likelihood	-1048.3					-1030.9					-1017.7			
Rho-square	0.164					0.185					0.196			

¹Indication of model fit
 $\rho^2 < 0.1$ indicates that the model fits the data quite limited
 $0.1 < \rho^2 < 0.3$ indicates that the model fits the data reasonable
 $0.2 < \rho^2 < 0.5$ indicates that the model fits the data reasonably good
 $\rho^2 > 0.5$ indicates a good model fit

As shown in Table 11, the MNL results provide information on the parameter value, standard error (SE), t-test and significance value. The parameter value indicates the direction and magnitude of the utility contribution of a contract element to an alternative.

- The magnitude is the value of a contract element multiplied by the value of its parameter.
- The standard error provides information on the inaccuracy of the parameter estimation of the model. The standard errors are relatively low for the significant (0.05 level) parameters, meaning the model can provide reliable results for the estimation of the mean values of the contract elements.
- The t-test and significance value are used to determine whether a parameter is significant. It is common to set the alpha at 5%. Since the hypothesis are constructed with a expected direction, an alpha of 10% can be used which results in a 5% error margin for the expected direction.

Comparing the two models on model fit is done by the Likelihood Ratio Test (LRT). The LRT is calculated at 26.4, the model with non-linear parameters is performing significantly better (at 0.05 level). The model that considers non-linearity will be further discussed in this chapter.

In chapter 3, hypothesis regarding the contract elements are constructed. The hypotheses of the contract elements are set regarding the effect of the element on the perceived utility. To start off, 7/8 parameters are found to be significant (at $p=0.05$) and are of the expected sign, except for contract duration:

- 1) Guaranteed energy (positive)
- 2) Remuneration 1 (positive)
- 3) Remuneration 2 (positive)
- 4) Discharging cycles 2 (negative)
- 5) Discharging cycles 2 (negative)
- 6) Contract duration (positive, not expected)
- 7) V2G constant (negative)

This entails that four contract elements are correctly hypothesized, as shown in Table 12.

Table 12: Contract element hypotheses

Hypotheses	Sign	H0 is rejected
H1: guaranteed energy has a positive effect on the perceived utility	Positive	Yes***
H2: remuneration has a positive effect on the perceived utility	Positive	Yes***
H3: battery degradation has a negative effect on the perceived utility	Negative	Yes***
H4: contract duration has a negative effect on the perceived utility	Positive	No***
H5: plug-in duration has a negative effect on the perceived utility	Negative	Yes *

Significance *=0.1 level, **=0.05 level, ***=0.01 level

The null-hypothesis for contract duration is rejected, but the hypothesis that contract duration has a negative influence on perceived utility cannot be accepted. The sign of contract duration implies that the longer a contract, the higher the perceived utility. The estimation of the results are shown in Figure 22.

In addition to the contract elements, a constant for V2G is estimated (-2.33). The constant provides information on how the utility of V2G differs from conventional charging (immediate start of charging when plugged into the grid). The constant for V2G is negative, significant and quite large. This entails that the respondents of the sample do like conventional charging over V2G, but the right mix of contract elements can persuade EV users into V2G. In essence, the utility function of V2G should exceed the base utility of conventional charging. The effects of the parameters on the utility is described in the next section.

Considering the significant parameters results in the following utility function for V2G contracts:

$$U(V2G) = -2.33 + 0.0182 * GE + 1.14 * RE1 + 0.654 * RE2 + 0.0489 * CD - 0.00489 * PI - 0.421 * DI1 - 1.48 * DI2$$

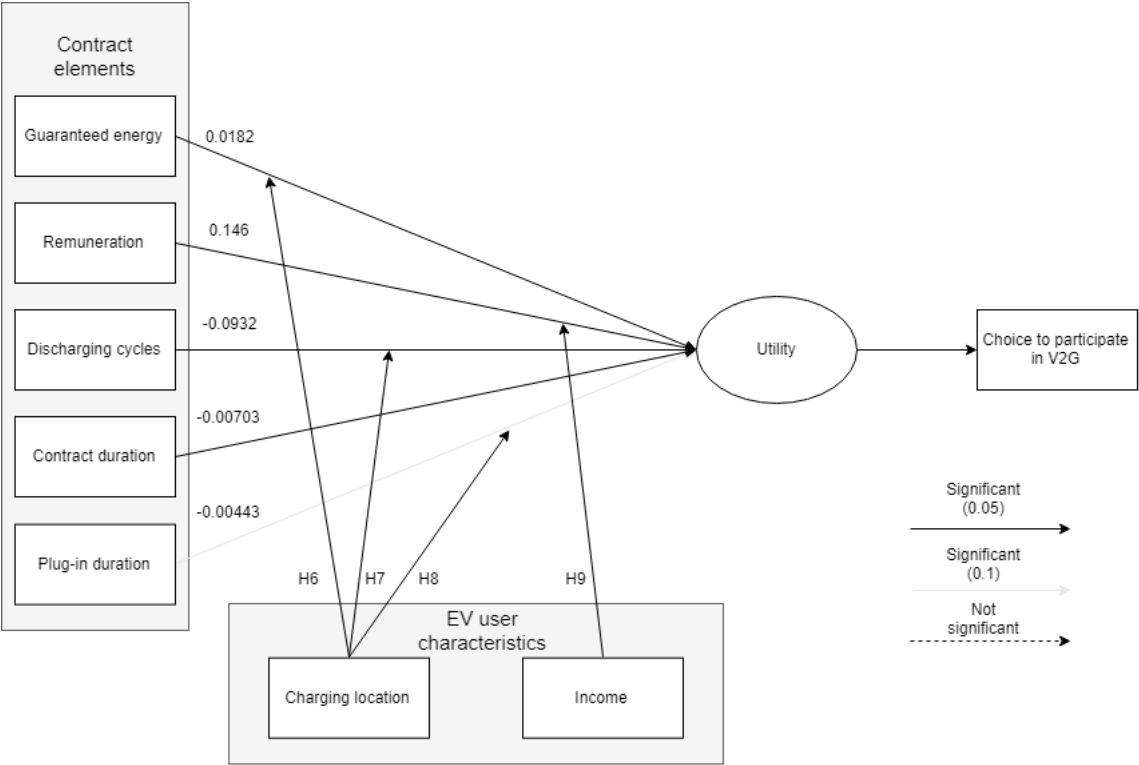


Figure 22: Conceptual model with contract element estimations

4.3 Interpretation of the contract elements

As can be seen in Table 12 and Figure 22, the significant parameters are in line with expectation regarding their sign. Guaranteed energy and remuneration have positive signs, meaning that the respondents value these attributes positively. The discharging cycles, plug-in duration and constant for V2G are attributes that are negatively valued by the respondents, therefore their sign is negative. The sign of contract duration is positive, meaning that longer contract durations are valued more by respondents.

Based on the utility function provided in the end of section 4.2, the curves of the utility functions can be determined for every contract element and calculations can be done. Table 13 shows the utility

contributions combined with the relative importance per contract element and the willingness to pay/get (WtP).

Table 13: Willingness to pay/get

Contract elements	Utility range	Utility change per unit	WtP per unit	Price per utility	Relative importance	Value difference	Price range
Guaranteed energy	1,272	0,0159	€ 0,08	€ 4,92	24%	80	€ 6,26
Remuneration	1,626	0,20325	€ 1,00	€ 4,92	31%	8	€ 8,00
Discharging cycles	1,059	0,1765	€ 0,87	€ 4,92	20%	6	€ 5,21
Contract duration	1,1247	0,0489	€ 0,24	€ 4,92	21%	23	€ 5,53
Plug-in duration	0,2415	0,00483	€ 0,02	€ 4,92	5%	50	€ 1,19

In the figures below, the alpha is set at 10% and the effects of the contract elements that have a p-value below 0.1 are graphically depicted. The figures show the change of utility per unit increase.

Guaranteed energy

Guaranteed energy has indeed a positive effect on the perceived utility. Meaning that the respondents' value higher amount of guaranteed energy in their EV during V2G. Given the sample, guaranteed energy has a relative importance of 24% considering the four other significant attributes. Thereby guaranteed energy has quite a large contribution to the utility associated with a V2G programs. Per km decrease of guaranteed energy the utility decreases and for one km increase in guaranteed energy utility increases. For each unit of decrease, the respondents are willing to get €0,08/km. The utility contribution of guaranteed energy is shown in Figure 23.

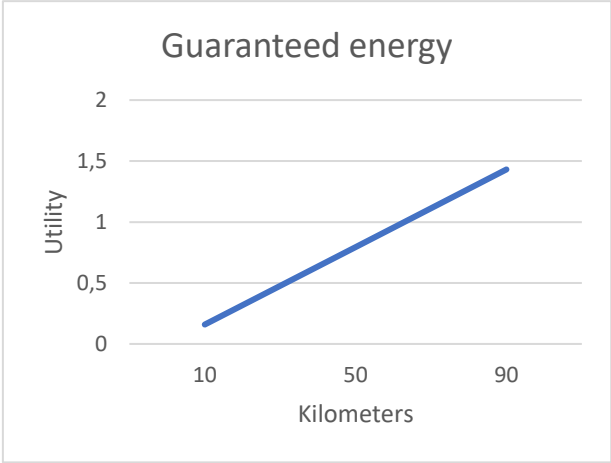


Figure 23: Utility contribution guaranteed energy

Remuneration

Remuneration has indeed a positive effect on the perceived utility. Higher remuneration increases the utility for the respondents. Meaning that higher remuneration is valued higher than lower remuneration by the respondents. In addition, remuneration has a large contribution to the utility associated with V2G programs, as the relative importance of this attribute equals 31%. In addition, this contract elements shows non-linear effects as the parameter estimates of RE1 and RE2 both have a value of 0.00. This means that respondents gain more utility for remuneration under €6,00

and gain less utility between €6,00 and €10,00 remuneration. The utility contribution for remuneration is shown in Figure 24.

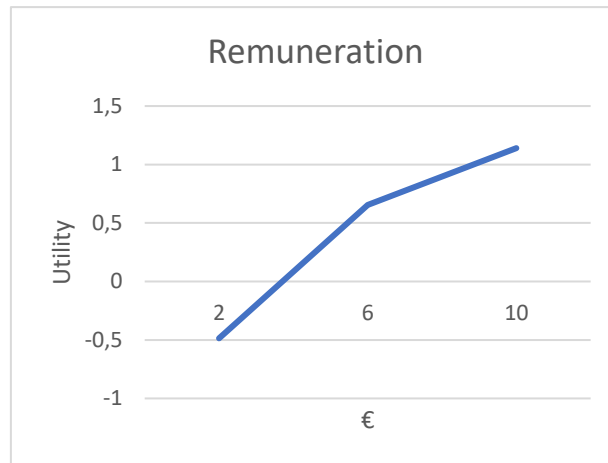


Figure 24: Utility contribution remuneration

Discharging cycles

Discharging cycles has indeed a negative effect on the perceived utility. The higher the number of discharging cycles, the lower the perceived utility for respondents. The amount of discharging cycles has quite a large contribution to the utility contribution, as the relative importance equals 20%. Per extra discharging cycle, respondents are willing to get €0,87 per V2G session. In addition, this contract elements shows non-linear effects as well. The p-values of DI1 and DI2 are 0.01 and 0.00 respectively. It shows that respondents utility decreases when discharging cycles are increased to 4. More than 4 discharging cycles will cause the utility to increase.

As it was explained to the respondents that 7 discharging cycles had the most impact on the lifetime of the battery, the obtained effect was not expected. If non-linearity was present, it was expected the perceived utility would decrease or stagnate with increasing discharging cycles. A possible explanation for this behaviour might be the fact that interpretation of the effects was left to the respondent to decide. This may explain that some EV users value the effects of discharging cycles on the battery more heavily than others. It might be the case, similar to literature, that there are two camps regarding battery degradation; believers and non-believers. However, when using the utility contributions of discharging cycles in the formula to calculate choice probabilities, the choice probability for more discharging cycles is higher than for less discharging cycles, which is not logical. Caution should be given to this fact when calculating demand for V2G. The utility contribution of discharging cycles is shown in Figure 25.

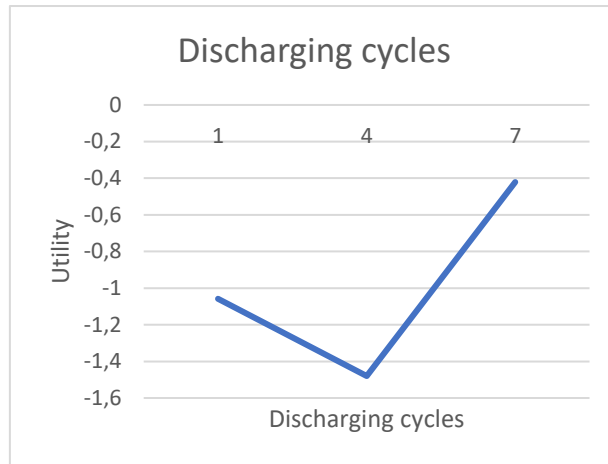


Figure 25: Utility contribution discharging cycles

Contract duration

Contract duration does significantly differ from zero, however not in the expected direction. The longer a contract, the more perceived utility respondents gain. The opposite was expected. The contract duration has a value of €0,24/month contract duration and has a contribution of 21% on the perceived utility. The utility contribution of contract duration is shown in Figure 26. A possible explanation for this observed behaviour might be that there are currently no competitive V2G contracts on the market. Usually, a benefit of a short-term contract is the fact that after the contract exceeds, a new contract can be chosen which might provide more value to the customer (Fudenberg et al, 1990). Since no alternative options exists yet, it might be the case that respondents are willing to commit for a longer time period. Combined with the fact that EV's do have a longer lifetime than two years, it is assumable that EV users are willing to commit for longer time periods to V2G programs as well. However, when alternative parties are offering contracts to the EV users, the original hypothesis may hold. Therefore, caution should be given to the calculations regarding the choice probabilities based on the utility contribution of contract duration. Based on this data, longer contract durations result in higher expected demand for V2G which the complete opposite might hold in reality.



Figure 26: Utility contribution contract duration

Plug-in duration

Plug-in duration is only present in volume-based contracts and has indeed a negative effect on the perceived utility of the respondents. The perceived utility of the respondents decreases when the plug-in duration increases. However, the contribution of this attribute to the total utility function equals 5%, meaning that the relative importance is small. The utility contribution for plug-in duration is shown in Figure 27.

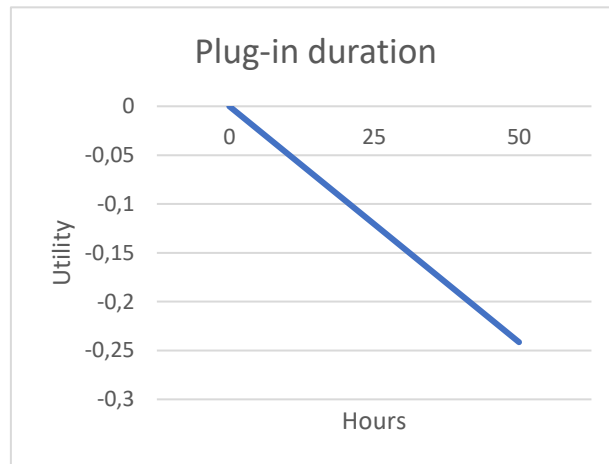


Figure 27: Utility contribution plug-in duration

V2G contract demand scenario's

After examining the impacts of the five contract elements on the perceived utility, these contract elements can be used to estimate the expected demand for V2G. To do so, the five contract elements are combined into a contract. A distinction is made between price-based contracts and volume-based contracts. Here, the utility of a contract is compared with the utility of the conventional way of charging. Based on the utility functions, the probabilities of respondents choosing a certain contract can be calculated, using the binary logit model. When keeping all contract elements constant and varying one of these elements, the individual effects of a contract element can be calculated. To do so, different scenarios are developed. These are presented hereunder. Due to the nature of the model and some unexpected results these observations should be taken with caution. The estimated probabilities of the demand for V2G are not highly reliable. Based on the retrieved data and the developed model, best estimates are given regarding the demand for V2G under different circumstances.

To determine the effects of certain contract elements on the demand for V2G a realistic contract elements are used for a "base" scenario. First, the demand for a base scenario is calculated. Then, three contract elements with a high relative importance will be varied between high, average and low levels to calculate the differences in expected demand.

The base scenario are constructed based on the first project that is implementing V2G to the market, OVO energy. Here, remuneration is set at €2,00/10 hour plug-in duration, guaranteed energy at 90 km, contract duration at 12 months, plug-in duration at 50 hours per week and discharging cycles at 4 per session. This is shown in Figure 28.

PRICE		VOLUME	
VERGOEDING	€2,00 per 10 uur	VERGOEDING	€2,00 per 10 uur
GEGARANDEERD BEREIK	90 km	GEGARANDEERD BEREIK	90 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	4 x per sessie
LENGTE VAN CONTRACT	12 maanden	LENGTE VAN CONTRACT	12 maanden
PLUG-IN TIJD	Geen verplichtingen	PLUG-IN TIJD	50 uur/week

Figure 28: Realistic contracts

The expected demand of a price contract is 28%, the expected demand for a volume-based contract is 22%. The difference of 6% is small and logical, as the relative importance of plug-in duration to the perceived utility is small as well. The estimated probabilities show that No-V2G option is evenly distributed with the V2G services. It is expected that, when offering price- and volume-based contracts, 50% of the EV users would appeal to a V2G contract based on the obtained sample. This is shown in Figure 29. However, it is assumed that more females are present in the population than present in the obtained sample. As shown in Caperello (2014), females are more reluctant regarding “range anxiety” than male users when driving EV’s. Based on the relative importance of guaranteed energy it may be expected that demand for V2G in the true population is likely to decrease. In contradiction, the sample contains relative “old” EV users as compared to the Nordic studies and most likely the population. As mentioned in Geske & Schumann (2018), it may be expected that young generations EV users show more affinity with V2G as they are more environmentally aware. This may have a positive effect on the demand for V2G.

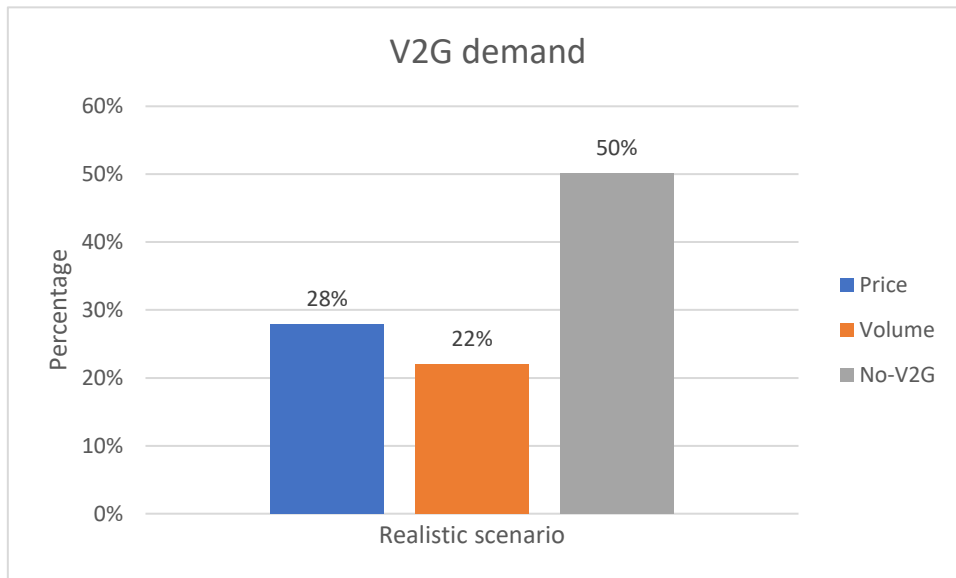


Figure 29: V2G realistic scenario

To put the base scenario into perspective, all contract elements can be set at “worst” case scenario and a “best” case scenario. These estimated probabilities show that demand for V2G is spread across a large range: 76% to 3% expected demand for providing no V2G. However, this is expected as in the “best” case scenario unrealistic values are taken in consideration, i.e. €10,00 remuneration/10 hour plug-in time. As compared base scenario, €2,00 per 10 hour plug-in duration is used. This is shown in Figure 30.

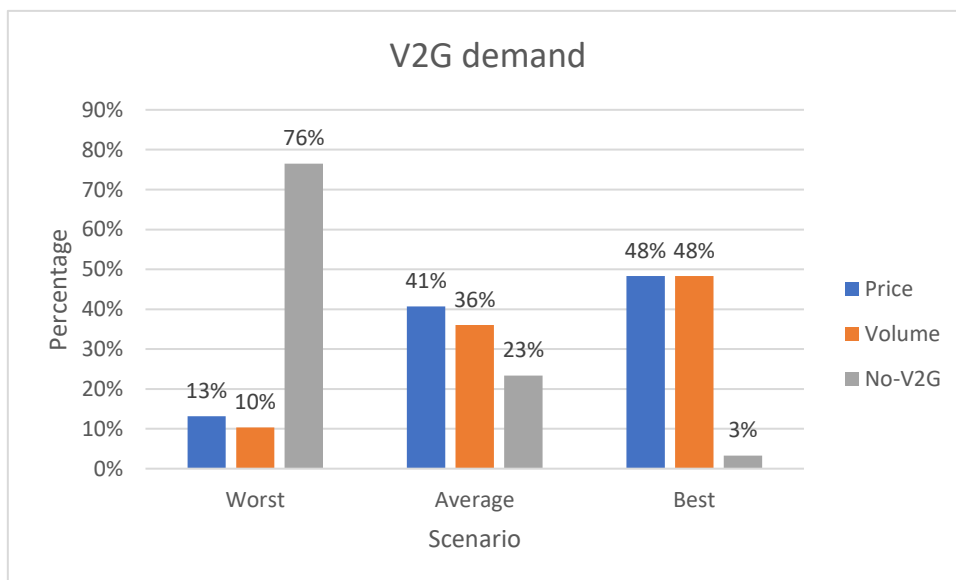


Figure 30: V2G demand scenario's

To determine the effects of a single contract element, all contract elements are held constant at the base scenario except for the contract element of interest. First, the contract element with the largest share in the perceived utility is varied, remuneration. This contract element is varied between €2,00-10,00 per 10 hour plug-in duration.

When providing €2,00 remuneration, it can be expected that 49% of the EV users would choose the option of providing no V2G services. This is comparable with the base scenario. Increasing the remuneration to €6,00, it can be expected that 23% of the EV users would choose the option of providing no V2G services. This increase in demand for V2G is expected due to the large contribution to the utility function by remuneration. In addition, when the remuneration is increased to €10,00, not such large increase in demand for V2G is expected; now 16% of the EV users are expected to not choose V2G options. Again, this is in line with the expectations as remuneration has a non-linear effect on the perceived utility. This is shown in Figure 31. For the target group, it is assumed that more females and younger EV users are present. It is not expected that females perceive remuneration different compared to males. Young EV users however, might value remuneration more than older EV users. This may result in less demand for V2G at low remuneration values but higher demand in high remuneration levels.

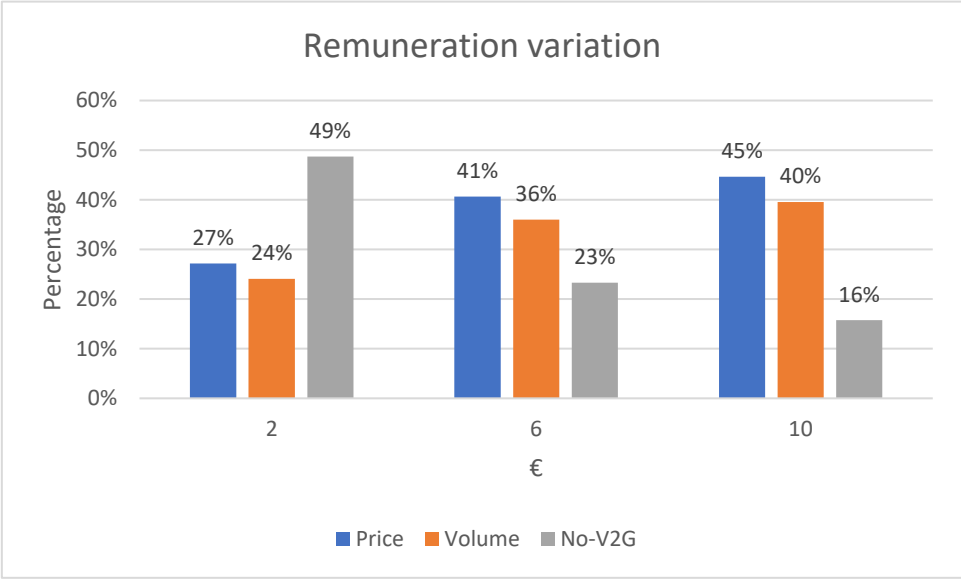


Figure 31: V2G demand remuneration

Second, the contract element with the second most share of perceived utility is calculated. All other contract elements are kept at the “base” scenario and guaranteed energy varies between 10-90 km. In this figure, a large distribution range is observed. In addition, it is observed that the expected demand for V2G increases rapidly when guaranteed energy is increased. Again, this is in line with expectations. Interesting to note is that considerable V2G demand is achieved with a remuneration of €2,00 per 10 hour. This is shown in Figure 32. Reflecting on the target group, the inclusion of more females and the fact that female EV users are more affected by “range anxiety” may result in even larger differences between low guaranteed energy V2G demand and high guaranteed energy V2G demand for the target group. It is assumed that the impact of guaranteed energy will play a larger role in the decision-making process of the target group to participate in V2G programs.

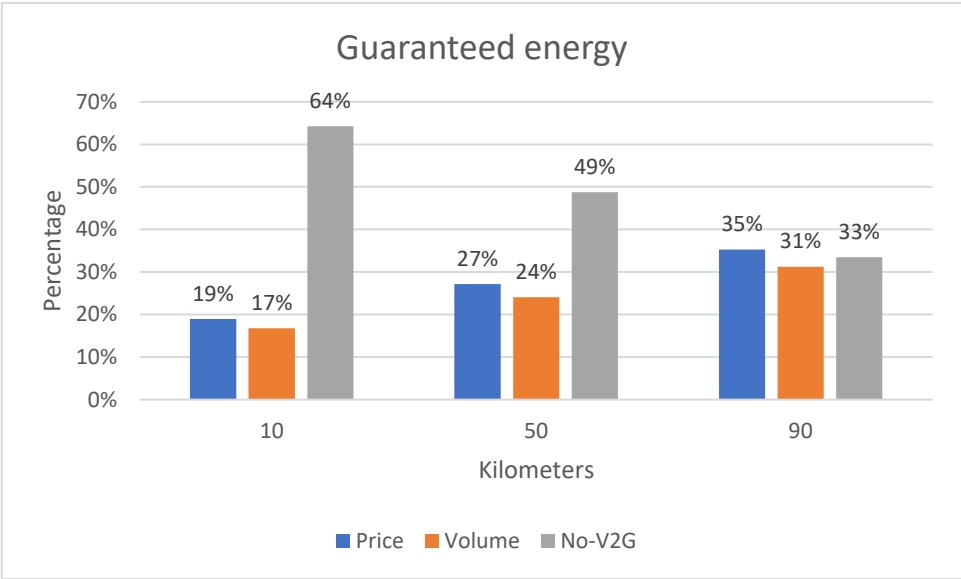


Figure 32: V2G demand guaranteed energy

Third, discharging cycles is varied between 1, 4 and 7, while the other contract elements are kept constant at the “realistic” level. In the base scenario, more than one discharging cycle per V2G session is logical. This explains the quite large demand for V2G at 1 discharging cycle, despite having a €2,00 per 10 hour remuneration. Increasing the number of discharging cycles to 4, results in a decrease of expected V2G demand (62% to 51%). More interestingly, the expected demand for V2G increases to 25% when 7 discharging cycles are used per V2G session. As mentioned, this was not expected behaviour. It was expected that demand for V2G would decrease evenly or more once more discharging cycles are present. This is shown in Figure 33.

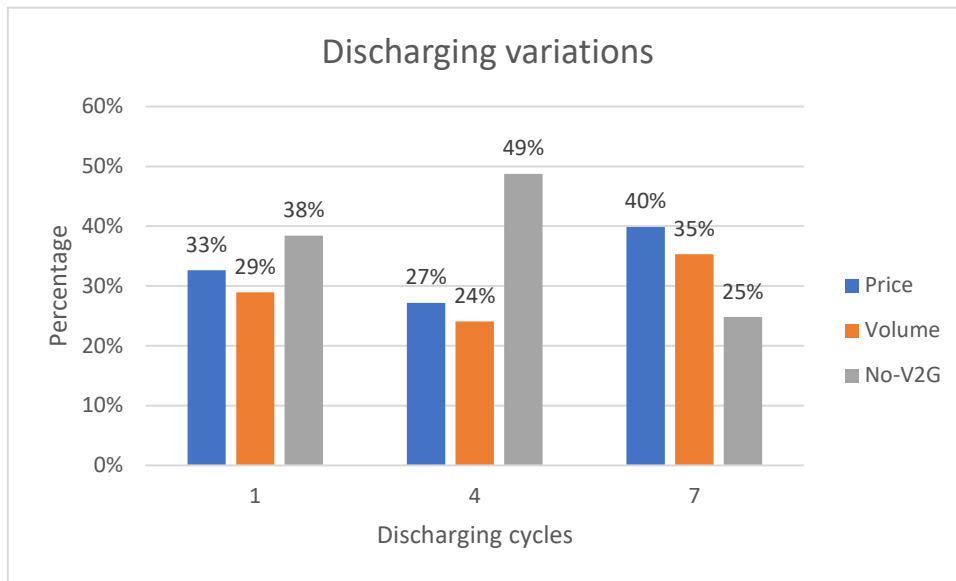


Figure 33: V2G demand discharging cycles

4.4 EV user characteristics

In addition to the hypotheses constructed for the contract elements, hypotheses for the EV users are developed. Insights are provided regarding different EV users groups. The charging location and income level are hypothesized to have an effect on the perceived utility regarding different contract elements. To test this, the utility functions as shown in 4.2 are stepwise extended with interaction effects. First, the model is extended with income as interaction effect and main effect. The utility functions then become:

$$V1 = \text{BETA_ASC} + \text{GE1} * \text{BETA_GE} + \text{RE1} * \text{BETA_RE} + \text{DI1} * \text{BETA_DI} + \text{CD1} * \text{BETA_CD} + \text{BETA_PI} * \text{PI1} + \text{BETA_ink} * \text{RE1} * \text{ink} + \text{BETA_inc} * \text{ink}$$

$$V2 = \text{BETA_ASC} + \text{GE2} * \text{BETA_GE} + \text{RE2} * \text{BETA_RE} + \text{DI2} * \text{BETA_DI} + \text{CD2} * \text{BETA_CD} + \text{BETA_PI} * \text{PI2} + \text{BETA_ink} * \text{RE2} * \text{ink} + \text{BETA_inc} * \text{ink}$$

$$V3 = 0$$

Results of the estimation are shown in Table 14. By adding parameters to the model, the model fit slightly improves. This is expected and does not result in a better model per se. Also, as expected, the parameter values stay more or less the same. All parameters are of the expected sign, including the interaction effect and main effect of income. However, the interaction effect for income is not significant (p-value of 0.43). Therefore, the null-hypothesis regarding income and remuneration is accepted. EV users with different income levels do not value remuneration any different with respect to their income level in this sample. This may partly be explained due to the fact that relative high-income levels are present in this sample. A distinction was made between low- and high-income levels, but the category with low-income levels contain respondents with an income level up to €70.000 due to the fact that only 19 respondents had an income less than €35.000. It may thus be the case that income does have an effect on the sensitivity to remuneration. The main effect of income is significant at 5% (p-value of 0.03). This means that in this sample, high income levels (>€70.000) perceive less utility for V2G as opposed to low income levels (<€70.000).

Table 14: EV user characteristics results

Parameter	Without income			With income		
	Value	Robust std error	Robust t-test	Value	Robust std error	Robus t-test
Guaranteed energy	0.0182	0.00177	10.26	0.0183	0.00177	10.35
Remuneration	0.146	0.0193	7.57	0.136	0.0246	5.53
Discharging cycles	-0.0932	0.0222	-4.20	-0.0933	0.0233	-4.20
Contract duration	-	0.00542	-1.30	-	0.00544	-1.29
	0.00703			0.00702		
Plug-in duration	-	0.00262	-1.69	-	0.00263	-1.62
	0.00443			0.00439		
V2G constant	-2.29	0.245	-9.35	-2.07	0.272	-7.61
Ink (interaction effect)				0.0289	0.0372	0.78
Inc (main effect)				-0.602	0.276	-2.18
work						
Number of observations	1152			1152		
Final Log-Likelihood	-1030.9			-1025.3		
Rho-square	0.185			0.190		

Extending the model with charging location as interaction effects and main effect results in an improved model fit but shows great differences regarding the parameter values and creates changes with respect to the signs of the parameters. This results in the acceptance of the null-hypotheses regarding the charging location; the charging location has no influence on perceived utility. This was not expected. Here, also a possible cause lies within the obtained sample rather than the missing of this effect. It was observed that almost all respondents – 91 – charged at least 1 hour at home. Obtaining data including EV users that are not able to charge at home may lead to different results.

Concluding from the EV user characteristics estimations, the null-hypotheses are accepted and the alternative hypotheses are rejected. This is shown in Figure 34.

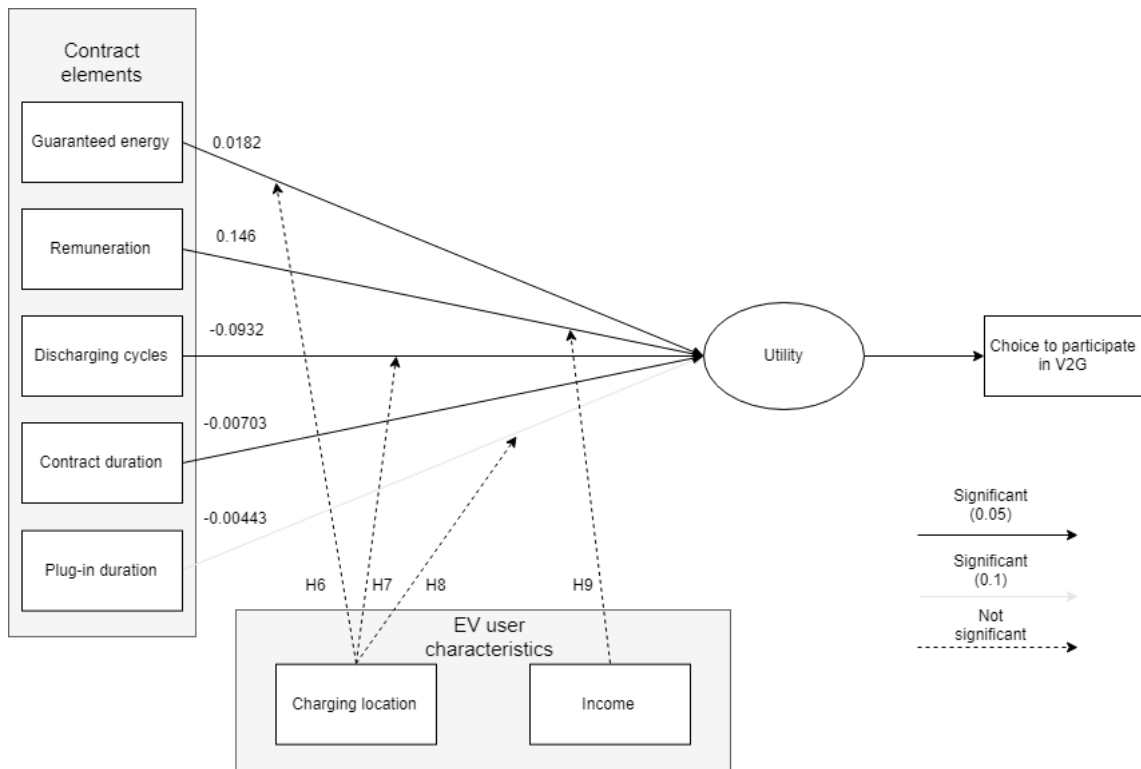


Figure 34: Conceptual model with interaction effects

4.5 Reflection on theoretical framework

As described in chapter 2, three other studies estimated choice models regarding V2G contracts. To put the results of this thesis in perspective, a comparison is provided. In Table 15, the comparison is shown based on the importance of attributes/contract elements.

Table 15: comparison with literature

	Thesis	Kubli et al. (2018)	Parsons et al. (2014)	Geske & Schumann (2018)
Order of relative Importance of contract elements	1. Remuneration	Remuneration (Green energy mix)	Remuneration	Guaranteed energy
	2. Guaranteed energy	Remuneration (Monthly power costs)	Guaranteed energy	Plug-in duration
	3. Contract duration	Discharging cycles combined with guaranteed energy	Plug-in duration	Remuneration (Discounts)
	4. Discharging cycles	Contract duration		
	5. Plug-in duration			

Comparing this thesis with the other studies shows that the relative importance of contract elements varies. Next, the contract elements that are used in this thesis will be compared with the results obtained in the other three stated preferences studies.

Remuneration

Remuneration is seen as most important contract element in three studies (including this thesis). However, as mentioned in Geske & Schumann (2018) and observed in this thesis, remuneration is not per se necessary to achieve considerable demand for V2G. This is possible due to the fact that other contract elements - guaranteed energy, contract duration and discharging cycles - have a large contribution to the perceived utility as well.

Guaranteed energy

In Parsons et al (2014) guaranteed energy is varied between 25 miles and 175 miles. Guaranteed energy is valued with €6.25 for every km increase in the range of 175 -150 km guaranteed energy and €55.30 in the range of 25-75 miles. The high values for guaranteed energy are explained by the fact that respondents were uncertain about earning money from energy companies. In Geske & Schumann (2018) it is shown that guaranteed energy contract elements dominate the remuneration contract element. In that particular study, guaranteed energy is varied between 10 and 50 km and valued with €2.33 for every km increase in guaranteed energy. The large drop in value for guaranteed energy might be explained by the fact that consumer behaviour is changed in the 4 years gap between both studies. In addition, in both studies no experienced EV users are questioned. In this sample, only experienced EV users are questioned making it likely that these users are more experienced with concepts as V2G and prices for charging an EV. Here, the price for 1 km increase of guaranteed energy is valued with €0.08. This may be explained by the fact that consumers behaviour regarding EV's and concepts is changing and current EV users are more willing to participate in V2G like programs. Another explanation might be the improvement of the charging infrastructure and fast charging possibilities. It is shown in this thesis that guaranteed energy is indeed an important contract element regarding the participation in V2G programs, but not that large of remuneration is required for an extra km of energy as found in earlier work, showing that possibly EV users are more willing to participate in V2G programs.

Contract duration

This contract element is only considered in the Kubli et al (2018) study. Here, it is shown that the longer a contract, the less utility was perceived by its end users. However, the relative importance of this contract element was found to be low. The findings of Kubli et al (2018) may be caused by the fact that the contracts were presented to the respondents as if it were electricity contracts and thus alternative contracts are also available. Based on the results obtained in this study longer contracts are valued more by the respondents, most likely in line with the lifecycle of the EV.

Discharging cycles

To the authors knowledge, this thesis is the first to measure the effects of battery degradation independently by using the contract element discharging cycles. It is shown that discharging cycles is a contract element that has a considerable effect on the perceived utility by EV users and influences the decision to participate in V2G programs. Limiting the number of discharging cycles in V2G programs might provide higher participation rates in V2G programs but decreases the opportunity of the aggregator to use the EV for V2G. In addition, limiting the number of discharging cycles may result in a decrease of other contract elements i.e. lower remuneration, lower guaranteed energy or longer plug-in durations. However, the effect of discharging cycles on utility shows some unexpected behaviour and requires further research.

Plug-in duration

Plug-in duration is used in Parsons (2014) and Geske & Schumann (2018). In Parsons (2014) high inconvenience costs are associated with plug-in duration €0.77/hour per day. They propose that the high costs associated with plug-in durations is due to the fact that respondents were not aware that their vehicle is idle most of the time. Therefore, it is likely that in this thesis lower costs associated with plug-in duration are obtained, as more experienced EV users are questioned. In addition, the plug-in duration is considered to be less important in the decision-making process as well. This is beneficial for DSO's and aggregators as required plug-in durations improve the predictability of value that is offered by V2G. When proposing a contract with required plug-in durations, not much participation in V2G will be lost, while the predictability of the amount of flexibility increases.

Conclusion on reflection of theoretical framework

Based on the comparison of existing literature on V2G contracts this thesis provides three important insights:

- 1) the number of discharging cycles have a considerable effect on the decision whether or not to participate in V2G programs and should be taken in consideration when designing V2G contracts
- 2) guaranteed energy is still considered as an important contract element, however, the costs for an increase in guaranteed energy have dropped considerably. This is also shown in plug-in duration
- 3) plug-in duration is not considered that important for EV users when participating in V2G programs

4.6 Conclusion

The key results of this empirical research are the following:

- Remuneration and guaranteed energy are the contract elements with the highest relative impact on utility. This is followed by the number of discharging cycles for each V2G session and the contract duration. Plug-in duration is a contract element with the least relative impact on the perceived utility.
- Plug-in duration has the least relative importance on the perceived utility. The plug-in duration is a contract element that is present in volume-based contracts but is not present in price-based contracts.
- The effects of remuneration and discharging cycles is non-linear.
- The number of discharging cycles are considered to be important in the decision-making of EV users to participate in V2G programs
- Guaranteed energy is still considered as important contract element, however the required compensation has dropped
- Remuneration is valued less in the range of €6,00 – €10,00 per 10 hour plug-in than in the range of €2,00 – €6,00 per 10 hour plug-in.
- The amount of discharging cycles has a larger impact on the perceived utility in the range of 1 – 4 discharging cycles compared to the range of 4 – 7 discharging cycles
- The cost for a km less guaranteed energy in the range 90-10 km equals €0,08.
- The cost for an additional discharging cycle per V2G session equals €0,87.
- The cost for an extra hour plug-in duration in the 0-50 hour/week range equals €0,02.
- The cost for a month shorter contract duration equals €0,24 per month.

- Due to the small relative importance of plug-in duration, no large differences between expected demand for V2G regarding price- and volume-based contracts are observed in the calculated demand for V2G.
- In the base scenario expected demand would result in 22% EV users choosing a volume-based contract and 28% EV users choosing a price-based contract.

Additional insights of this empirical research are the dominance of the No-V2G option above a V2G contract. However, there are small percentages of the respondents that do choose for a V2G contract instead of their conventional way of charging. Moreover, the constant for V2G is negative and quite large compared to the other contract elements. Despite remuneration being the contract that has the largest share in the utility contribution, remuneration is not necessary to create demand for V2G. If EV users are provided with guaranteed energy for unforeseeable demand of mobility, an increase in utility and expected demand is observed. In addition, in this sample no significant effects are found regarding the influence of charging location and income level on certain contract elements. It is observed that higher income levels do result in a slight decrease of perceived utility for V2G.

5. Conclusion, recommendations & discussion

Structure

In this chapter an answer will be provided to the main research question as provided in the introduction. In section 5.1 the main question will be answered followed by the argumentation for this answer by answering to the two sub questions. Next, in section 5.2 recommendations and directions for future research are provided. The chapter ends with discussion on the limitations of this thesis.

5.1 Conclusion

The main research question of this thesis is as follows:

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

It is observed that two contract types are relevant for the DSO:

- 1) Price-based
- 2) Volume-based

These contracts differ in terms of one contract element: plug-in duration, which is present in the volume-based contract. Since the relative importance of this contract element is only 5%, differences in expected demand of the contracts are not that large. When proposing required plug-in times to EV users, more predictability is provided to the market parties. This makes V2G more valuable as the predictability of EV availability is increased without losing much EV user participation. In contradiction, the contract elements that are considered to be important for EV users are: remuneration, guaranteed energy and discharging cycles. It is shown that one of these three contract elements can be used to increase demand for V2G. It is not necessary to use a combination of these contract elements to increase demand. However, high levels of these contract elements are necessary when using only one of these contract elements. When realistic values are considered, combinations provide more value.

To understand what contract elements are feasible for implementation, it was necessary to gain insights in the electricity market and the impact V2G has on the current electricity market. This was done by examining the USEF framework and current literature on V2G contracts. Thereby, an answer is provided to the first sub question:

SQ: 1. According to the current developments, what type of V2G contracts are feasible for implementation?

Implementing V2G in the current electricity market is not straightforward. A new role, the aggregating role, has yet to be defined. The DSO's are not permitted by law to fulfil this role. In addition, the EV user itself is not able to fulfil this role because of not enough flexibility available to trade on electricity markets. This has two consequences:

- 1) a new relationship unfolds between the aggregator and the EV user. This will take the form of a contract
- 2) in the future, different parties could enter the market and are able to fulfil the role of the aggregator, creating uncertainty regarding formalization of contracts

This uncertainty results in endless options regarding the contract elements that are present in a contract. In this thesis, generic contract elements based on current literature are used. Due to a lack of literature on V2G contracts, a comparison is made with demand response contracts. Park Lee (2018) proposes three contract types which are based on demand response contract elements, however they accommodate for fuel cell EV's only. By researching the state of the art of V2G contract literature, the proposed contracts were extended and adjusted to accommodate for DSO's and battery EV's. These contain five contract elements:

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

Then, the contract elements were used in the stated choice experiment and analysed by using the MNL model. Thereby an answer is given to the second sub question:

SQ 2: What is the expected usage of V2G by current EV users under different V2G contracts?

The five contract elements are used in the stated choice experiment. The results have shown five contract elements that have a significant influence on the perceived utility by EV users. The significant contract elements can be ordered in terms of relative importance. The ranking order, from highest relative importance to lowest is as follows:

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

The results have shown that EV users do not prefer V2G per se, but when compensated i.e. with remuneration or guaranteed energy, they are willing to accept discomfort and participate in V2G programs. Remuneration and guaranteed energy contribute for 55% of the perceived utility. However, remuneration and guaranteed energy cannot exceed too high as this will limit the value of V2G. In addition, plug-in duration only contributes for 5% of the perceived utility, while this contract element is seen as a key difference between the price- and volume-based contract. It is thus not expected that users show great difference regarding the two contracts.

In a base scenario, the expected demand for a price-based contract for V2G equals 28% and 22% for a volume-based contract. Varying remuneration, guaranteed energy and the amount of discharging cycles results in the singular effects of a contract element on the expected demand for V2G. It is shown that these three contract elements can increase the expected demand for V2G to promising percentages, such that the demand for the no-V2G option is decreased to at least 33%. The small difference between price-based and volume-based contracts show potential for aggregators in the sense that EV users are quite willing to commit to a prespecified amount of V2G. This results in quite predictive behaviour. Caution must be given to the non-representativeness of the obtained sample. The incorporation of more females in the sample might result in a decrease in demand due to the fact that "range anxiety" is felt more heavily by female EV users (Caperello, 2014). In addition, the

sample contains relatively “old” EV users. Young EV users are more aware of environmental effects and might in their terms increase the demand for V2G (Geske & Schumann, 2018).

In addition, it is shown that EV users with high income levels perceive less utility regarding V2G than EV users with a low income. The demand for V2G, in the “base” scenario, decreases with 13% and 10% for price-based and volume-based contracts respectively. In this sample, no significant relation was observed between the charging location and the demand for V2G services.

5.2 Recommendations

Three types of recommendations will be discussed in this section:

- 1) Recommendations for the DSO
- 2) Recommendations for governmental regulation
- 3) Recommendations for future research

5.2.1 Recommendations for the DSO

The aim of this thesis is to provide insights in the decision-making process of EV users regarding V2G contracts to show the potential value of V2G. As shown in the results, contract elements do influence the decision to participate in V2G programs and when using realistic contracts, considerable demand for V2G can be achieved. Thus, showing the potential of V2G as a flexibility service.

In comparison with the spot prices for electricity at the APX market, considerable demand for V2G can be expected. Calculating the base scenario was done by using an electricity price of €0.037/kWh – based on 5.4 kWh/hour equalling a remuneration of €2.00/10 hour plug-in duration – and is the equivalent of low spot prices for electricity in period of March 5, 2018 up until March 5, 2019. In this period electricity prices varied between €0.0209/kWh and €0.0852/kWh on the APX spot market (APX, 2019). Configuring to an average battery capacity of 5.4 kWh, remuneration can vary between €1.12/10-hour plug-in and €4.60/10-hour plug-in to low and high electricity prices respectively. Based on the results obtained in this thesis, the expected demand for V2G when electricity prices exceed €0.037/kWh equals 50% and increases when electricity prices rise. Due to the set-up of the experiment, no statements can be made on the expected demand for V2G below this electricity price. However, this only occurred on less than 10 days in this period. As remuneration can be lower than the electricity price, there is a potential for V2G business models. This entails that V2G might be a feasible flexibility option. It is therefore that recommendations are made to the DSO’s to further determine the value of V2G.

Three steps are provided to the DSO’s in which the value of V2G can be determined. The results of this thesis serve as input for these steps.

Explore locations where flexibility services are desired and beneficial

The first step for DSO’s is to identify areas where grid capacity issues are occurring or might occur in the future. As mentioned in the introduction, the potential of flexibility services for DSO’s are location specific. Notion should not only be given to the grid, but also to the number of EV’s and charging points in a certain area. If areas are identified that contain a high number of EV’s and capacity issues, V2G can be considered as an alternative for grid expansion and investments can be postponed or avoided.

Determine the value that V2G can generate in a certain area

The second step lies in identification of the value that can be generated through V2G in the chosen areas. The foundation of value of V2G lies in the capacity of the battery that is present in the EV. As observed in this thesis, EV users are exposed to “range anxiety” when providing V2G services. It is considered as an important contract element that plays a role in the decision-making to participate in V2G programs. Therefore, the importance of exploring the amount of EV’s in a region is found in the different battery capacities of EV’s. Some EV’s have a range of 100 km, while others have a range of 500 km. In the base scenario 90 km guaranteed energy is used, meaning that for one EV DSO’s can only use the 10 km for V2G and for the other DSO’s can use 410 km of electricity. It is important to note the difference when calculating the amount of electricity that can be used in V2G services. Combining the information obtained when exploring locations and the expected participation in V2G programs, the value of V2G can be calculated.

When using price-based contracts, no restrictions are present regarding the plug-in duration. It can then not be assumed that the expected participation rates in V2G are obtained. However, as the difference in expected demand for V2G between price- and volume-based contracts is small, it is advisable to use the plug-in duration in the contract such that more predictable V2G behaviour can be obtained.

Once the expected value that can be provided by V2G is determined, a cost benefit analysis can be made determining whether a flexibility service like V2G can provide more value than investing in grid expansion.

Co-create a V2G contract with aggregators and optimize the compensation

After exploring the locations where V2G is valuable, a V2G contract can be designed. It can be valuable to co-create the contract with the aggregator. Designing the contract entails making a trade-off between increasing demand for V2G by lowering the compensation elements or maintaining high compensation elements with lower demand for V2G. For example, increasing the amount of guaranteed energy will increase the demand for V2G. However, it would be interesting to research whether more value of V2G is generated by having less EV’s with a large battery capacity available for V2G or having more EV’s available with less battery capacity for V2G. This trade-off is not only relevant for guaranteed energy, but for all contract elements used in this thesis. In addition, as the relative importance of contract elements are estimated in this thesis, it is advisable to keep changes to the most important contract elements as small as possible, as these have the most effect on the expected demand for V2G.

5.2.2. Recommendations for governmental regulation

The three trends that are currently occurring in the Netherlands were the starting point of this thesis. These three trends have consequences for the electricity market as a whole. Currently, the electricity market is designed in a way that fair and open competition is provided such that consumers are free to choose energy suppliers. However, due to the high investment cost and the sub-additive cost function that is present in the electricity grid, the transmission and distribution of electricity remains a natural monopoly. Hence, prices are regulated by the Authority Consumer and Market (ACM).

To cope with the three trends, flexibility services are desired in the electricity market. This – as mentioned in chapter 2 – requires a new party to enter the market; the aggregator. As the accumulation of flexibility from V2G services requires most likely an ICT solution, no high investment costs are expected for aggregators and no natural monopoly is expected to form (USEF, 2018). In that

sense, no governmental intervention is required and aggregators can freely join the market, stimulating competition. The development of the role of the aggregator and which party fulfils this role can be set up free to the market. However, the implementation of V2G to the electricity market does generate a few implications for policy and regulation.

Firstly, as the electricity market and the automotive industry are combined, standardization on larger scale is necessary. As multiple aggregators can join the market, different V2G mechanisms can be in place. One could argue that governmental regulation can be used to create a common standard regarding V2G mechanisms. This way interoperability is assured. Currently, in the Netherlands the ISO 15118 protocol (V2G mechanism) is used as standard without governmental regulation (Elaad, 2019). Thereby providing room for other companies to provide innovative/better standards. As the electricity market is highly dependent on the other parties in the value chain, it is assumed that the market can generate a standard. However, as the electricity market is also dependent on the automotive industry, the scope of the standard becomes supranational. For example, if the Netherlands is using the ISO 15118 standard, but China is using the ChaDemo standard (other V2G mechanism) (Chademo, 2019), it is likely that – for instance – Nissan will produce EV's with only ChaDemo standard. The Netherlands is dependent on the automotive market in terms of standard protocols for V2G. Therefore, it is advisable to develop regulation on at least a European level. In this way the automotive market is forced to develop standards for Europe as a whole, otherwise a large market share will be lost.

Another market imperfection that is brought along by V2G and this standard protocol, are privacy and security issues. The standard mechanism that is necessary for V2G is ICT-based and thereby it is monitored where the EV is connected. With all new ICT, concerns regarding privacy and security arise. As such data can for instance be used to track when a person is home or not. Furthermore, the connection to the electricity grid makes it sensitive for possible cyberterrorism attacks. Here governmental regulation and monitoring (by the ACM) would be necessary, as these effects are not captured by the market itself. Again, since the standards are required on a large supranational scale, this is no different for the privacy and security regulations. Given the different perceptions regarding privacy and security in continents, European level is assumed to be feasible.

In addition, as shown in the sample and in the Nordic study, high income levels are observed among the EV users. This is also observed by other studies and implies that only the “rich” can benefit from a V2G solution creating inequity in society. The Dutch government can stimulate the usage of EV's of low-income groups by stimulating the development of low cost EV's or increase knowledge/awareness about cheaper EV's. The focus of these regulations is thus purely on the Netherlands.

5.2.3 Future research

Based on this thesis, a few recommendations for future research can be provided. The recommendations are divided into four segments: technological aspects, laws and taxations, user behaviour and business models. To the authors knowledge and in line with the study conducted by Sovacool et al., (2018), the literature on V2G is incomplete and focusses mostly on the benefits V2G offers to the environment. However, V2G possess several barriers that need to be overcome.

Technological aspects

Clarity on the technological effects of V2G should be clearer. Here, insights in the effects of V2G on the battery are desired. Due to the rise of pilot projects it is assumed that this will be available in the

near future. However, it is also mentioned that the widely adopted type of battery (Lithium-ion) determines the impact on the batteries' lifetime. It would be desirable to identify battery types that are most suited for V2G services, i.e. batteries that are capable of multiple discharging cycles per day. As now is assumed that more discharging cycles decreases the batteries longevity, the perception regarding discharging cycles might change once more clarity is provided. This can thus have consequences for the expected demand of V2G.

In addition to the technological effects on the EV, insights in the effects of V2G on the technological system are desired. V2G requires longer plug-in times than conventional charging. The results show that EV users do not experience large discomfort regarding longer plug-in durations while providing V2G services. When V2G is applied, more pressure on the charging infrastructure may be expected. It would therefore be interesting to see what the impact of V2G on the current infrastructure might be and how V2G could contribute to optimising the charging point infrastructure in large cities. Here a combination can be sought for with policies that are reducing connection times which withholds EV users from unnecessary connections to the grid. An example could be that EV users are only allowed to connect to the grid when V2G is provided.

Laws and taxations

As V2G is a new concept, no laws and taxation regulations are formalised yet. Future research could look into different laws and taxations that are required for V2G. In addition, political involvement in the development of V2G is necessary from the beginning on such that it is known what policies are lacking and require adjustments. Then the political debate/discussion could start earlier such that it might not cause a barrier for the implementation of V2G. As shown above, issues regarding privacy and security can be looked into. These factors are not taken into consideration in this thesis, but may play a role in the decision making process of EV users.

User behaviour

More pilot projects are undertaken providing an opportunity to infer EV users' preferences regarding different use cases. Here, pilot studies can be executed such that discomfort is taken away. For example, long term parking spaces provide an excellent opportunity for the usage of V2G, as the contract element of guaranteed energy is no longer present as the EV is parked for longer term. As this contract element has a large contribution to the decision-making process to participate in V2G programs, higher participation rates might be expected. It would be interesting to see how EV users, who park for multiple days would respond to V2G contracts. Another example of taking away guaranteed energy as barrier is the fact that people who have two cars rely not heavily on the guaranteed energy in one of their vehicles.

It would also be valuable for aggregators to understand how EV users respond to different type of remuneration structures. For instance, looking at differences between discounts at the purchase of an EV or discounts at their monthly energy bill as remuneration structures can provide insights for the aggregator. As remuneration has the largest contribution to the decision-making process it is assumed that different formulations of this contract element can generate large differences in participation rates.

Third, it would be desirable to identify the underlying reasons regarding the preferences of EV users. In this thesis only five contract elements are used, while in reality other factors contribute to these decisions as well. Here, a distinction can be made in whether the concept of V2G impacts personal

comfort levels or that other personal situations have a share in the decision-making process of EV users.

Business models

As mentioned in the recommendations for the DSO, it is important to identify how and where value is created by V2G. This applies not only to the DSO's, but to every party that is present in the electricity supply chain. Here the financing and monetization of V2G requires further attention. The results obtained in this thesis are the first step in determining the value of V2G as expected demand for V2G can be calculated. This, then serves as input for a cost benefit analysis.

5.3 Discussion

In this section the limitations of this thesis are discussed as these have an impact on the results that are obtained.

Aggregator and uncertainty regarding contract elements

As mentioned in chapter 2, the fulfilment of the role of the aggregator is not yet defined. In the future, it might be the case that different aggregators are competing in the electricity market. Consequently, these parties can determine the contract elements that are presented to the EV users. This may lead to other contract elements than used in this thesis and may thus result in different participation rates in V2G programs by Dutch EV users. In this thesis two contracts (price- and volume-based) and five contract elements are considered. The contracts and contract elements are chosen with the focus on the DSOs' objectives. Including other contract elements may result in different preferences regarding V2G contracts. For instance, when the CPO fulfils the role of the aggregator, it is possible that parking spaces instead of remuneration are used as contract element. In addition, when car manufactures become the aggregator, remuneration might be fulfilled by providing discounts on the EV. It is expected that discounts upfront are valued higher by EV users than monthly remuneration structures. This may lead to changes in the constant for V2G. As observed from the results, remuneration has the largest relative importance of the contract elements. Changing or formalizing this contract element differently may have a large impact for the participation in V2G programs. Adding more contract elements to the contract will most likely result in small changes, as it is observed that three contract elements have a large relative importance and contribute to the decision-making process. When those three contract elements remain in the contract, similar V2G participation rates may be expected. Understanding how Dutch EV users respond to different contract elements that might replace these three contract elements is desired as this might have an effect on the participation rates in V2G programs. This is not empirically tested so additional research is required to get more insights in the actual impact of other contract elements and formalization of contract elements on the participation in V2G programs. This will provide aggregators the required information to attract more customers and provide more value for grid operators.

Survey design

When distributing a survey, the survey needs to be checked on reliability and validity to ensure that reliable and valid data is obtained. Reliability is to check whether the questions are interpreted the same in the same population. Validity refers to checking whether the questions measure the variables as intended. This is not executed in this thesis resulting in uncertainty regarding the reliability and validity of the data. Respondents did provide feedback on this survey and this feedback was processed to ensure understandability of the survey.

Qualtrics was used to create the survey and distribute the survey. However, this tool did not allow for randomisation in the survey questions. Randomisation can be useful to reduce unobservable error resulting from impulsive decisions or self-controlled decisions by respondents. The survey is structured by starting with a few questions regarding the charging behaviour, followed by the choice experiment and closing of with some personal characteristics. It is observed that more response is generated at the beginning of the survey than at the final questions. This can be explained by the fact that respondents are losing interest in the questions and thus make impulsive decision (or none). By randomisation of the questions this effect would likely be less observable. A higher response may not per se change the outcomes of this thesis but may make it more likely that the sample was representative to the population. However, a maximum of 144 respondents were obtained which may not ensure representativeness as well.

Stated preference vs revealed

As discussed in chapter 3, stated data is used to infer EV users' preferences regarding V2G contracts. The limitations of stated data pose three problems:

- 1) Respondents do not feel the consequences of their choice
- 2) Respondents have perfect information regarding their alternatives
- 3) It is unknown if respondents actually choose what they have said they would do

For the results obtained in this thesis, this might result in underestimation of battery degradation, plug-in duration and contract duration by the respondents. Thus, in reality and when the consequences of these contract elements are felt by the users, the relative importance of these contract elements may be higher and thus EV users require higher compensation than presented in this thesis. Consequently, this makes the value of V2G decrease.

Revealed data collection contains real market alternatives and thereby reveal what people actually choose when they have to make a decision. For example: the time of the day that EV users charge their EV. Using this type of data increases the reliability and validity of the study, which is denoted in the literature as the most important advantage (Louviere et al., 2000). Therefore, this type of data collection is desired if there are no changes expected in the set of alternatives that people can choose from. If this is the case, choices can be forecasted. Due to the novelty of V2G no revealed data is available. It is recommended to validate the results in this thesis with revealed data in the future as the combination of stated and revealed data adds value (Louviere et al., 2000).

Attribute levels

The development of stated choice experiment contained decisions that result in limitations regarding the set-up of the attribute levels. To be more specific two contract elements are chosen with attribute levels that do not encompass the whole range. In this respect, guaranteed energy and plug-in duration. For guaranteed energy a range between 10-90 km is chosen, which does not cover the full range of an EV. Therefore, no conclusions can be drawn outside that range missing out on the full picture of guaranteed energy. However, the results within this chosen range provide more value as they provide more room for flexibility. If an EV can be discharged up until only 10 km, the full battery can be used for V2G. When the EV can be discharged up until 180 km, less battery capacity can be used for V2G. This range can explain the importance of the contract element by the respondents. This part of the battery contributes more to "range anxiety" than an almost full battery. Therefore, the impact of guaranteed energy would likely decrease when a full range is used. With increasing ranges of EV's, it is likely that the guaranteed energy contract element will be less important in the

decision-making process and lower compensations are required for decreasing the guaranteed energy as obtained in this thesis. It is assumed that this effect will not be linear and guaranteed energy is valued more in the low levels compared to the high levels.

Regarding the plug-in duration, the full range would obviously be 24*7 hours of maximum plug-in duration. However, the range that is chosen, is 0-50 hours per week. This is based on plugging in the EV at home at night every weekday. However, in terms of V2G, a lot of respondents mentioned that they would plug-in longer and more often than their current behaviour. From the results it is observed that plug-in duration has a small contribution on utility. Perhaps if this range is extended, the contribution of plug-in duration would increase. Besides, respondents are in this experiment free to determine how these 50 hours are distributed over the week. In reality, it is more likely that a DSO would like to have EV's available at a certain moment of the day. This is an extra restriction that would likely increase the importance of the contract element. It may be thus expected that higher compensation is required for plug-in duration than obtained in this thesis. This may also have consequences for the conclusion regarding the two different contracts. If plug-in duration becomes more important for EV users, it is likely that expected demand for a volume-based contract decreases while the expected demand for a price-based contract increases. This then results in less predictable V2G behaviour.

Extending both ranges for guaranteed energy and plug-in duration requires further research.

In addition, discharging cycles are presented to the respondents as 1, 4 and 7 discharging cycles per session. However, no information was provided to the respondents how much effect 1, 4 and 7 discharging cycles has on the battery. Current literature lacks on clear results regarding V2G and battery degradation, so it was chosen to let the respondents interpret the amount of discharging cycles themselves. Once more clarity is given regarding the effect of V2G on the battery degradation, more research can be conducted to the effects of battery degradation. Once more clarity is given regarding the effects of discharging cycles on the battery's lifetime, clearer effects of the amount of discharging cycles may be expected. It may be expected that the more impact discharging cycles has on the battery's lifetime, the higher the required compensation might be.

The other contract elements are chosen with the complete range and no problems are expected.

[Recruitment of respondents](#)

In this thesis three ways of recruiting respondents were used:

- 1) VER
- 2) Accenture
- 3) Snowballing

This has consequences for the sample that was retrieved. At the "VER" mostly enthusiastic EV users are represented, who are willing to do something about either the environment or with their EV. This might result in a higher willingness to participate in V2G programs than average EV users. It is likely that in reality EV users require higher compensation for the experienced discomfort. In addition to the VER, employees of Accenture have been asked to fill in the questionnaire. These might compensate for the high willingness to do something with the EV. Accenture employees drive a lot to clients, which is why they value their range more than the average EV driver. Thus, making them experience more discomfort regarding the guaranteed energy and require higher compensation for this discomfort. However, having Accenture employees in the sample, results likely in more highly

educated respondents and more high-income levels. This also may result in less willing to participate in V2G programs. Furthermore, snowballing was used however it is not sure how many respondents are reached with this method.

No data is available on Dutch EV users socio-demographics. This means that it is not possible to test for representativeness. To give an indication, the sample is compared with a study that has been conducted in five Nordic countries (Sovacool., 2018). That sample is compared with this study resulting in a few socio-demographics that are comparable. However, the categories are not per se comparable with those of the Netherlands. For example, the average income of the Nordic countries is higher in comparison with those of the Netherlands. In the comparison, the data did not accommodate for this.

MNL model

Regarding the estimations of the expected demand of V2G contracts, the MNL model is used. This means that the Independence of Irrelevant Alternatives property (IIA) holds. The IIA property entails that the relative popularity of alternative A and B does not depend on C. With this limitation, the RUM-MNL model would decrease the choice probabilities of A and B with same ratio if C increases, even if alternative C competes stronger with alternative A than with alternative B. However, if A and C 'belong' to the same category of alternatives, B should intuitively decrease less than A. Moreover, A should decrease even more than B. Regarding the V2G contracts, price- and volume-based contracts do have something in common: providing V2G compared to a no-V2G option. For example, when increasing the remuneration in a price-based contract, decreases the utility for the no-V2G option and volume-based contract evenly. In reality, it could be expected that an increase in remuneration for a price-base contract would result in a decrease of expected demand for a volume-based contract and almost no decrease in expected demand for the no-V2G option. It is therefore recommended to estimate a (panel) Mixed Logit model to accommodate for the IIA property of the MNL model. Again, it might be expected that demand for V2G is lower than found in this thesis.

Results

This is a first empirical research of consumers preferences in the Netherlands. Additional research is required to validate the results that are obtained. In addition, more advanced modelling is required to determine heterogeneity among Dutch EV users, as well as decision rule research would provide value to the underlying preferences of EV users. In this thesis – based on random utility theory – it is assumed that people are fully rational decision-makers and choose alternatives based on an alternative with the highest utility. In fact, all people have different heuristics to make a decision. These are called decision-rules. For instance, decisions based on minimizing regret can be researched. Here advanced random regret models can be used. This could – for instance – measure the effects of discharging cycles on the utility differently, as these effects are yet unknown. It might be the case that EV users are minimizing regret and value discharging cycles negatively. Other decision rules are satisficing or elimination by aspects.

6. Literature

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Appendix 1: USEF

EV charging locations and USEF

USEF describes the relationships between supplier, aggregator and the prosumer in detail. But, EV's are a special form of ADS because of the unique characteristics EV's possess. The unique characteristics consist of (list is not exclusive):

- The need of EV users to move from A to B
- Different charging locations due to the need for mobility
- Different charging locations mean different market models

Therefore, the inclusion of EV's into the framework requires further attention.

Adding V2G to USEF introduces new relationships between parties that are already in place in the EV value chain. Parties that are involved in V2G depend on charging location, as EV's can be charged at either private locations, semi-public locations or public locations.

Charging locations

For private (home) charging no adoptions of the USEF are required and the EV user becomes the prosumer. However, for semi-public and public charging stations the value chain of EV's consists of the following parties: the EV user, the CPO and the E-mobility service provider and thereby require adoptions in the USEF framework. Here, there are three options possible for the fulfilment of the role of the prosumer; either the CPO, the E-mobility service provider or the EV user becomes the prosumer.

The prosumer enfold a relationship with the aggregator. In the case of the CPO or the E-mobility service provider becoming the prosumer, it is also likely that they would fulfil the role of the aggregator. The different options of which party fulfils the role of the aggregator will be discussed in the next section.

Table 16: Charging location

Charging location	Adoptions in USEF?	Role of prosumer?
Private	No	EV user
(Semi-)public	Yes	EV user/CPO/E-mobility service provider

Different aggregator models

The role of the aggregator is to accommodate flexibility to parties in the electricity market. More specifically, in terms of V2G, the aggregator is responsible for creating a flexibility pool with the available EVs at any given point in time.

However, it is unclear which party will assume the role of the aggregator. The DSO supplying electricity to the consumer has a logical position to take the role of the aggregator, yet also other market parties are able to fulfil this aggregating role. For example, Jedlix (a platform that connects EV users with electricity suppliers) is already operating as aggregator in the Netherlands.

In the case of the EV users becoming the prosumer, there is a relationship between the supplier of electricity and the aggregator. The prosumer cannot become the aggregator because of insufficient

volume of flexibility (Tennet, 2018). The aggregator then acts on behalf of the prosumer and thereby controls the EV’s charging process. Currently, there are two options which seem most logical to fulfil the aggregating role:

- 3) The CPO. This seems logical, as multiple charging stations are managed by the CPO and therefore sufficient flexibility volume is available. This means that the CPO is only active in certain regions, otherwise a monopoly is formed, which would damage economic welfare (Sharkey, 1982). An example of this: Newmotion is a Dutch CPO who is seeking to fulfil the role of the aggregator.
- 4) The E-mobility service provider. Here enough flexibility volume is generated since this party already has multiple contracts with EV users and therefore, the E-mobility service provider can become the aggregator.

So, for the semi-public and public charging location it is most likely that the CPO or E-mobility service provider will take the role of the aggregator while for the private charging location a new aggregator role must yet be identified.

Either the CPO or the E-mobility provider aggregator option is logical as there is enough volume of flexibility available and there are already existing contracts with the EV user. So, any party that has enough EV’s available can take the role of the aggregator; e.g. a parking space operator, car manufacturer, employer or station owner.

In the future, the role of the aggregator could be fulfilled by new parties that are able to enter the market.

The contract can be designed such that it accommodates the objective of the party fulfilling the role of the aggregator. Therefore, differences in contract elements can be present due to different parties fulfilling the role of the aggregator. Depending on which party fulfils the role of the aggregator has consequences for, especially, the type of remuneration that is provided to the EV users. Since new parties are also able to fulfil the role of the aggregator, the contract elements that will be present in the contract are uncertain. This uncertainty may have consequences for the services that are desired by the Dutch DSO’s. For example, if a parking space operator takes the role of the aggregator, parking spaces could be offered to those who would plug-in their EV to use V2G. Whereas when an E-mobility service provider takes the role of the aggregator, EV users are able to plug-in their EV to use V2G at any given location and are not bounded to a specific parking garage. In other words, the party that fulfils the role of the aggregator will design the incentives in the contract such that the parties’ interests are achieved. The options are depicted in

Table 17: Aggregator options

Charging location	Aggregator
Private	New party
(semi-) Public	CPO; E-mobility service provider; New party

Table 18: Aggregator options

Appendix 2: literature review

Contract designs

Parsons et al. (2014) used guaranteed range after using V2G, required plug in time and monetized remuneration as contract design. Geske & Schuman (2018) used the same contract design as Parsons et al., (2014) but included also a board computer in the contract. The board computer is used to define the timing and length of the next trip, such that the amount of energy required for the next trip is guaranteed. Therefore, trips that are longer than the minimum guaranteed range can be done as well. Kubli, Loock & Wustenhagen (2018) used a similar contracting scheme, in which the flexibility, power mix, contract duration and monthly power costs is used.

Also, Kubli et al. (2018) extend the contracts used in Parsons et al. (2014) and Geske & Schumann (2018) by adding a power mix as remuneration and try to observe the effects of the contract duration. Kubli et al. (2018) define the power mix as the different sources of electricity that consumers want to use. Moreover, in the definition of flexibility Kubli et al. (2018) added discharging cycles to measure battery effects. A discharging cycle is defined as the starting point of unloading the EV up until the unloading stops. The unloading not necessarily stops at depletion of the EV, but can also take place when the State of Charge is still at 80%. However, this is combined with the guaranteed charging level after making use of V2G in the flexibility options as shown in the table, making it impossible to measure either of these effects directly.

Battery degradation

Battery degradation is a topic within V2G that has been researched by many (Marongiu et al., 2015; Saxena et al., 2015; Wang et al., 2016; Hu, et al., 2017). Concluding from the research it could be stated that V2G creates a higher use of the battery and consequently causes stress on the battery which results in a reduction of the longevity of the battery. Wang et al. (2016) found that the cost for battery degradation per charge are 0.20\$ - 0.45\$. Additional discharging of EV batteries to the power grid will consequently result in a deterioration of the batteries performance (Dubarry, Devie & McKenzie, 2017).

In contradiction there are studies that claim the opposite, Uddin et al. (2017) claim that V2G actually can extend the life of the batteries that are present in EV's. This incongruity between the results from Dubarry and Uddin resulted in a collaborative publication. Their main conclusion reflects on the impact V2G has on the battery life of the EV. Continuously discharging the EV to the grid will result in battery determination. However, smart algorithms providing access to the stored electricity in the battery when there are no contrary effects on the battery durability will extend the batteries longevity (Uddin, Dubarry & Glick, 2018). However, Maronigie et al (2015) conclude that V2G impacts the batteries' lifetime negatively but the amount of degradation determines on the frequency of usage, meaning there exists a tradeoff in which the battery not wearied down more than uncontrolled charging.

In literature it is thus unknown what effects V2G has on the batteries' longevity. However, in a recent pilot study called INVENT in California observing that V2G does some additional damage to the batteries' longevity. This is also confirmed by a recently finished pilot called Parker in Denmark (Parker, 2018). The impact of V2G on the batteries' longevity depends on the service in which full charging/discharging is the worst for the batteries' lifetime (INVENT, 2018).

Moreover, EV users are reluctant on their battery and therefore battery degradation is considered as a negative aspect of V2G (Hu et al., 2013). Effecting the battery has an influence on the so-called “range anxiety” of EV users (Neubauer & Wood, 2014). Therefore, battery degradation is also considered in this study

Appendix 3: methods

Revealed vs stated data

Revealed data collection contains real market alternatives and thereby reveal what people actually choose when they have to make a decision. For example: the time of the day that EV users charge their EV. Using this type of data increases the reliability and validity of the study, which is denoted in the literature as the most important advantage (Louviere et al., 2000). Therefore, this type of data collection is desired if there are no changes expected in the set of alternatives that people can choose from. If this is the case, choices can be forecasted. However, one limitation of revealed data collection is the incapability to include *new* alternatives. For example: adding V2G to the charging behaviour of EV users. The alternative of V2G is not on the market yet and can therefore not be measured by revealed data. This will especially pose problems if there are new attributes in the alternatives. For V2G new attributes arise; as remuneration is provided and plug in times are required which is not the case in conventional charging of an EV.

Besides the incapability to include new alternatives, revealed data poses other limitations as well. Firstly, revealed data collection will result in data with insufficient variation, as choices which have a low level of occurrence in real life are not included in the data. Secondly, the choice set of the respondent is unknown so only information is obtained on the chosen alternative. Thirdly, multicollinearity among attributes arises and fourthly, many respondents are required as for each respondent only one choice is observed.

Stated data collection contains of hypothetical choice situations presented to the respondents. Using the stated data collection method, the researcher constructs the choice sets the respondent can choose from and the researcher can construct hypothetical situations that do not (yet) exist. Therefore, hypothetical alternatives can be measured, and the data collection method allows for non-existing alternatives and new attributes. Moreover, as the researcher constructs the choice sets it also provides a solution to insufficient variation, the unknown choice set, multicollinearity and the number of respondents required. Based on the choices people make, preferences regarding certain attributes and alternatives can be inferred. Another advantage of stated data collection, is the fact that each choice set counts as one observation consequently leading to less respondents required to create reliable parameters.

Limitations of Rum

Despite being a popular method, which is widely applied in research, the method, however, has its limitations. The model is based upon three assumptions that are not always fully realistic. The first of the assumptions of the method is the fact that all relevant variation in utility across individuals and alternatives is captured in the systematic utility function. It is therefore assumed that the unobserved part of the utility function, the error term, are independent from each other. It is therefore assumed that these error terms are not correlated with each other. It is this assumption that leads to the elegant and user-friendly formula.

However, when two or more alternatives 'intuitively' have something in common that is not captured by the systematic utility part of the utility function, this will end up in the unobserved part of the utility function; the error term. Consequently, this results in correlated error terms and therefore one could not say that these error terms are independent from each other. When assuming independent error terms leads to biasness and flawed choice probabilities. Not accounting

this will lead to strange results such as misplaced, counterintuitive or inappropriate choice probabilities (Train, 2009; Vojacek & Pecakova, 2010; Wittink, 2011).

The second assumption holds that the error terms of different alternatives are identically distributed, meaning that the mean, variance and the shape of the function of the errors of different alternatives are identical.

The third assumption is that the error terms of the different alternatives are type 1 Extreme Value distributed.

Together, these three assumptions are known as the independent, identical distributed (i.i.d.) type 1 Extreme Value of the error terms in the RUM-MNL model.

The i.i.d. assumption of the RUM-MNL model results in the limitation of the Independence of Irrelevant Alternatives (IIA). The IIA property entails that the relative popularity of alternative A and B does not depend on C. With this limitation, the RUM-MNL model would decrease the choice probabilities of A and B with same ratio if C increases, even if alternative C competes stronger with alternative A than with alternative B. However, if A and C 'belong' to the same category of alternatives, B should intuitively decrease less than A. Moreover, A should decrease even more than B. This problem is denoted in Train (2009) which is called the red-bus—blue bus problem. The problem is as follows: Imagine a transportation market with two products, a car and red busses. Both transportation services have a market share of 50%. Suppose a second bus service is added to the transportation market, this time blue busses. Assuming the IIA property the blue bus would take market shares equally from the car as the red bus, resulting in a total of 67% market share for the busses and 33% for the car. However, it is more logical to expect that the blue bus would take market share mostly from the red bus, such that the total share of the busses would remain close to 50%.

So, i.i.d. assumptions are required to provide a user-friendly formula to calculate choice probabilities, but when assumed incorrectly, the choice probabilities are flawed, the IIA property enfolds and parameters are biased.

Appendix 4: Survey

Here, the survey that is presented to the respondents is presented.

Vehicle to Grid

Welkom

Geachte heer/mevrouw,

Dank voor uw deelname aan dit onderzoek. Dit onderzoek bestaat uit twee delen: uit een vragenlijst en 12 keuzesets. Het totale onderzoek duurt ongeveer 10 minuten.

Onderwerp

Mijn naam is Jip Zonneveld en ik ben een masterstudent Complex Systems Engineering and Management aan de TU Delft. Mijn onderzoek focust zich op het verkennen van de bereidheid van Nederlanders met een elektrische auto tot deelname in programma's, waarbij de auto voor meer wordt gebruikt dan alleen het verplaatsen van A naar B. Het gebruik van de elektrische auto als bron voor energieopslag, waarbij stroom teruggeleverd kan worden aan het elektriciteitsnet, staat hierbij centraal. Om de bereidheid tot deelname aan dit soort programma's onder gebruikers te onderzoeken heb ik deze enquête opgesteld, die wordt verspreid onder Nederlanders met een elektrische auto.

Alle deelnemers blijven anoniem en de gegevens zullen vertrouwelijk worden behandeld.

Mocht u nog vragen en/of opmerkingen hebben betreffende deze enquête, dan kunt u mij bereiken op j.zonneveld@student.tudelft.nl

0% ————— 100%



Vehicle to Grid

Als onderzoeker wil ik u om toestemming vragen om deel te nemen in het onderzoek naar de bereidbaarheid van Nederlandse elektrische rijders naar Vehicle to Grid. Mochten hier nog vragen over bestaan, dan kunt u mij bereiken op bovenstaand e-mail adres.

Ik heb de intentie van dit onderzoek gelezen en begrepen. Ik heb vragen kunnen stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.

Akkoord

Ik ben een vrijwillige deelnemer in dit onderzoek en ik begrijp dat ik kan weigeren om vragen te beantwoorden. Ik begrijp dat ik mijzelf kan terugtrekken aan deelname aan dit onderzoek, zonder daarvoor een reden te geven.

Akkoord

Ik begrijp dat meedoen in dit onderzoek inhoudt dat ik vragen zal beantwoorden die in deze enquête gepresenteerd worden.

Akkoord

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

Akkoord

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

Akkoord

Ik geef toestemming om de gegevens die ik hier beschikbaar stel op te slaan in de TU Delft Survey database, zodat men hier in de toekomst meer onderzoek naar kan doen of van kan leren.

Akkoord



0% ————— 100%



Vehicle to Grid

Geef een schatting van het aantal uur per dag dat uw elektrische auto aan het opladen is op een van de volgende plaatsen.

Thuis	<input type="text" value="0"/>
Werk	<input type="text" value="0"/>
Onderweg (zoals FastNed)	<input type="text" value="0"/>
Publieke parkeergarage	<input type="text" value="0"/>
Andere plekken	<input type="text" value="0"/>
Total	<input type="text" value="0"/>

Geef aan wat voor u van toepassing is:

Ik lease een elektrische auto

Ik heb een elektrische auto aangeschaft

Anders:

Voor het vervolg van de survey wil ik u vragen zich voor te stellen alsof u een elektrische auto heeft aangeschaft.

Het volgende gedeelte bestaat uit 12 keuzes waarin twee contracten met elkaar vergeleken worden.

Bij de 12 keuzesets wil ik u vragen zich voor te stellen dat u bij het aanschaffen van uw elektrische auto kunt kiezen uit twee verschillende Vehicle to Grid (verder: V2G) contracten. Kies steeds het contract dat het beste bij u past door de verschillende elementen in de contracten te vergelijken. Op de volgende pagina krijgt u een video te zien waarin het concept V2G en de bijbehorende contract elementen uitgelegd worden.



0% 100%





Als u de video (klik hierboven als deze niet zichtbaar is) bekeken heeft en alles duidelijk is, kunt u deze tekst overslaan tot aan het voorbeeld. Daar zijn de contract elementen nogmaals uitgelegd, zodat u deze kunt raadplegen wanneer dat nodig is.

“**Vehicle to grid**” (verder: V2G) is een concept waarbij de batterij van uw elektrische auto wordt gebruikt voor elektriciteitsopslag. Als er genoeg elektriciteit beschikbaar is dan kan de elektrische auto worden opgeladen. Als er te veel vraag is naar elektriciteit, dan kan de energie die nog in uw elektrische auto zit, door te ontladen, teruggeleverd worden aan het elektriciteitsnet. Hiermee zou V2G kunnen bijdragen aan het in balans houden van de vraag en aanbod in elektriciteitsmarkt. Ook kan op deze manier bijvoorbeeld op momenten dat de zon veel schijnt of dat het veel waait, de zonne- en windenergie opgeslagen worden in uw elektrische auto, om dit later te gebruiken op momenten dat er weinig zon- of windenergie beschikbaar is. Voor het terugleveren van elektriciteit krijgt u een vergoeding. Deze is afhankelijk van hoelang u uw auto beschikbaar stelt voor V2G, de zogenaamde plug-in tijd.

Voorbeeld: Hieronder is een voorbeeld weergegeven van een keuze optie.

Welk contract heeft uw voorkeur?

Contract 1		Contract 2	
CONTRACT 1		CONTRACT 2	
VERGOEDING	€3,50 per 10 uur	VERGOEDING	€5,00 per 10 uur
GEGARANDEERD BEREIK	50 km	GEGARANDEERD BEREIK	10 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	7 x per sessie
LENGTE VAN CONTRACT	24 maanden	LENGTE VAN CONTRACT	12 maanden
PLUG IN TIJD	Geen verplichting	PLUG IN TIJD	50h/week

Uitleg van de verschillende contract elementen:

Vergoeding: U ontvangt een vergoeding voor het terugleveren van electriciteit. Dit varieert tussen de €2,00 en €5,00 per 10 uur dat uw auto ingeplugd is.
Gegarandeerde bereik: Dit is het minimale bereik van uw elektrische auto dat beschikbaar blijft gedurende het gebruik van V2G. De batterij zal nooit verder ontladen dan een minimale grens (deze varieert tussen de 10 en 90 km).
Ontladen van de batterij: Hiermee worden de negatieve effecten bedoeld van het meerdere malen ontladen van het elektrische voertuig. Hoe vaker men ontladt, hoe minder lang de batterij namelijk meegaat. Hier wordt gevarieerd tussen de 1 en 10 keer ontladen per laadsessie.
Lengte van het contract: Dit is de duur van het contract, de opties variëren tussen 1 maand en 2 jaar.
Plug-in tijd: De tijd die de elektrische auto per laadsessie beschikbaar moet zijn voor V2G. De minimale plug-in tijd varieert tussen de 0 en 50 uur per week. Op het moment dat u niet aan de verplichte plug-in tijd voldoet, ontvangt u geen vergoeding. Als u vaker voldoet aan de verplichting, ontvangt u een extra vergoeding.

Hieronder zijn de 12 keuze sets weergegeven. Hierbij is de vraag telkens: Ervanuitgaande dat alle andere contract elementen gelijk blijven, welk contract heeft uw voorkeur?

Probeer uw keuze zo realistisch mogelijk te houden.



Vehicle to Grid

1. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€6,00 per 10 uur	VERGOEDING	€10,00 per 10 uur
GEGARANDEERD BEREIK	50 km	GEGARANDEERD BEREIK	10 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	7 x per sessie
LENGTE VAN CONTRACT	24 maanden	LENGTE VAN CONTRACT	12 maanden
PLUG-IN TIJD	Geen verplichtingen	PLUG-IN TIJD	50 uur/week
<input type="radio"/>		<input type="radio"/>	

← [Progress bar] →

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

2. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€6,00 per 10 uur	VERGOEDING	€10,00 per 10 uur
GEGARANDEERD BEREIK	90 km	GEGARANDEERD BEREIK	90 km
ONTLADEN VAN DE BATTERIJ	7 x per sessie	ONTLADEN VAN DE BATTERIJ	1 x per sessie
LENGTE VAN CONTRACT	1 maanden	LENGTE VAN CONTRACT	12 maanden
PLUG-IN TIJD	50 uur/week	PLUG-IN TIJD	Geen verplichtingen

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

3. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€10,00 per 10 uur	VERGOEDING	€6,00 per 10 uur
GEGARANDEERD BEREIK	10 km	GEGARANDEERD BEREIK	50 km
ONTLADEN VAN DE BATTERIJ	7 x per sessie	ONTLADEN VAN DE BATTERIJ	4 x per sessie
LENGTE VAN CONTRACT	12 maanden	LENGTE VAN CONTRACT	24 maanden
PLUG-IN TIJD	50 uur/week	PLUG-IN TIJD	50 uur/week

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

4. Welk contract heeft uw voorkeur?

CONTRACT 1			CONTRACT 2		
VERGOEDING	€10,00 per 10 uur		VERGOEDING	€2,00 per 10 uur	
GEGARANDEERD BEREIK	10 km		GEGARANDEERD BEREIK	10 km	
ONTLADEN VAN DE BATTERIJ	1 x per sessie		ONTLADEN VAN DE BATTERIJ	7 x per sessie	
LENGTE VAN CONTRACT	1 maanden		LENGTE VAN CONTRACT	12 maanden	
PLUG-IN TIJD	25 uur/week	<input type="radio"/>	PLUG-IN TIJD	Geen verplichtingen	<input type="radio"/>

Contract 1 Contract 2

◀ ▶

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

5. Welk contract heeft uw voorkeur?

CONTRACT 1			CONTRACT 2		
VERGOEDING	€2,00 per 10 uur		VERGOEDING	€2,00 per 10 uur	
GEGARANDEERD BEREIK	10 km		GEGARANDEERD BEREIK	10 km	
ONTLADEN VAN DE BATTERIJ	7 x per sessie		ONTLADEN VAN DE BATTERIJ	1 x per sessie	
LENGTE VAN CONTRACT	12 maanden		LENGTE VAN CONTRACT	1 maanden	
PLUG-IN TIJD	Geen verplichtingen	<input type="radio"/>	PLUG-IN TIJD	25 uur/week	<input type="radio"/>

Contract 1 Contract 2

◀ ▶

Zou u de gekozen optie verkiezen boven standaard opladen?

Ja

Nee

6. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€10,00 per 10 uur	VERGOEDING	€10,00 per 10 uur
GEGARANDEERD BEREIK	90 km	GEGARANDEERD BEREIK	10 km
ONTLADEN VAN DE BATTERIJ	1 x per sessie	ONTLADEN VAN DE BATTERIJ	1 x per sessie
LENGTE VAN CONTRACT	12 maanden	LENGTE VAN CONTRACT	1 maanden
PLUG-IN TIJD	Geen verplichtingen	PLUG-IN TIJD	25 uur/week

Zou u de gekozen optie verkiezen boven standaard opladen?

- Ja
- Nee

7. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
REMUNERATION	€6,00 per 10 hours	VERGOEDING	€2,00 per 10 uur
GUARANTEED RANGE	50 km	GEGARANDEERD BEREIK	90 km
DISCHARGING OF THE BATTERY	4 x per session	ONTLADEN VAN DE BATTERIJ	1 x per sessie
CONTRACT DURATION	24 months	LENGTE VAN CONTRACT	12 maanden
PLUG IN TIME	50 hour/week	PLUG-IN TIJD	50 uur/week

Zou u de gekozen optie verkiezen boven standaard laden?

- Ja
- Nee

8. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€10,00 per 10 uur	VERGOEDING	€6,00 per 10 uur
GEGARANDEERD BEREIK	50 km	GEGARANDEERD BEREIK	50 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	4 x per sessie
LENGTE VAN CONTRACT	24 maanden	LENGTE VAN CONTRACT	24 maanden
PLUG-IN TIJD	25 uur/week	PLUG-IN TIJD	Geen verplichtingen

Zou u de gekozen optie verkiezen boven standaard laden?

Ja

Nee

9. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€6,00 per 10 uur	VERGOEDING	€10,00 per 10 uur
GEGARANDEERD BEREIK	90 km	GEGARANDEERD BEREIK	50 km
ONTLADEN VAN DE BATTERIJ	7 x per sessie	ONTLADEN VAN DE BATTERIJ	4 x per sessie
LENGTE VAN CONTRACT	1 maanden	LENGTE VAN CONTRACT	24 maanden
PLUG-IN TIJD	Geen verplichtingen	PLUG-IN TIJD	25 uur/week

Zou u de gekozen optie verkiezen boven standaard laden?

Ja

Nee

10. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€2,00 per 10 uur	VERGOEDING	€6,00 per 10 uur
GEGARANDEERD BEREIK	10 km	GEGARANDEERD BEREIK	90 km
ONTLADEN VAN DE BATTERIJ	1 x per sessie	ONTLADEN VAN DE BATTERIJ	7 x per sessie
LENGTE VAN CONTRACT	1 maanden	LENGTE VAN CONTRACT	1 maanden
PLUG-IN TIJD	25 uur/week	PLUG-IN TIJD	Geen verplichtingen

Zou u de gekozen optie verkiezen boven standaard laden?

Ja

Nee

11. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€2,00 per 10 uur	VERGOEDING	€2,00 per 10 uur
GEGARANDEERD BEREIK	90 km	GEGARANDEERD BEREIK	50 km
ONTLADEN VAN DE BATTERIJ	1 x per sessie	ONTLADEN VAN DE BATTERIJ	4 x per sessie
LENGTE VAN CONTRACT	12 maanden	LENGTE VAN CONTRACT	24 maanden
PLUG-IN TIJD	50 uur/week	PLUG-IN TIJD	25 uur/week

Zou u de gekozen optie verkiezen boven standaard laden?

Ja

Nee

12. Welk contract heeft uw voorkeur?

CONTRACT 1		CONTRACT 2	
VERGOEDING	€2,00 per 10 uur	VERGOEDING	€6,00 per 10 uur
GEGARANDEERD BEREIK	50 km	GEGARANDEERD BEREIK	90 km
ONTLADEN VAN DE BATTERIJ	4 x per sessie	ONTLADEN VAN DE BATTERIJ	7 x per sessie
LENGTE VAN CONTRACT	24 maanden	LENGTE VAN CONTRACT	1 maanden
PLUG-IN TIJD	25 uur/week	PLUG-IN TIJD	50 uur/week

Contract 1 Contract 2

Zou u de gekozen optie verkiezen boven standaard laden?

Ja

Nee



0% 100%



Wat is uw jaarlijks inkomen?

<20.000

20.000-35.000

35.000-70.000

>70.000

Wat is uw hoogst behaalde diploma?

Geen/lager- of basisonderwijs

VMBO/MAVO

MBO

HAVO/VWO

HBO

WO

Anders:



0% — 100%



Wat is uw leeftijd?

<25

25-34

35-44

45-54

55-64

>65

We thank you for your time spent taking this survey.
Your response has been recorded.

0% — 100%

Appendix 5: MNL estimations

Basic MNL model

Parameters to be estimated

BETA_GE = Beta('BETA_GE',0,-1000,1000,0)

BETA_RE = Beta('BETA_RE',0,-1000,1000,0)

BETA_DI = Beta('BETA_DI',0,-1000,1000,0)

BETA_CD = Beta('BETA_CD',0,-1000,1000,1)

BETA_PI = Beta('BETA_PI',0,-1000,1000,1)

V1 = BETA_ASC + GE1 * BETA_GE + RE1 * BETA_RE + DI1 * BETA_DI + CD1 * BETA_CD + PI1 * BETA_PI

V2 = BETA_ASC + GE2 * BETA_GE + RE2 * BETA_RE + DI2 * BETA_DI + CD2 * BETA_CD + PI2 * BETA_PI

V3 = 0

```

      Number of estimated
      parameters: 6
      Sample size: 1152
      Excluded observations: 0
      Init log likelihood: -1265.601
      Final log likelihood: -1030.855
      Likelihood ratio test for
      the init. model: 469.493
      Rho-square for the init.
      model: 0.185
      Rho-square-bar for the init.
      model: 0.181
      Akaike Information
      Criterion: 2073.710
      Bayesian Information
      Criterion: 2104.005
      Final gradient norm: +1.384e-003
      Diagnostic: Trust region algorithm with simple bounds
      (CGT2000): Convergence reached...
      Iterations: 7
      Data processing time: 00:00
      Run time: 00:00
      Nbr of threads: 2

```

Estimated parameters

Name	Value	Std err	t- test	p- value	Robust Std err	Robust t- test	p- value
------	-------	---------	------------	-------------	-------------------	-------------------	-------------

BETA_ASC	-2.29	0.237	-9.66	0.00		0.245	-9.35	0.00	
BETA_CD	-0.00703	0.00579	-1.21	0.22	*	0.00542	-1.30	0.20	*
BETA_DI	-0.0932	0.0216	-4.31	0.00		0.0222	-4.20	0.00	
BETA_GE	0.0182	0.00174	10.45	0.00		0.00177	10.26	0.00	
BETA_PI	-0.00443	0.00258	-1.72	0.09	*	0.00262	-1.69	0.09	*
BETA_RE	0.146	0.0183	7.97	0.00		0.0193	7.57	0.00	

Results in 5 estimated parameters, CD insignificant

Low correlations between the parameters

Coefficient 1	Coefficient 2	Covariance	Correlation	t-test	p-value	Rob. cov.	Rob. corr.	Rob. t-test	p-value
BETA_CD	BETA_PI	9.97e-007	0.0668	-0.42	0.67	1.76e-006	0.124	-0.45	0.65
BETA_DI	BETA_PI	-3.84e-006	-0.0688	-4.04	0.00	-5.47e-006	0.0940	-3.93	0.00
BETA_CD	BETA_DI	2.34e-005	0.187	4.04	0.00	2.14e-005	0.178	3.94	0.00
BETA_CD	BETA_GE	1.16e-006	0.115	-4.31	0.00	1.02e-006	0.106	-4.57	0.00
BETA_DI	BETA_GE	-1.43e-006	-0.0379	-5.12	0.00	-6.13e-006	0.156	-4.94	0.00
BETA_GE	BETA_RE	5.57e-006	0.175	-7.06	0.00	7.32e-006	0.214	-6.73	0.00
BETA_CD	BETA_RE	-4.67e-006	-0.0441	-7.87	0.00	-1.11e-006	0.0106	-7.62	0.00
BETA_GE	BETA_PI	9.91e-007	0.221	8.16	0.00	9.44e-007	0.203	7.94	0.00
BETA_PI	BETA_RE	8.08e-006	0.171	-8.33	0.00	1.16e-005	0.230	-7.98	0.00
BETA_DI	BETA_RE	6.84e-006	0.0173	-8.51	0.00	3.63e-005	0.0848	-8.49	0.00
BETA_ASC	BETA_DI	-0.00192	-0.373	-8.93	0.00	0.00182	0.334	-8.68	0.00
BETA_ASC	BETA_CD	-0.000555	-0.404	-9.53	0.00	0.000534	0.402	-9.24	0.00

BETA_ASC	BETA_PI	-0.000271	-0.443	-9.59	0.00	-0.000294	-0.457	-9.29	0.00
BETA_ASC	BETA_GE	-0.000248	-0.599	-9.69	0.00	-0.000247	-0.568	-9.39	0.00
BETA_ASC	BETA_RE	-0.00267	-0.615	-9.79	0.00	-0.00327	-0.691	-9.42	0.00

MNL with non-linearity

Parameters to be estimated

BETA_GE = Beta('BETA_GE1',0,-1000,1000,0)

BETA_RE1 = Beta('BETA_RE1',0,-1000,1000,0)

BETA_DI1 = Beta('BETA_DI1',0,-1000,1000,0)

BETA_CD = Beta('BETA_CD1',0,-1000,1000,0)

BETA_PI = Beta('BETA_PI1',0,-1000,1000,0)

BETA_ASC = Beta('BETA_ASC',0,-1000,1000,0)

BETA_RE2 = Beta('BETA_RE2',0,-1000,1000,0)

BETA_DI2 = Beta('BETA_DI2',0,-1000,1000,0)

V1 = BETA_ASC + GE1 * BETA_GE + R1d * BETA_RE1 + R2d * BETA_RE2 + D1d * BETA_DI1 + D2d * BETA_DI2 + CD1 * BETA_CD + PI1 * BETA_PI

V2 = BETA_ASC + GE2 * BETA_GE + R1b * BETA_RE1 + R2b * BETA_RE2 + D1b * BETA_DI1 + D2b * BETA_DI2 + CD2 * BETA_CD + PI2 * BETA_PI

V3 = 0

```

      Number of estimated
      parameters: 8
      Sample size: 1152
      Excluded observations: 0
      Init log likelihood: -1265.601
      Final log likelihood: -1017.717
      Likelihood ratio test for
      the init. model: 495.768
      Rho-square for the init.
      model: 0.196
      Rho-square-bar for the init.
      model: 0.190
      Akaike Information
      Criterion: 2051.434

```

Bayesian Information Criterion: 2091.828
Final gradient norm: +9.828e-004
Diagnostic: Trust region algorithm with simple bounds (CGT2000): Convergence reached...
Iterations: 8
Data processing time: 00:00
Run time: 00:00
Nbr of threads: 2

Estimated parameters

Name	Value	Std err	t-test	p-value		Robust Std err	Robust t-test	p-value	
BETA_ASC	-2.33	0.224	-10.38	0.00		0.237	-9.84	0.00	
BETA_CD1	0.0489	0.0154	3.17	0.00		0.0155	3.15	0.00	
BETA_DI1	-0.421	0.165	-2.56	0.01		0.166	-2.54	0.01	
BETA_DI2	-1.48	0.354	-4.19	0.00		0.355	-4.18	0.00	
BETA_GE1	0.0159	0.00218	7.33	0.00		0.00217	7.34	0.00	
BETA_PI1	-0.00483	0.00256	-1.89	0.06	*	0.00254	-1.90	0.06	*
BETA_RE1	1.14	0.145	7.86	0.00		0.147	7.75	0.00	
BETA_RE2	0.654	0.223	2.93	0.00		0.229	2.86	0.00	

Correlation of coefficients

Coefficien t1	Coefficien t2	Covariance	Correlation	t-test	p-value	Rob. cov.	Rob. corr.	Rob. t-test	p-value
BETA_CD1	BETA_GE1	-1.32e-005	-0.392	2.01	0.04	-1.31e-005	-0.388	2.00	0.05
BETA_ASC	BETA_DI2	0.0125	0.157	-2.17	0.03	0.0159	0.189	-2.18	0.03
BETA_RE1	BETA_RE2	0.0162	0.500	2.48	0.01	0.0171	0.507	2.44	0.01
BETA_DI1	BETA_PI1	-4.07e-005	-0.0967	-2.52	0.01	-5.90e-005	-0.140	-2.50	0.01

BETA_DI1	BETA_GE1	0.000150	0.418	-2.67	0.01	0.000158	0.438	-2.65	0.01
BETA_CD1	BETA_RE2	0.00209	0.605	-2.82	0.00	0.00229	0.646	-2.77	0.01
BETA_CD1	BETA_DI1	-0.000528	-0.208	2.79	0.01	0.000528	-0.205	2.77	0.01
BETA_GE1	BETA_RE2	-0.000251	-0.516	-2.84	0.00	0.000246	-0.496	-2.78	0.01
BETA_PI1	BETA_RE2	9.36e-005	0.164	-2.96	0.00	0.000137	0.237	-2.89	0.00
BETA_DI1	BETA_RE2	-0.0207	-0.564	-3.12	0.00	-0.0204	-0.538	-3.10	0.00
BETA_DI1	BETA_DI2	0.0294	0.504	3.47	0.00	0.0295	0.501	3.46	0.00
BETA_CD1	BETA_PI1	3.51e-006	0.0890	3.49	0.00	7.49e-006	0.190	3.52	0.00
BETA_DI2	BETA_RE2	-0.0580	-0.733	-3.96	0.00	-0.0611	-0.753	-3.90	0.00
BETA_CD1	BETA_DI2	-0.00479	-0.877	4.17	0.00	0.00484	-0.878	4.16	0.00
BETA_DI2	BETA_PI1	-6.94e-005	-0.0766	-4.18	0.00	0.000135	-0.150	-4.16	0.00
BETA_DI2	BETA_GE1	0.000411	0.534	-4.25	0.00	0.000417	0.540	-4.24	0.00
BETA_ASC	BETA_DI1	-0.0110	-0.298	-6.05	0.00	-0.0121	-0.309	-5.81	0.00
BETA_GE1	BETA_PI1	4.61e-007	0.0828	6.46	0.00	6.76e-008	0.0123	6.26	0.00
BETA_DI2	BETA_RE1	-0.00689	-0.134	-6.56	0.00	0.00878	-0.168	-6.46	0.00
BETA_DI1	BETA_RE1	-0.00260	-0.109	-6.76	0.00	0.000957	-0.0392	-6.91	0.00

BETA_CD1	BETA_RE1	0.000214	0.0954	-7.55	0.00	0.000380	0.166	-7.51	0.00
BETA_GE1	BETA_RE1	8.25e-006	0.0261	-7.75	0.00	2.07e-005	0.0646	-7.65	0.00
BETA_PI1	BETA_RE1	5.21e-005	0.140	-7.91	0.00	5.54e-005	0.148	-7.80	0.00
BETA_ASC	BETA_RE2	-0.0126	-0.252	-8.42	0.00	-0.0168	-0.311	-7.92	0.00
BETA_ASC	BETA_CD1	-0.00145	-0.418	-10.28	0.00	-0.00171	-0.466	-9.73	0.00
BETA_ASC	BETA_PI1	-0.000249	-0.433	-10.30	0.00	-0.000257	-0.427	-9.77	0.00
BETA_ASC	BETA_GE1	-0.000214	-0.438	-10.40	0.00	-0.000215	-0.417	-9.87	0.00
BETA_ASC	BETA_RE1	-0.0152	-0.465	-10.88	0.00	-0.0186	-0.533	-10.23	0.00

Smallest singular value: 5.89961

Income and charging location

Parameters to be estimated

BETA_GE = Beta('BETA_GE1',0,-1000,1000,0)

BETA_RE1 = Beta('BETA_RE1',0,-1000,1000,0)

BETA_DI1 = Beta('BETA_DI1',0,-1000,1000,0)

BETA_CD = Beta('BETA_CD1',0,-1000,1000,0)

BETA_PI = Beta('BETA_PI1',0,-1000,1000,0)

BETA_ASC = Beta('BETA_ASC',0,-1000,1000,0)

BETA_RE2 = Beta('BETA_RE2',0,-1000,1000,0)

BETA_DI2 = Beta('BETA_DI2',0,-1000,1000,0)

V1 = BETA_ASC + GE1 * BETA_GE + RE1 * BETA_RE + DI1 * BETA_DI + CD1 * BETA_CD + BETA_PI * PI1 + BETA_ink * RE1 * ink + BETA_inc * ink

$$V2 = \text{BETA_ASC} + \text{GE2} * \text{BETA_GE} + \text{RE2} * \text{BETA_RE} + \text{DI2} * \text{BETA_DI} + \text{CD2} * \text{BETA_CD} + \text{BETA_PI} * \text{PI2} + \text{BETA_ink} * \text{RE2} * \text{ink} + \text{BETA_inc} * \text{ink}$$

$$V3 = 0$$

Estimated parameters

Name	Value	Std err	t-test	p-value		Robust Std err	Robust t-test	p-value	
BETA_ASC	0.341	0.893	0.38	0.70	*	0.914	0.37	0.71	*
BETA_CD	-0.00687	0.00584	-1.18	0.24	*	0.00550	-1.25	0.21	*
BETA_DI	-0.0935	0.0217	-4.30	0.00		0.0224	-4.17	0.00	
BETA_GE	0.00852	0.0124	0.68	0.49	*	0.0128	0.67	0.50	*
BETA_PI	-0.00443	0.00260	-1.70	0.09	*	0.00264	-1.68	0.09	*
BETA_RE	0.137	0.0229	5.99	0.00		0.0246	5.57	0.00	
BETA_home	0.00801	0.00776	1.03	0.30	*	0.00794	1.01	0.31	*
BETA_inc	-0.624	0.278	-2.25	0.02		0.279	-2.24	0.03	
BETA_ink	0.0293	0.0372	0.79	0.43	*	0.0374	0.78	0.43	*
BETA_loc1	-1.79	0.539	-3.33	0.00		0.549	-3.26	0.00	
BETA_loc2	-0.882	0.363	-2.43	0.02		0.370	-2.38	0.02	
BETA_work	0.00346	0.00519	0.67	0.50	*	0.00533	0.65	0.52	*

Correlation of coefficients

Click on the headers of the columns to sort the table [[Credits](#)]

Coefficient1	Coefficient2	Covariance	Correlation	t-test	p-value		Rob. cov.	Rob. corr.	Rob. t-test	p-value
BETA_GE	BETA_home	-9.12e-005	-0.945	0.03	0.98	*	-9.58e-005	-0.947	0.02	0.98 *

BETA_ASC	BETA_RE	-0.00332	-0.162	0.2 3	0.82	*	- 0.0051 0	-0.227	0.2 2	0.82	*
BETA_GE	BETA_work	-6.32e- 005	-0.979	0.2 9	0.77	*	- 6.65e- 005	-0.979	0.2 8	0.78	*
BETA_ASC	BETA_ink	0.00244	0.0734	0.3 5	0.73	*	0.0041 4	0.121	0.3 4	0.73	*
BETA_ASC	BETA_GE	-0.00889	-0.801	0.3 7	0.71	*	- 0.0094 1	-0.808	0.3 6	0.72	*
BETA_ASC	BETA_home	0.00517	0.747	0.3 8	0.71	*	0.0054 9	0.758	0.3 7	0.71	*
BETA_ASC	BETA_work	0.00364	0.785	0.3 8	0.70	*	0.0038 4	0.789	0.3 7	0.71	*
BETA_ASC	BETA_PI	- 0.000278	-0.120	0.3 9	0.70	*	- 0.0003 39	-0.141	0.3 8	0.71	*
BETA_ASC	BETA_CD	- 0.000475	-0.0912	0.3 9	0.70	*	- 0.0002 40	- 0.0477	0.3 8	0.70	*
BETA_CD	BETA_PI	1.10e- 006	0.0727	- 0.3 9	0.69	*	1.78e- 006	0.122	- 0.4 2	0.67	*
BETA_ASC	BETA_DI	-0.00185	-0.0953	0.4 9	0.63	*	- 0.0012 7	- 0.0620	0.4 7	0.63	*
BETA_GE	BETA_ink	1.17e- 005	0.0253	- 0.5 3	0.59	*	7.42e- 006	0.0155	- 0.5 3	0.60	*
BETA_home	BETA_ink	-4.88e- 006	-0.0169	- 0.5 6	0.58	*	- 5.75e- 006	- 0.0193	- 0.5 5	0.58	*
BETA_inc	BETA_loc2	0.00233	0.0231	0.5 7	0.57	*	0.0026 9	0.0260	0.5 6	0.57	*
BETA_ink	BETA_work	-5.03e- 006	-0.0261	0.6 9	0.49	*	- 4.62e- 006	- 0.0232	0.6 8	0.50	*

BETA_PI	BETA_ink	2.81e-006	0.0291	-0.91	0.36	*	-4.64e-006	-0.0469	-0.90	0.37	*
BETA_CD	BETA_ink	3.34e-007	0.00154	-0.96	0.34	*	4.43e-006	0.0215	-0.96	0.34	*
BETA_ASC	BETA_loc2	-0.307	-0.948	0.98	0.33	*	-0.319	-0.944	0.96	0.34	*
BETA_ASC	BETA_inc	-0.0310	-0.125	1.00	0.32	*	-0.0412	-0.161	0.97	0.33	*
BETA_GE	BETA_PI	1.06e-006	0.0327	1.03	0.30	*	1.32e-006	0.0393	1.00	0.32	*
BETA_CD	BETA_GE	-3.50e-007	-0.00482	-1.12	0.26	*	-1.84e-006	-0.0261	-1.10	0.27	*
BETA_home	BETA_work	3.63e-005	0.900	1.19	0.23	*	3.81e-005	0.902	1.17	0.24	*
BETA_PI	BETA_work	-2.19e-008	-0.00162	-1.36	0.17	*	-1.59e-007	-0.0113	-1.32	0.19	*
BETA_CD	BETA_work	5.59e-007	0.0184	-1.34	0.18	*	1.14e-006	0.0389	-1.38	0.17	*
BETA_PI	BETA_home	4.95e-009	0.000245	-1.52	0.13	*	-2.64e-007	-0.0126	-1.48	0.14	*
BETA_ASC	BETA_loc1	-0.438	-0.910	1.52	0.13	*	-0.457	-0.910	1.49	0.14	*
BETA_CD	BETA_home	1.27e-006	0.0281	-1.55	0.12	*	2.03e-006	0.0465	-1.58	0.12	*
BETA_DI	BETA_inc	-7.33e-005	-0.0121	1.90	0.06	*	4.09e-005	0.00655	1.90	0.06	*
BETA_RE	BETA_ink	-0.000505	-0.593	2.00	0.05		-0.000577	-0.625	1.92	0.06	*
BETA_inc	BETA_loc1	0.00238	0.0159	1.94	0.05	*	0.00471	0.0307	1.92	0.05	*

BETA_inc	BETA_ink	-0.00909	-0.880	-	2.1	0.04	-	0.0092	-0.881	-	2.0	0.04
				0			1			9		
BETA_DI	BETA_loc2	-2.53e-005	-0.00321	2.1	7	0.03	-	0.0002	-	2.1	2	0.03
							35		0.0284			
BETA_CD	BETA_inc	-2.16e-006	-0.00133	2.2	2	0.03	-	2.18e-005	-	2.2	1	0.03
									0.0142			
BETA_PI	BETA_inc	-1.84e-005	-0.0256	2.2	3	0.03	-	3.66e-005	0.0497	2.2	2	0.03
BETA_inc	BETA_work	3.42e-005	0.0238	-	2.2	0.02	-	5.30e-005	0.0357	-	2.2	0.02
				6						5		
BETA_GE	BETA_inc	-8.49e-005	-0.0246	2.2	7	0.02	-	8.41e-005	-	2.2	6	0.02
									0.0236			
BETA_home	BETA_inc	3.16e-005	0.0147	2.2	8	0.02	-	5.26e-005	0.0237	2.2	7	0.02
BETA_CD	BETA_loc2	-3.38e-005	-0.0160	2.4	1	0.02	-	0.0001	-	2.3	6	0.02
							20		0.0588			
BETA_loc2	BETA_work	-0.00157	-0.834	-	2.4	0.02	-	0.0016	-0.842	-	2.3	0.02
				1			6			6		
BETA_home	BETA_loc2	-0.00209	-0.741	2.4	1	0.02	-	0.0022	-0.754	2.3	7	0.02
							1					
BETA_PI	BETA_loc2	3.84e-006	0.00408	2.4	2	0.02	-	1.37e-005	0.0140	2.3	7	0.02
BETA_ink	BETA_loc2	0.000296	0.0219	2.5	0	0.01	-	1.32e-005	-	2.4	5	0.01
									0.0009			
BETA_GE	BETA_loc2	0.00365	0.810	2.5	2	0.01	0.0038	7	0.821	2.4	8	0.01
BETA_RE	BETA_loc2	-	-0.0234	2.8	0	0.01	8.21e-005	2	0.0090	2.7	5	0.01
		0.000194										

BETA_DI	BETA_ink	1.34e-005	0.0165	-2.87	0.00	8.78e-006	0.0105	-2.83	0.00
BETA_RE	BETA_inc	0.00322	0.506	2.85	0.00	0.00380	0.553	2.86	0.00
BETA_DI	BETA_loc1	-7.02e-005	-0.00599	3.15	0.00	-0.000475	-0.0386	3.09	0.00
BETA_home	BETA_loc1	-0.00345	-0.824	3.30	0.00	-0.00364	-0.835	3.24	0.00
BETA_loc1	BETA_work	-0.00209	-0.747	-3.31	0.00	-0.00221	-0.755	-3.25	0.00
BETA_CD	BETA_loc1	-7.76e-005	-0.0247	3.31	0.00	-0.000196	-0.0649	3.25	0.00
BETA_PI	BETA_loc1	4.53e-006	0.00324	3.32	0.00	2.74e-005	0.0189	3.26	0.00
BETA_ink	BETA_loc1	0.000255	0.0127	3.38	0.00	-0.000195	-0.00949	3.31	0.00
BETA_GE	BETA_loc1	0.00521	0.777	3.40	0.00	0.00552	0.788	3.34	0.00
BETA_loc1	BETA_loc2	0.176	0.899	-3.43	0.00	0.183	0.900	-3.37	0.00
BETA_RE	BETA_loc1	-0.000279	-0.0226	3.58	0.00	0.000230	0.0170	3.51	0.00
BETA_DI	BETA_GE	-4.00e-006	-0.0148	-4.05	0.00	-1.28e-005	-0.0448	-3.88	0.00
BETA_DI	BETA_PI	-3.81e-006	-0.0676	-4.03	0.00	-5.78e-006	-0.0977	-3.91	0.00
BETA_CD	BETA_DI	2.41e-005	0.190	4.04	0.00	2.21e-005	0.180	3.92	0.00

BETA_DI	BETA_work	9.23e-007	0.00818	-4.34	0.00	2.83e-006	0.0238	-4.23	0.00
BETA_DI	BETA_home	2.11e-006	0.0125	-4.41	0.00	4.99e-006	0.0281	-4.31	0.00
BETA_GE	BETA_RE	1.65e-006	0.00580	-4.95	0.00	9.64e-006	0.0307	-4.70	0.00
BETA_RE	BETA_home	1.79e-006	0.0101	5.36	0.00	-1.98e-006	-0.0101	4.98	0.00
BETA_RE	BETA_work	1.68e-006	0.0141	5.71	0.00	-4.13e-007	-0.00315	5.30	0.00
BETA_CD	BETA_RE	-4.71e-006	-0.0352	-6.04	0.00	-3.54e-006	-0.0261	-5.68	0.00
BETA_PI	BETA_RE	6.97e-006	0.117	-6.23	0.00	1.28e-005	0.197	-5.84	0.00
BETA_DI	BETA_RE	2.48e-006	0.00499	-7.32	0.00	3.43e-005	0.0621	-7.15	0.00

Smallest singular value: 0.853341