The effect of contract attributes on the willingness to participate in V2G contract for EV and non-EV drivers in the Netherlands

A Discrete Choice Modelling Research

Sebastian E. Margry

Master Thesis Report

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A Discrete Choice Modelling Research

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Cover image: https://greenfleet.net/features/02022021/v2g-technology-whats-it-fleets

PREFACE

Dear Reader,

I am pleased to present the findings of my Master Thesis, completed in fulfillment of the MSc program in Complex Systems Engineering and Management (CoSEM) at Delft University of Technology. This thesis investigates the factors that influence the willingness of Dutch car drivers to participate in Vehicle-to-Grid (V2G) contracts, a promising technology that enables the use of renewable energy storage and provides a source of grid stabilization.

I would like to express my gratitude to my supervisors for their invaluable guidance and feedback throughout the research process. Eric Molin's expertise in the field of Choice Modeling provided invaluable support for the realization of this Thesis. Furthermore, I would like to thank Jerico Bakhuis for his regular meetings and guiding me through the research design process. I also want to thank Emile Chappin for his personal support, and his wife for kindly recording the text of my explanation video in the survey.

Lastly, I would like to thank my parents for their unconditional support and encouragement, even during the most challenging times.

Finally, I hope that this thesis will contribute to the existing body of knowledge in my field of study and serve as a starting point for future research.

Sebastian Margry
Amsterdam, May 2023

ABSTRACT

This study examines the relative importance of contract attributes in the context of Vehicle-to-Grid (V2G) contracts by means of a choice experiment. The experiment was conducted with 67 Dutch car drivers, including both EV drivers and non-EV drivers. They were asked to choose between two V2G contracts with different contract attributes and an option “no V2G contract”. The contract attributes had varying levels of remuneration, guaranteed minimum driving range, and required plug-in time during weekdays and weekends. The data collected was analyzed using a Multinomial Logit model (MNL) to estimate the utility function of the V2G contracts and to identify the most important attributes for the respondents. Besides, an estimation could be made on the preference of a V2G contract over no contract at all. The results showed that, surprisingly, the attribute remuneration had a relatively low importance coefficient and did not have a significant impact on the perceived utility of the respondents. On the other hand, it could be proved that consumers perceive different utility during weekdays and weekends, preferring more flexibility in the weekends. Guaranteed minimum driving range resulted to be the most important contract attribute. The results show that there is a relatively high willingness to participate in V2G contract both among EV-drivers as potential future EV-drivers. The results can be used for policymakers and aggregator companies to design more effectively V2G contracts and to promote the adoption of EVs in a more sustainable way enhancing the energy transition. According to this study the V2G system results to be profitable for the aggregator for various scenarios and really promising. Some application possibilities are suggested in this research, and from them could be concluded that there can be achieved satisfaction for all stakeholders involved.

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LIST OF ABBREVIATIONS

V2G	Vehicle-to-Grid
RES	Renewable Energy Sources
EV	Electric Vehicle
TSO	Transmission System Operator
DSO	Distribution System Operator
BRPs	Balance Responsible Parties
BSPs	Balance Service Providers
MNL	Multinomial Logit
RUM	Random Utility Maximization

1. INTRODUCTION

In 2019 the transportation sector accounted for approximately 17% of worldwide greenhouse gas emissions, being the second largest CO_2 emitting sector after the electricity and heat sector, which accounted for 31% of the world's greenhouse gas emissions (Ritchie et al., 2020). For the Netherlands, this amount was calculated at 14%, being the third largest emitting sector after the electricity and heat sector (28%) and the aviation and shipping sector (22%) (Ritchie et al., 2020). Under the 2015 Paris Agreement, nations agreed to take policy measures to limit global warming to 2.0 degrees Celsius, preferably 1.5 degrees Celsius, by reducing greenhouse gas emissions, the primary cause of anthropological climate change (UNFCCC, 2015). The Dutch Government adjusted its policy in line with this Agreement and presented a Climate Agreement in 2019, aiming to reduce greenhouse gas emissions in the Netherlands by 49% in 2030 compared to 1990 levels, and eventually achieve climate neutrality in 2050 (Government of the Netherlands, 2019). The commitments are divided per sector and consist of built environment, mobility, industry, agriculture and land use, and electricity. There is also an emphasis on cross-sector system integration, since combining different industries can enhance the integration of renewable energy sources (RES).

In compliance with the Climate Agreement, the Netherlands has the ambition of zero-emission for passenger vehicles by 2030 (NEA, 2022). Therefore, the Dutch Government is stimulating the use and development of electric vehicles (EVs), considering them a promising technology. It does this by tax incentives and creating awareness. Moreover, it supports companies that offer renewable energy products through governmental partnership programs (NEA, 2022). The results have led to a yearly increase in EV sales. In 2021 30% of the newly sold passenger cars were EVs, having the fourth highest market share after Norway (86%), Iceland (72%), and Sweden (43%). Furthermore, the Netherlands benefits from having the second highest public charger to vehicle ratio after Korea, with four EVs per charger (IEA, 2022).

However, large-scale implementation of EVs with a large share of intermittent energy resources (i.e., wind and solar power) in the electricity grid causes challenges. A high share of EVs in a local area will lead to high electric power demand, which can cause voltage fluctuation and supply shortages (Bibak & Tekiner-Moğulkoç, 2021). On the other hand, the intermittent nature of RES can cause surpluses in electricity production, for example, when there is much wind but low demand, and a deficit when there is no sun in the evening while charging demand from EVs is high. These challenges call for efficient system integration to coordinate supply to demand. A possible solution is by linking the power and transport sectors (Robinius et al., 2017). Fluctuations of wind and solar power call for the necessity of storage options. While currently batteries are not suitable for long-term storage of high quantities, they could serve as grid-stabilizing components with a short response time, for example in EV batteries (Robinius et al., 2017).

Vehicle to Grid (V2G) is a concept that deals with the aforementioned challenges, by connecting the energy and transport sectors. This technology enables a bi-directional energy flow between the electricity grid and the plugged EV, in which the EV acts as a kind of battery (V2GHub, 2022). The advantage of such a technology is that it can provide a solution for the intermittent nature of RES. During off-peak demand, unused power from intermittent RES will be wasted. The V2G technology can be used to store off-peak demand power. During peak demand, the energy stored in EVs can be discharged to provide demand response services to the grid to manage load variations (Hannan et al., 2022; V2GHub, 2022). This can lead to a decrease in the costs of backup power generation since it decreases the dependency on central power plants during peak loads (Bibak & Tekiner-Moğulkoç, 2021). In return, the V2G participant can get a remuneration for the experienced discomfort or a compensation on its energy bill. The participant needs to be incentivized in some manner to participate in the V2G system.

Moreover, V2G can provide grid stability. The transition from fossil fuel sources to renewable sources focuses on the electrification of many industries, such as district heating, steel industry, transport industry, hydrogen production, and many more. The electrification of these industries will lead to a significant increase in electricity demand. V2G can play an important role in providing grid stability, offering flexibility in frequency regulation, and hence manage overcapacity.

Currently, the technology is still in pilot phase. According to V2G Hub (2022), at this moment 107 projects are running across 25 countries (of which 14 in the Netherlands) and 50 projects were identified to have physical deployment of V2G technology for a specific use case (Everoze & EV Consult, 2018). Since V2G is still in pilot phase, there are many barriers to overcome, such as range anxiety, unwillingness to accept a third party to access the EV battery, battery degradation and complexity. Although most of the literature is focused on technical or economic aspects, there are also barriers in the social domain which are less subject of study (Sovacool et al., 2018). The adoption of V2G can offer a valuable source of energy storage and accelerate more efficient EV integration in a future energy system with RES (Baumgartner et al., 2022). The success of V2G is strongly related to the willingness to participate in V2G programs. However, the existing knowledge about drivers' preferences for participating in V2G is limited (Kubli, 2022).

The literature on willingness to participate in V2G has gradually been growing over the years. A useful instrument to assess the willingness to participate is through choice models. A few studies (e.g.: Parsons et al., 2014; Geske & Schumann, 2018; Noel et al., 2019a; Zonneveld, 2019; Huang et al., 2021; Kajanova et al., 2022) used this method to analyze the consumer's willingness to participate in V2G programs. By subjecting respondents to hypothetical choices, they acquire information about consumer preferences and under what circumstances they are willing to participate in V2G programs. This knowledge is essential for the implementation of such a system. Most of these studies concluded that consumers are only willing to participate against high remunerations for their experienced discomfort. The greatest influencing factors in this respect are the minimum guaranteed driving range and their range anxiety (Tepe et al., 2022). It would be interesting to know whether eliminating these barriers will influence the willingness to participate. Many studies focusing on social aspects identify range anxiety as an important barrier. But only Huang et al. (2021) have tested the elimination of range anxiety in relation with V2G in a choice model. They designed a choice model with two contexts, one in a hypothetical situation where fast charging is possible, minimizing the range anxiety barrier, and another with the current charging situation. They concluded that in a fast-charging situation, i.e., charge EV to 100% within 5 minutes, consumers are more willing to participate (Huang et al., 2021). Krueger & Cruden (2020) suggest that enabling EV users to state charging preferences via simple user interfaces might increase the acceptance of V2G and hence reduce the range anxiety barrier. Also, Geske & Schumann (2018) suggest, reflecting on their performed choice experiment, that it would be interesting to specify the timing of the 'next trip' and the minimum range input more accurately. The resulting predictability could be rewarded by a special remuneration, enhancing the willingness to participate.

The literature review has provided valuable information on the willingness to participate in V2G contracts and the most important contract attributes that influence this willingness. However, further research is necessary to gain a deeper understanding of the preferences of Dutch car drivers. One gap in previous research is the difference between weekdays and weekends, which could provide valuable insights for the aggregator when shaping the contracts. Knowing whether the preferences of EV drivers differ between weekdays and weekends is important because it can impact the aggregator's ability to design the V2G contract that would be appealing to the target group. The preferences and behavior of EV drivers might differ during the week when they are commuting to work compared to the weekends when they have more leisure time and potentially different charging needs. This can improve the chances of EV drivers to participate in V2G contracts and increase the overall success of the program. By taking into account the differences in preference between weekdays and weekends, the aggregator can create a more attractive V2G contract, which can result in higher participation rates and a more successful program overall. Additionally, the findings of these questions could inform policies and regulations related to the promotion of sustainable transport and the development of a V2G system. The results could have a potential contribution to the creation of a more sustainable and efficient energy system for society. Considering that, according to Dutch Policy, all newly sold cars must be electric from 2030 and 70% of all electricity generated must be from wind and solar power (Rijksoverheid, 2022), a V2G system could become more important in the future to ensure reliability of the energy supply.

Therefore, to address this gap in the literature, the following research question is formulated:

What is the impact of contract attributes on the willingness of Dutch car drivers to participate in V2G contracts?

To answer the main question, the following sub questions are formulated:

Sub 1: ***What contract attributes currently identified in the literature have an influence on the participation in V2G?***

Sub 2: ***What is the effect on the willingness to participate when weekdays and weekends are distinguished in the contracts?***

The aim of this research is to gain new empirical insights into consumer behavior regarding participation in V2G contracts. Although this is not the first study performing a choice experiment with V2G contracts, this study seeks to find new insights with respect to new contract attributes. Specifically, this research investigates whether there is a difference in preference between minimum plug-in time during weekdays and in the weekend. Furthermore, as people are becoming more aware, and the previous studies are somewhat outdated, this study also includes non-EV drivers such that their preferences can be distinguished from those of EV drivers.

In this way, also a contribution is made to society. Better knowledge of consumer's preferences with respect to V2G can be useful for future actors and policymakers in the design of the V2G system, in particular, V2G contracts. Apart from the direct actors involved in V2G, society as a whole could benefit from the implementation, since the system can enhance grid stability and reliability. And last but not least, it can contribute to the integration of renewable energy sources, which are considered as the main energy sources that can contribute to tackling climate change. Hence, enhancing the acceleration of integrated renewable energy systems where V2G may play a vital role. In order to gain these new empirical insights, a choice experiment will be designed and performed to test the hypothesis on the willingness to participate in V2G contracts.

To answer the research question, a stated choice experiment will be designed based on the findings in the literature. This choice experiment will hence be distributed through a survey among Dutch car drivers. The survey will be designed in Qualtrics and include an explanatory video which will be tested such that it is understandable for the respondents what is the survey about. The aim is to receive at least 100 responses. After that, the acquired data will be analyzed by estimating a Multinomial Logit model based on the Random Utility Maximization theory. This is an effective way to infer the preferences of the respondents on the V2G contracts. The estimated parameters give insights in the preferences and their distribution among the different contract attributes. This will be further explained in Chapter 4.

The remainder of this research is as follows. Chapter 2 will provide background knowledge regarding V2G that is necessary for understanding the theory behind V2G, its related actors and the possible contractual structures with consumers. Chapter 3 provides a literature review on the yet performed studies with respect to the willingness to participate in V2G. This will conclude with a knowledge gap that will be further used for the design of this research. Chapter 4 will explain the steps in the methodology to answer the research question. Attention will be paid on stated choice experiments and the statistical analysis of inferring consumer preferences. The design of the choice experiment and the survey will be presented. Chapter 5 depicts the results of the analysis which in Chapter 6 will be used to get a deeper insight into the possible application of those results. Furthermore, a comparison is made with previous results in the literature. Chapter 7 and Chapter 8 will end the research with a conclusion and discussion, respectively, to reflect on the findings of this thesis and propose suggestions for further research.

2. THE V2G SYSTEM

This section aims to reflect on the general knowledge of the V2G system. The definition of the concept, the system actors and business models will be explained.

2.1. The V2G system

V2G is a new concept in EV design. The basic concept entails that EVs provide power to the grid while parked and plugged in (Kempton & Tomić, 2005). Currently, there only exists a unidirectional energy flow from the electricity grid (through chargers) to plugged-in EVs. A V2G charger will also be able to send power back to the electricity grid, enabling a bidirectional energy flow between the EV and the grid. The EV can act as a kind of battery source for the energy system. This can be useful in an energy system that is highly dependent on intermittent energy resources such as wind and solar power, since the production output of these sources cannot be controlled (i.e., are weather dependent), nor easily be stored. The next step in this system is the establishment of a communication pathway between the grid operator and the EV. The plugged-in EVs should get instructions about the amount of power flow the grid requires (Noel et al., 2019b). Technically speaking, the communication can either be directly between the EV and the grid operator or with the intervention of a third party acting as aggregator. However, literature suggests that it is more convenient with the intervention of an aggregator, which will collect the aggregated power from a pool of V2G-capable EVs, since most electricity markets require a minimum power capacity to place bids (Noel et al., 2019b; Park Lee et al., 2018; Sovacool et al., 2020).

2.2. V2G system actors

The literature describes a wide range of stakeholders that play a role in the V2G system. These include automotive manufacturers, battery manufacturers, EV owners, energy suppliers, Transmission System Operators (TSO), Distribution System Operators (DSO), fleet operators, aggregators, electric vehicle supply equipment (EVSE), electricity grid operators and others (e.g.: Noel et al. 2019; Sovacool et al. 2020; Lee et al. 2020). However, three primary actors in the V2G system can be identified: EV owners, aggregators and electricity grid operators.

EV owners play a vital role in the V2G system, since the system depends on their driving and charging behavior, but ultimately on their willingness to participate. The EV owners can benefit from the revenues generated by participating in the electricity market (Noel et al., 2019c). These economic savings can make it more attractive for EV drivers to participate in a V2G system. The most common barriers for participating in V2G system that are identified in the literature are range anxiety, battery degradation, freedom impediment to use your car, or consumers unwilling to accept a third party to use their battery, and complexity for consumers to understand (Parsons et al., 2014; Noel et al., 2019b; Noel et al., 2019c; Sovacool et al., 2020). Although battery degradation seems obvious, there is not yet a consensus in literature what the effect will be on the long term. Most papers suggest simplifying the system to overcome the aforementioned barriers, for example by creating an easy interface for consumers.

The next actor is the aggregator, which is considered important to participate in the electricity markets on behalf of the EVs. EV owners are not able to participate on the various electricity markets because they require a minimum capacity to participate. TenneT, the Dutch Transmission System Operator (TSO), requires a minimum capacity of 1MW or multiples of 1MW to participate on the market (TenneT, 2022). Most fast chargers nowadays have a (dis)charging capacity of at least 50kW. So, with these chargers, at least 20 EVs should be aggregated to be able to participate on the electricity market. The most convenient way described in literature, is with the intervention of an aggregator which acts as an intermediary agent. The intervention of an aggregator implies the need of an agreement between the EVs and the aggregator, which can be made in the form of a contract (Park Lee et al., 2018). An aggregator can hence offer a more economically efficient way for V2G-capable EVs to participate on the electricity markets (Noel et al., 2019b). When aggregators own a large pool of aggregated EVs, the grid operator can benefit from it, since it provides a large amount of backup power on the electricity market. It can offer stability and flexibility as a market participant (Sovacool et al., 2020).

The third primary actor in the V2G system is the electricity grid operator. The structure of this actor varies per country and market and can be divided in the following sub actors: TSO, Balance Responsible Parties (BRPs) and Balancing Service Providers (BSPs). The TSO, in the Netherlands represented by TenneT, is the owner and operator of the transmission grid. Since it has the responsibility of maintaining system security, it is also responsible for balance management (De Vries et al., 2019). Balance management implies the assurance of a stable frequency of 50 Hz by restoring the balance between supply and demand of electrical power for its responsible area. This reserve power is traded through a balancing market (TenneT, 2022). Besides the TSO, two other actors are also active in the balancing market: Balance Responsible Parties (BRPs) and Balancing Service Providers (BSPs). BRPs consist of large producers, large consumers and supply companies (De Vries et al., 2019); while BSPs consist of market participants that offer reserve power for balancing services to the TSO (De Vries et al., 2019; TenneT, 2022). The aggregator would take a role as BSP in the electricity system and interact with the TSO. The TSO will buy reserve power on the balancing market and the aggregator will offer V2G capacity in the form of bids. When needed, the TSO will buy ancillary service capacity on the balancing market and subsequently send the signal to all BSPs, including the aggregator (Noel et al., 2019b). Especially, within the balancing market, V2G can offer value for frequency regulation. Kempton & Tomić (2005) and Sovacool et al. (2020) agree that the best match for V2G services is with frequency regulation, since it is continuously needed, it requires high power capacity but limited energy capacities, and requires quick response; all of which coincide with the advantages of aggregated V2G-capable EVs. Connected EVs are able to react extremely fast, with a time delay of 5 seconds. The grid can greatly benefit from the flexibility offered by the V2G system by means of storage.

Furthermore, the Distribution System Operator (DSO) also takes an important role in the V2G system. It is responsible for the electricity distribution on low and middle voltage level to end-users (industry and households). The DSOs receive electricity transmitted by the TSO and distribute it to end-users (Noel et al., 2019b). Typically, BSPs are actors that are connected to the high voltage level grid, interacting directly with the TSO. In the V2G system, the reserve power from EVs is provided from the end-user, so at DSO level, because of which it will also interact with local grids.

2.3. V2G business model

In order to let V2G work, there must be (financial) incentives for the actors. The literature describes different business models for V2G. The most crucial part is determining which electricity market is/are most suited to sell V2G service. Kempton & Tomić (2005) are one of the first authors analyzing the different markets V2G can participate in in the USA, being baseload power, peak power, spinning reserves and regulation. As already discussed by Kempton & Tomić (2005) and more recent articles on the topic (Mullan et al., 2012; Sovacool et al., 2020; Turton & Moura, 2008), EVs are not able to provide baseload power at competitive prices. This due to the nature of the baseload power market where market participants are focused on large-scale all-time running power plants with low variable costs. Of the remaining markets (peak power, spinning reserves and regulation), frequency regulation is seen as the most suitable market to trade V2G power. Peak power is infrequently used and when used very energy intensive (Sovacool et al., 2020). Spinning reserve and frequency regulation seem more convenient, these are traded in a separate ancillary service market and are continuously needed, does not require high energy capacities and need quick reactions, which makes it a good fit for the purpose of V2G. In the Netherlands frequency regulation is traded as an ancillary service on the balancing market as explained in the previous section. It is expected that due to the rise of RES the mismatch between demand and supply will increase in the future, which will lead to an increase of the need of ancillary services such as frequency regulation, making V2G even more valuable in the future (Noel et al., 2019b).

The proposed business model is straightforward in concept. The aggregator offers the aggregated V2G capacity on the balancing market. When needed, the TSO will buy this offered power against the ancillary market price (which is cleared every 15 minutes) to balance the market. As such, a transaction flow exists between the aggregator and the TSO. A part of the revenue is kept by the aggregator, while the other part is transferred to the aggregated EVs as stated in their contracts, depending on the contract terms. Figure 1 depicts a conceptual figure of this value chain. Based on a calculation provided by Noel et al. (2019b), which models an EV that is 72% of the time connected to the grid with a (dis)charging capacity of 10kW, the revenues per EV were calculated on $2,000 per year. Assuming the aggregator would take half of the profit, the EV owner could earn $1,000 per year when having its EV connected to the grid for 72% of the time.

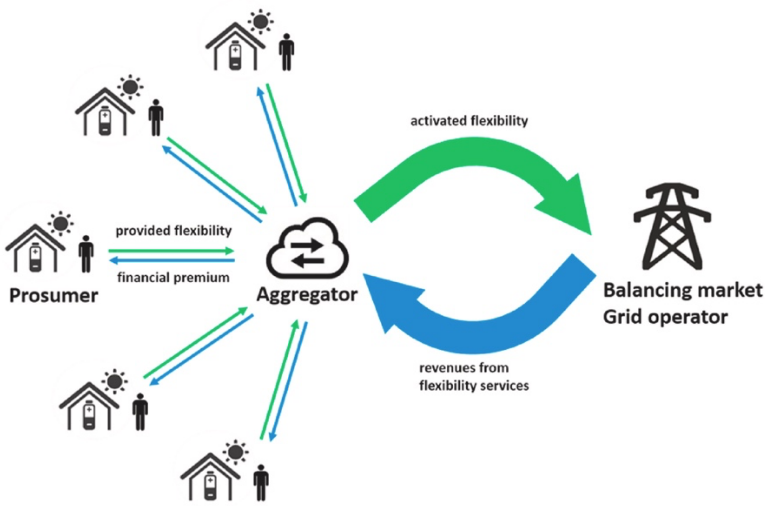

Figure 1: from Kubli & Canzi (2021). Conceptual figure of the value chain of the V2G system. Aggregators collect tradable electricity from a pool of connected V2G users (prosumers) which provide flexibility. This flexibility is offered on the balancing market, resulting in a revenue for the aggregator, of which a part is allocated to the V2G users (prosumers).

3. Literature review

The aim of this section is to gain state of the art knowledge of choice experiments on the willingness to participate. It seeks to identify what factors are already examined through choice experiments and which not, and which can contribute to new insights with respect to the willingness to participate in V2G programs.

3.1. Literature review methodology

First a preliminary general search about the V2G concept was conducted, using academic and non-academic sources. After gaining general knowledge about the field of interest, a search for recent review papers was performed to search for useful key word. This preliminary research led to the following key words:

(Vehicle-to-Grid OR V2G), social acceptance, social awareness, (choice behavior OR choice experiment OR choice analysis OR choice model) and the Netherlands.

The literature search was conducted on the online database ScienceDirect. By applying different combinations of search strings, using the aforementioned key words, a selection of articles was made. This selection was assessed qualitatively by reading the corresponding abstracts and evaluating whether the article could be useful for the topic of study.

3.2. V2G choice models

Having identified which actors play an important role in the V2G system, and which business models are considered feasible for the large-scale diffusion of V2G, this section reviews the choice experiments used in the literature to infer consumer preferences with respect to the willingness to participate in V2G contracts.

The conceptualization of the V2G system is in an advanced stage, yet the public's perception of the concept is still under-investigated. Little is known about the consumer's interest in such system. A few studies have quantified what the willingness is to participate in V2G through a stated choice experiment. Parsons et al. (2014) are the first known for performing a choice experiment of V2G by doing a follow up of a choice experiment on EV adoption on a US driver's sample (Hidrue et al., 2011). The respondents were asked to consider a next car purchase. Based on the price range of their next purchase, two alternative EVs were given tight to a V2G contract. These V2G contracts were designed with the following attributes: minimum guaranteed driving range, required plug-in time per day, annual cash back payment and price relative to the respondent's preferred gasoline vehicle. From the experiment could be concluded that drivers see high inconvenience cost with signing a V2G contract, stating as most probable factor the desire for flexibility of drivers. Furthermore, the authors propose a V2G system without being tight to a contract, a so-called pay-as-you-go service. However, considering the minimum bids in ancillary markets which are considered to make the best fit with V2G capacity, a pay-as-you-go service seems infeasible. Moreover, this study is a bit outdated, since the awareness and desires of consumers have changed with respect to EVs. At the time Parsons et al. (2014) performed their experiment, the adoption rate of EVs was extremely low, and the charging infrastructure was still in development. It can be expected that consumers today would respond different to the proposed alternatives.

Geske & Schumann (2018) also performed a discrete choice experiment, but on a sample of German EV and potential EV drivers, and had as objective to identify decisive parameters for the consumer's willingness to participate in V2G. Their approach was similar to Parsons et al.

(2014), only that the sample now consisted of EV and potential EV drivers. The contract attributes were also adopted from the work of Parson et al. (2014), though the remuneration scheme was different. Instead of an annual cash back a monthly remuneration was used and a fixed one-time payment to the participant. The representativeness of the sample had a close fit with data of German vehicle users. “Range anxiety” and “minimum range” proved to be the most important factors. If the guaranteed minimum driving range barrier was eliminated the remuneration was not important any more for the participants. It concluded that remuneration cannot be expected to be very supportive in this respect, but that the major barrier is the range. Which can be considered in line with findings of Parsons et al. (2014).

In contrast, Zonneveld (2019) performed a similar experiment among Dutch EV drivers and concluded that remuneration does play a significant role for the adoption of V2G. “Range anxiety” and “minimum range” seemed less important than the findings of Geske & Schumann (2018) on the German sample. This misalignment could arise from different socio-demographic characteristics between German and Dutch EV drivers. For example, Germans may drive more km’s on a daily average compared to Dutch people. Not surprising, larger samples and different socio-demographic groups are suggested to improve the model. It would be wise to align the Dutch survey respondents with the sociodemographic data of Dutch vehicle users. However, it seems that this data is lacking.

Huang et al. (2021) also did a discrete choice experiment for V2G on Dutch EV drivers, but added a context parameter. One of the contexts was based on the current EV recharging time and one on a speculative fast recharging in the future, which made them able to assess the impact of future battery technology on V2G contracts. In line with previous studies, they concluded that guaranteed minimum battery level (an equivalent of guaranteed minimum range) is one of the most important design parameters for the willingness to participate. However, they concluded that in the absence of this barrier (i.e., through fast charging able to charge your car within 5 minutes) the willingness to participate increased significantly.

The previous studies focused on groups consisting of EV drivers (or potential EV drivers) in mostly the Netherlands and Germany, with different findings in both countries. Kajanova et al. (2022) performed a similar discrete choice model for EV drivers in Slovakia. In line with Dutch EV drivers, remuneration is an important decision factor for V2G participation. If the monetary gain for the participant is higher, it is willing to sell higher amount of energy to the aggregator. Nevertheless, the author suggests using larger samples and with different socio-demographic groups to obtain more viable results.

Only one author analyzed the combination of V2G with car sharing (Gschwendtner & Krauss, 2022). They investigated whether V2G could improve the attractiveness of carsharing. By means of a stated-choice experiment, car sharing in combination with V2G is chosen in favor of just EV car sharing. The contract attributes are similar to previous studies, and include minimum driving range, cost per hour (before remuneration), remuneration, access time and egress time. The analysis was performed on a sample of German and Swiss EV drivers. Also, this author suggests different types of remuneration and different geographic locations for more viable results.

From the literature review on V2G choice models can be concluded that the parameters ‘range anxiety’ or ‘minimum guaranteed driving range’ play a decisive role on the consumer’s willingness to participate in a V2G system. Remuneration, as expected, is also considered an important contract attribute, but does not always outweigh the inconvenience of the minimum driving range. Only Huang et al. (2021) added a context variable such that this inconvenience was eliminating. The result is that the willingness to participate increased. By eliminating more, or other possible barriers and transpose them in a contract attribute, new insights can be obtained with respect to the willingness to participate. The previous studies have made some suggestions regarding further research, but these have not yet been applied, and therefore knowledge is lacking on this respect. No previous study has examined the difference in preference when the guaranteed plug-in time differs during weekdays and weekends. This could be a new approach that helps enhancing the willingness to participate.

4. METHODOLOGY

This section describes the method that will be used to analyze the willingness to participate in V2G for Dutch car drivers. It describes the basics of discrete choice experiments and discusses the contract attributes that will be used for the experiment.

4.1. Stated choice experiment

Stated choice experiment is a type of survey-based research method that intends to elicit preferences and choices made by individuals in a hypothetical scenario. Respondents are subjected to multiple choice tasks with different alternatives. These alternatives are presented to the respondents in the form of choice tasks, which are groups of options that vary based on different attributes and attribute levels. In a stated choice experiment, the respondent is asked to select the most preferred option from each choice task. This information can then be used to understand how individuals make decisions and to estimate their underlying preferences. System designers and policy makers can use these results to understand factors that influence decision-making, which can be used to make decisions in product design, or to evaluate the impact of policy implementations. Hence, stated choice experiments can provide valuable insights into consumer preferences.

Stated choice experiments can be considered an effective research method to analyze the willingness to participate in V2G contracts since they provide a systematic way to measure individual preferences and evaluate the trade-off between different attributes of the contract. Given the complex nature of the V2G system, and the fact that the design of it is still in conceptual phase, understanding the factors that influence the willingness to participate in V2G contracts is of crucial importance for aggregators and other actors involved in the design of the V2G system. Since most likely the system will only function in a scenario where EV drivers are engaged in a contract with an aggregator.

The main advantage of a stated choice experiment in this context, is that choices can be observed for situations that not yet exist. They allow researchers to study people's preferences in hypothetical situations. This means that participants are asked to make choices based on simulated scenarios, without actually having to engage in real-life decision-making. The designer of the choice experiment can use different choice attributes with different levels of which the respondent can choose of. Since the V2G system is still in conceptual phase, the preferences of future adopters can (easily) be obtained through a stated choice experiment, and hence be used to optimize the design of the V2G system. Besides, it is able to find heterogeneity in the preferences of different respondent groups.

Stated preference, however, has some drawback. The main drawback is that the choices made in the experiment are not actually felt, not knowing whether the respondents would really choose the option in real life, which can affect the validity of the results obtained. But if the objective is to examine preferences for new alternatives or attributes, not yet existent, such as in a V2G system, then stated choice experiments are still very useful. In this way the trade-offs people would make in a real situation can be inferred. Especially how they trade-off the different contract attributes, which lead to a perceived utility. The assumptions is that the person seeks to maximize this perceived utility. It is key that the hypothetical choice sets are made as realistic as possible, and easy to understand for the respondents. Therefore, for this research, a stated choice experiment will be designed and analyzed.

Random Utility Maximization (RUM) theory

In this research a discrete choice model will be estimated based on Random Utility Maximization (RUM) theory, a commonly used theoretical framework in choice experiments. The RUM-choice model subjects a decision maker to choose one alternative from a choice set of multiple alternatives, for example, different modes of transportation (train, bus, car). These alternatives are characterized by multiple attributes, which can be related for example to time or cost, and have different attribute levels. In this way, the decision-maker is forced to make a trade-off between the different levels of the contract attributes. These trade-offs will eventually be decisive for the alternative chosen by the decision-maker. The RUM model proposes that the utility of each alternative is composed of a systematic part, representing an individual's preferences, and an error term, representing the random noise in the decision-making process. This systematic part of the utility is represented by (V) and is the sum of all the attributes levels chosen (x) multiplied by the corresponding weight or importance (β) assigned to that attribute. The goal of the model is to estimate these weights based on the alternatives that are chosen. The error term (ε) is added to the systematic utility. This error term represents all other factors that influence the decision-maker but are unobserved and cannot be measured. The total utility function is depicted in the following formula:

$$U_{in} = V_{in} + \varepsilon_{in} = \sum_m \beta_m \cdot x_{im}\, \beta + \varepsilon_{in} \quad (1)$$

The RUM model assumes that the decision-maker chooses the alternative that has the highest utility. This is expressed as follows:

$$U_i > U_j \text{ and } i \neq j \quad (2)$$

Where:

i, j represent the alternatives (e.g. contract 1 and contract 2),
m represents the attribute (e.g. time and cost),
x represents the attribute level (e.g. 10 minutes or €2),
β represents the weight parameter associated with the attribute (to be estimated as explained in the next section), and
ε represents the unobserved randomness.

Fout! Verwijzingsbron niet gevonden. depicts a conceptualization of the RUM model. This will be the base model for the choice experiment in this research.

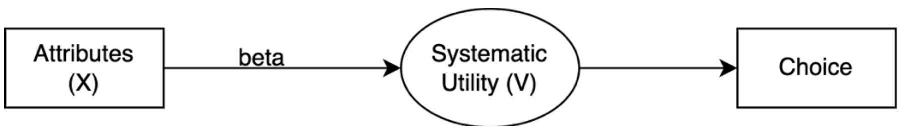

Figure 2: conceptual model of the RUM theory

Multinomial Logit model

To estimate the RUM model, Daniel McFadden's Multinomial Logit (MNL) model is used. This model assumes that the unobserved randomness ε is independent and identically distributed according to Extreme Value type I distribution, where $var(\varepsilon) = \frac{\pi^2}{6}$. Hence, the probability of alternative i being chosen can be represented in the following formula:

$$P(i) = \frac{e^{V_i}}{\sum_J e^{V_j}} \quad (3)$$

For the design of the choice experiment, the contract attributes should be chosen and the corresponding attribute levels. Based on the research objective and previous studies in the literature, the next section will be dedicated to review which contract attributes will be used in this design.

4.2. Relevant attributes and attribute levels

Fixed remuneration

Remuneration is always considered in V2G contracts to compensate for the service provided and the discomfort experienced by the participant. All previous studies on V2G contract (Parsons et al., 2014; Geske & Schumann, 2018; Zonneveld, 2019; Huang et al., 2021; Kajanova et al., 2022) found that remuneration has a positive effect on the willingness to participate in V2G contracts. Parsons et al. (2014), Geske & Schumann (2018) and Zonneveld (2019) used fixed remuneration schemes per year, month, or other fixed time span. Huang et al (2021) also added an extra remuneration for times the EVs were plugged-in outside of the contract times. However, this extra remuneration had no significant impact on the preference for V2G contract. In this design, the remuneration will be based on the potential revenue as calculated by Noel et al. (2019b). They estimate a yearly revenue of $2,000 and find it feasible that 50% of that revenue is for the aggregator, leaving the EV owner with $1,000 for 70% of the time being connected to the grid. Therefore, as contract attribute, a monthly remuneration scheme is proposed with the following levels: €50, €100, and €150.

Variable remuneration

Neither of the previous studies considered the price the respondent pays for the energy when recharging after a discharge. For the conciseness of the survey, the respondents should be able to evaluate whether they do not pay more for charging their EV with respect to discharging. Since the price of the remuneration is fixed per month and per amount of discharge hours, it cannot easily be calculated whether the respondent receives more remuneration than it pays for the energy. Therefore, a fixed extra remuneration for every kWh discharged is used in the contract. To make it easy for the respondents, this extra remuneration is considered to be equal to the energy price used for charging the EV per kWh. In this case the respondent would never pay more for energy when the EV is discharged, and the remuneration is totally based on the fixed amount that they receive per month as explained in the previous section.

Guaranteed minimum driving range or battery level

Guaranteed minimum driving range or the guaranteed minimum battery level is the range or battery level the EV must have at any time during V2G services. This ensures the participant that he always has a minimum driving range for emergencies while connected to the V2G program. All studies cited in the previous section included guaranteed minimum driving range or battery level in their V2G contracts and found significant positive impact on the utility of the participant. This means that a higher guaranteed minimum driving range increases the utility of the participant. Parsons et al. (2014), Geske and Schumann (2018) and Zonneveld (2019) included the minimum driving range in miles or km's, while Huang et al. (2021) expressed the minimum driving range by a minimum percentage of the battery level. Geske and Schumann (2018) based the minimum driving range levels in their experiment on the average driving range in Germany (38 km). Zonneveld (2019) did the same for the Dutch drivers (40 km) and also added as minimum level the maximum distance to any hospital in the Netherland (10 km).

In this study the guaranteed minimum driving range attribute levels are set at 10, 65 and 120 km respectively. They represent short minimum driving range for emergency activities as driving to the hospital (10 km), medium for work or urgent visit to someone not that far (65 km), and long guaranteed minimum driving range (120 km).

Plug-in time

Plug-in time entail represents the time the EV is plugged-in per unit of time to the grid. The plug-in time is a fundamental part of the V2G system and should therefore be established in the V2G contract. All previous studies considered plug-in time in their V2G contract, although with different units. Parson et al. (2014) used minimum plug-in hours per day, ranging from 5 to 20 hours plugged-in per day. Geske and Schumann (2018) used two different units in their contracts and used required plug-in times per week in day and required plug-in time per day in hours. As such, the contract establishes the amount of days per week the participant should be plugged-in and the hours per day it is plugged-in, resulting in more flexibility for the participant since he is not obliged to be plugged-in every day. Zonneveld (2019) defined the plug-in time as hours per week, also not obliged to be connected to the grid every day. Huang et al. (2021) chose for hours per day, and concluded that the plug-in time has a non-linear negative effect on the preference for V2G contracts, i.e., people dislike plug-in time exponentially when the plug-in time increases, as was also the concluded by Parsons et al. (2014).

Previous studies did not take into account whether people have different preferences regarding plug-in time on weekends compared to weekdays. A typical working person probably does not use their car much during weekdays besides from going to work. This implies that during weekdays this person has more time available to plug-in his car because he does not have time to drive while working. Although people may actually not drive significantly more in the weekends, it is expected that people prefer not to be tied to a long plug-in time on weekends because they still have more free time that they may want to use their car.

This hypothesis will be tested by changing the previously used contract attribute "plug-in time" into two contract attributes, namely plug-in time in the weekends and plug-in time on weekdays. Nevertheless, the attribute levels will be the same for both versions, and are chosen at: 5, 10 and 15 hours per day respectively.

Discharging cycles

Discharging cycles may affect battery degradation. Although the literature is undisclosed about the effects of discharging cycles, mainstream V2G literature suggest discharge cycles have a negative effect on the lifetime of the battery (Noel et al., 2019b). Zonneveld (2019) included discharging cycles in the V2G contracts and emphasized its respondents that more discharge cycles would enhance the battery degradation. Therefore, it was expected to have a negative effect on the willingness to participate, as it would also affect the range anxiety. When the battery degraded, the maximum range decreases. Hence, he concluded that an increase in discharging cycles indeed has a negative effect on the perceived utility. Huang et al. (2021) also considered discharging cycles in the design of their V2G contract. They also concluded that discharging cycles have a strong negative effect on the preference for V2G.

Although there is no strong consensus about the degree of battery degradation due to discharge cycles, this contract attribute will not be taken into account in the choice model. Instead, the respondents are told that science is undisclosed about this topic, and that they do not have to worry extremely about this effect when taking the survey. They can assume it will not negatively affect their battery.

Contract duration

Zonneveld (2019) is the first to include contract duration between the aggregator and the V2G participant. He based the contract duration on phone subscription, setting three attribute levels: one month, one year and two years. It was expected that the contract duration would have a negative effect on the perceived utility, i.e., the longer the contract the lesser the willingness to participate, but the experiment resulted in a higher utility for a longer contract. Huang et al. (2021) also included turned out in the designed V2G contract. They also cited Kubli et al. (2018) which did not perform a choice experiment on a specific V2G contract but added contract duration through smart charging in an electricity contract. As Kubli et al (2018) had an opposite result compared to Zonneveld (2019), Huang et al. (2021) decided to add it to their contract design. In their conclusion, there is no clear evidence that people are concerned about the duration of V2G contracts.

In this experiment, the contract duration will not be taken into account. Instead, the respondents are told that the contracts can be stopped at any moment, and that they are not tight to long-term contracts. For instance, when people intend to go on holiday with their EV they can stop the contract for a month.

Weekdays and weekend

To determine if there are any differences in the willingness to participate between weekdays and days in the weekend, this will also be taken into consideration in the choice model. To the knowledge of the author, this has not yet been performed in a previous study. It is expected that respondents have different preferences on their car usage in weekdays compared to the weekend. To evaluate the willingness, these are both taken into account in the choice model as explained under plug-in time.

Selection of attributes

After reviewing the literature in the previous section, four contract attributes were selected to assess their impact on the willingness to participate in V2G contracts, two of them are previously used in literature, and the other two are adapted to gain new insights in consumer behavior. The selected attributes and their corresponding attribute levels are displayed in Table 1.

Table 1: selected contract attributes and their attribute levels.

Attribute	Explanation	Attribute levels
Remuneration	Monthly remuneration for providing V2G according to contract.	50, 100, 150 [€ per month]

Guaranteed minimum driving range	The V2G system will never discharge under the minimum guaranteed driving range.	10, 65, 120 [km]
Plug-in time weekdays	Minimum time the EV should be plugged in during weekdays.	5, 10, 15 [h/day]
Plug-in time weekend	Minimum time the EV should be plugged in during weekend days.	5, 10, 15 [h/day]

Hypothesis

Based on the previous selection of attributes, the hypothesis are stated in Table 2.

Table 2: hypothesis on V2G contract attributes.

Number	Attribute	Hypothesis
H_0		The null-hypothesis state that all parameters are zero for the population, and hence the attributes have no effect on the perceived utility.
H_1	Remuneration	A higher remuneration has a positive effect on the respondent's utility, the consumer perceives a higher utility when it earns more money.
H_2	Guaranteed minimum driving range	A higher guaranteed minimum driving range has a positive effect on the respondent's utility, when the consumer is able to have a higher guaranteed minimum driving range at any time, he perceives a higher utility.
H_3	Plug-in time weekdays	The minimum plug-in time at weekdays has a negative effect on the respondent's utility. When the consumer is obliged to connect his car more hours in a day, he perceives a lower utility. However it is expected that this negative effect is relatively higher for the weekend. Most ordinary people that work during weekdays will probably have a routine and are not able to use their car for some time during the day, so they do not care if their car has to be connected for some time of the day.
H_4	Plug-in time weekend	The minimum plug-in time during the weekend has also a negative effect on the respondent's utility. It is expected that this perceived utility is relatively higher than during weekdays since the consumers would like to have more freedom at days that they are free.

Conceptual model

Figure 3 gives an overview of the model structure, based on the RUM model and the attributes and attribute levels chosen. The attribute levels should determine the perceived utility of the respondents. Moreover, also socio-demographic characteristics and other driver characteristics may influence the utility of the respondent, and hence the choice to be willing to participate in V2G.

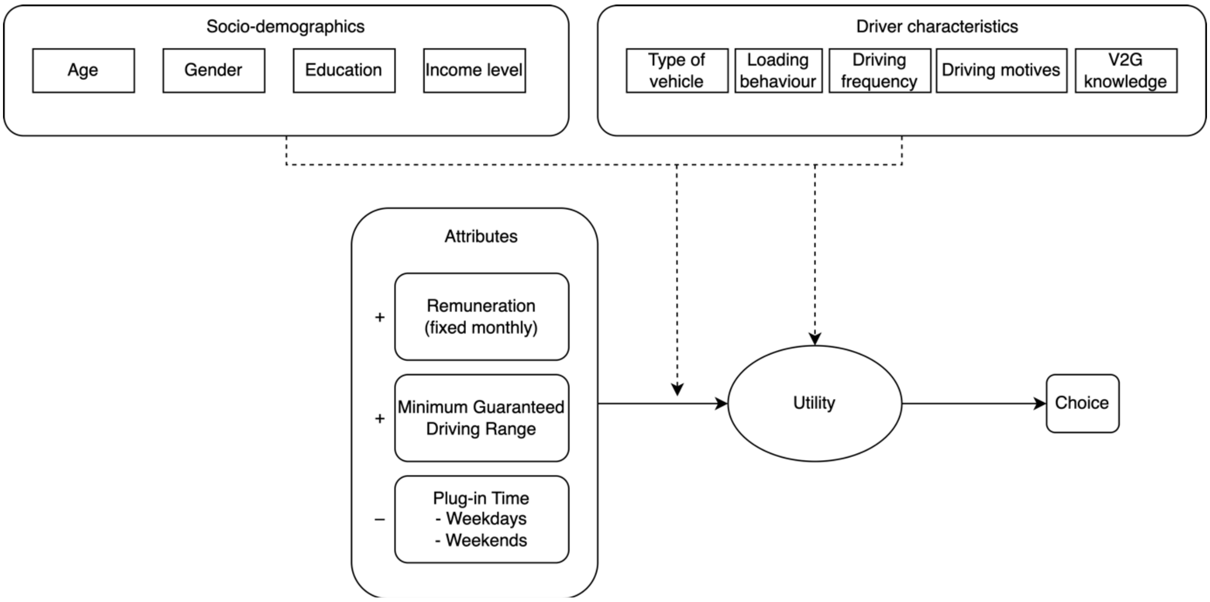

Figure 3: conceptual model of the choice experiment.

4.3. Model

As explained in the previous section, the experiment will consist of the four attributes chosen, with each three attribute levels. In order to make it not too hard for participants to participate in the choice experiment, it is chosen to make a design with two contracts, i.e., two alternatives. These alternatives will have the same attributes but with different attributes levels which the respondent should evaluate. Since the objective of this study is not only to evaluate the importance of the different attribute but also to investigate whether consumers are willing to participate in V2G contracts at all, there is also chosen for an opt out option. This gives the respondent the option to not participate in any V2G contract at all.

In order to distribute the survey, a design should be made of the choice experiment. This section briefly elaborates on potential experimental designs which can be used for this research.

Full and fractional factorial designs

A full factorial design considers each possible choice situation based on the number of alternatives, number of attributes and number of attribute levels. This entails that in a choice experiment consisting of four attributes, with each three attribute levels, and two alternatives, this would result in 3^{2x4} = 6,561 possible choice situations. Since it is not feasible to let respondents face that many choice situations, a fractional factorial design is more suitable for this research. In this design, only a subset of the full choice situation is used. However, the subset should be generated and chosen such that attribute level balance is satisfied (ChoiceMetrics, 2021).

Orthogonal and efficient designs

Orthogonal designs have been used very mainstream over the past decades. Nowadays, they compete with efficient designs. The design is orthogonal when attribute level balance is satisfied and all parameters are independently estimable (ChoiceMetrics, 2021). This means that there is zero correlation between attributes, which results in low standard errors. The amount of levels of each attribute appear an equal number of times. Disadvantages are the existence of dominance of one of the alternatives. This means that all attribute levels in one alternative are considered “better than” or “equally good as” the other alternative, resulting that each respondent would choose the same alternative or that the trade-off is not useful for the model. On the other hand, efficient designs are based on prior information. This helps avoiding dominance in choice sets and may increase the reliability of the estimated parameters. However, when the prior information is incorrect, parameters may be biased. In this research, it is chosen to make an orthogonal design, due to the difficulty of obtaining priors from the plug-in attributes for weekdays and weekends.

Because it is not feasible to let respondents consider all possible options, a fractional factorial design will be used. The fractional factorial design can be either random, orthogonal or efficient. For an efficient design, parameters from literature of from a pilot study is needed. Since this is outside the objective of this study, it is chosen to perform an orthogonal design. Orthogonal design allows for a much smaller number of choice sets, which makes it useful for the purpose of this research.

Ngene

Now that an orthogonal fractional factorial design is chosen for the choice experiment in this research, the choice sets should be generated. Ngene is a useful software which can design choice sets. Based on the before explained RUM model, the number of alternatives, attributes and attribute levels, the following code is used as input in Ngene to generate an orthogonal fractional factorial design with 9 choice tasks:

```
?choice experiment
;alts = alt1,alt2
;rows = 9
;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]
/
U(alt2)=b1*A+b2*B+b3*C+b4*D
$
```

The output was 9 choice tasks of two alternatives. After evaluation, dominance resulted in 2 of the 9 choice sets. Therefore, the experiment was regenerated multiple times with Ngene. However, the dominance kept present. Therefore, dominance was eliminated by hand, ensuring that attribute level balance was satisfied. This was done by changing the attribute levels in two choice sets. As a consequence, correlation was introduced between attributes. However, it is tried to keep the correlation at a minimum by ensuring all attribute levels occur an equal amount among the choice sets, as too much correlation increases the standard error of the parameters. Table 3: final design of the choice set. depicts the final design of the choice experiment based on the design generated by Ngene and the manually elimination of dominant choice sets.

Table 3: final design of the choice set.

	Rem_alt1	Day_alt1	Weekend_alt1	Radius_alt1	Rem_alt2	Day_alt2	Weekend_alt2	Radius_alt2
Choice 1	50	5	5	10	100	5	10	120
Choice 2	150	10	10	10	100	10	5	65
Choice 3	100	15	15	10	50	10	15	120
Choice 4	100	10	5	65	50	5	5	10
Choice 5	50	5	10	65	150	15	5	120
Choice 6	150	15	15	65	100	5	15	10
Choice 7	150	15	5	120	150	10	10	10
Choice 8	100	5	10	120	150	5	15	65
Choice 9	50	10	15	120	50	15	10	65

4.4. Target group

The target group for the choice experiment consists of all Dutch car drivers. In this respect also non-EV drivers are included. As of 1st of January 2022, about 8.8 million passenger cars were registered in the Netherlands, of which 725 thousand were EVs, a percentage of 8.2% (CBS, 2022). By using a large and diverse target group, classes can be identified with respect to taste heterogeneity, such that the willingness to participate can be better classified. The choice experiment will in this way allow to obtain heterogeneity in the preferences of the Dutch car drivers. This is important because the preferences and behaviors of car drivers can vary widely, and it is necessary to understand these differences in order to design V2G contracts that are attractive and appealing to a broad range of car drivers. To determine different classes, the following socio-demographic questions will be added:

- Gender
- Age
- Education level
- Income level

Furthermore, questions about the type of car that the respondents drive will be asked, and about their driving motives and frequency. It is expected that these characteristics can give a better impression on the willingness to participate in V2G contract by different groups.

4.5. Data collection

Survey design

The choice experiment will be distributed through a survey platform, specifically Qualtrics. The survey is designed in a way that it will first provide the respondents with some prior information about the research and the V2G concept. This is important in order to give the respondents a clear understanding of what the experiment is about and what they will be asked to do. A video was made and included in the explanation such that the V2G concept could be visualized. This information is crucial in order to ensure that the respondents have a basic understanding of V2G, and how it works. The video can be accessed with the following link: https://youtu.be/WcrUbdCkKKo.

After the prior information, the choice experiment is started and the respondents are asked to evaluate two contract alternatives and choose their most preferred contract or choose to not engage in a contract at all. If the respondent chooses the latter option, he or she is forced to also make a choice between the two projected contracts, such that this information can be used to say something about the willingness to participate in V2G contract. Besides, if too few people choose for a V2G contract, the data can still be used to estimate the model based on the forced question. Figure 4 depicts an example of one of the choice tasks which were presented to the respondents in the survey.

Bij het keuze-experiment worden negen situaties gesimuleerd. Maak bij elk situatie een afzonderlijke afweging van uw gewenste keuze.

Keuzeset 1 van 9

Bekijk de onderstaande keuzeset.

Contract Element	V2G Contract 1	V2G Contract 2	Geen Contract
Vergoeding	€50 per maand	€100 per maand	–
Dagelijkse plug-in (werkdagen)	5 uur per dag	5 uur per dag	–
Dagelijkse plug-in (weekend)	5 uur per dag	10 uur per dag	–
Gegarandeerde actieradius	10 km	120 km	–

Van de drie opties gaat mijn voorkeur uit naar:

- V2G Contract 1
- V2G Contract 2
- Geen contract

Figure 4: example of a choice task as presented to the respondents in the survey. In case the respondent chose "no contract", he/she was forced to make a choice in the hypothetical option that he/she must have chosen one of the contract (this part is not depicted in the figure).

After the choice experiment, the respondents are asked for some socio-demographic data as explained above. When the respondent has an EV he/she will be asked for his motives why he/she drives an EV and when the respondent is a non-EV driver he/she will be asked if he/she is interested in driving an EV in the future. Furthermore, questions about their driving frequency are asked and about their motives if they would consider participating in V2G. After the survey is designed, it is distributed among Dutch car drivers.

Recruitment of respondents and distribution of survey

The recruitment of respondents for the choice experiment is a crucial aspect of the survey design. The goal is to reach a representative sample of Dutch car drivers, and therefore, multiple channels will be used to recruit participants. Firstly, the participants will be recruited through personal channels by sharing the survey link with people I know, asking them to re-share the link as much as possible. Secondly, the survey link will be shared on social media platforms such as LinkedIn, where it will be posted on my profile and re-shared by others. This method will increase the reach of the survey, and hopefully attract participants who are interested in the topic. The combination of these recruitment methods is expected to increase the response rate and provide a broad and representative sample of the target population. The aim is to get at least 100 respondents, this is equivalent to 900 choice observations.

4.6. Data analysis

The data collected from the survey will be downloaded from Qualtrics in an Excel format. The data will then be cleaned and adjusted to prepare it for use in the software "R". R is a widely used programming language for statistical computing and will be used to perform the data analysis. To carry out the analysis, the Apollo software package will be used in R. This package is specifically designed for choice modelling and will be used to perform a Multinomial Logit Model, as already explained in section 4.1. This model will be used to estimate the parameters and their reliability, which will provide valuable insights into the willingness to participate in V2G contract among Dutch car drivers or other sub groups from the respondents. The results of this analysis will help to understand the underlying factors that influence the respondent's preferences and trade-offs.

5. RESULTS

This section describes and analyses the results obtained from the survey. It elaborates on different models used and on the parameters that are estimated.

5.1. Survey sample

During the period of February 3rd to February 17th, 121 responses were received to the survey. However, only 67 of these responses were completed. Therefore, the aim of 100 respondents was not achieved. Notably, most respondents who did not complete the survey dropped out at the first choice task of the total of nine choice tasks. It is worth mentioning that, according to feedback, older respondents had difficulties understanding the V2G concept and the attached choice experiment. To avoid losing respondents' attention, a trade-off had to be made between providing a detailed explanation and keeping the survey length manageable. This was done by only adding the most necessary about V2G in the video and by limiting the choice sets to 9. It is known that long surveys can result in large dropouts (Qualtrics, 2022).

5.2. Socio-demographic characteristics

In the survey, respondents were asked to provide their socio-demographic information, including gender, age, educational level, and income. This information allows for an evaluation of the representativeness of the sample. Comparing the socio-demographic characteristics of the sample to available data on Dutch drivers can give an indication of how representative the sample is of the population. Statistics Netherlands (CBS) do not have socio-demographic data about car drivers in particular, but they do have data on the socio-demographic characteristics of Dutch car owners. Although car drivers and car owners are not exactly the same, these data are used for the analysis of the representativeness. Table 4 depicts the comparison between the sample of Dutch car drivers and the population of Dutch car owners.

The representativeness of a sample is important in order to generalize the findings of the research to the population. In this case, the target group was Dutch car drivers. In the sample, 58% were male and 40% were female (the remaining 2% would not say its gender). While this percentage is not equal to the population sample (65% male and 35% female), the difference is not substantial enough to question the representativeness of the sample on this characteristic alone. Besides, it can be concluded that both in the survey sample as in the population males are overrepresented. In terms of the type of vehicles, 29.9% of the sample drive electric of hybrid electric vehicles, while 70.1% drive conventional vehicles compared to 9.7% and 90.3% in the population respectively. This indicates that the survey sample has a higher proportion of electric and hybrid drivers than what is present in the population. It is important to note that overrepresentation of a particular group in a survey can potentially lead to biases in the results. The overrepresentation of electric and hybrid drivers may bias the results towards their preferences and behavior, potentially making it difficult to generalize the findings to the entire population of Dutch car drivers. However, the overrepresentation of electric and hybrid car drivers can also be useful in the evaluation of the differences in preferences between conventional car drivers and electric and hybrid car drivers. This should be taken into account when interpreting the results of the MNL model.

Table 5 gives an overview of the income distribution and educational level of the survey sample. It should be noted that no data was found with respect to these socio-demographic characteristics of the population of Dutch car drivers in general. Therefore no comparison can be made with the true population and hence no conclusion can be drawn with respect to the representativeness of the survey sample for these characteristics. However, it can be said the there is an overrepresentation of higher educated people (HBO and WO), and that the income distribution is more or less equally distributed among lower incomes, middle incomes and higher incomes. Nevertheless, data about income distribution (CBS, 2020) for the whole Dutch population shows a less equal distribution. Still it is hard to say whether this also accounts for Dutch car drivers. Therefore, no conclusions can be drawn with respect to the representativeness of this characteristic.

Table 4: comparison of socio-demographic characteristics between the survey sample (N=67) and the true population (CBS, 2022; Autoweek, 2020; NEA, 2023).

Characteristic	Level	Survey sample (%)	Population (%)
Gender	Male	58%	65%
	Female	40%	35%
	Not specified	2%	-
Age	18 – 25 years	0%	3.6%
	25 – 30 years	13.4%	6.4%
	30 – 40 years	4.5%	15.4%
	40 – 50 years	14.9%	16.9%
	50 – 60 years	17.9%	22.8%
	60 – 65 years	10.4%	9.8%
	65+ years	38.8%	25.1%
EV vs non-EV	Drives EV or hybrid	29.9%	9.7%
	Drives conventional	70.1%	90.3%

Table 5: income distribution and educational level of the survey sample (N=67). No data is available on the population of Dutch car drivers with respect to this socio-demographic characteristics.

Characteristic	Level	Survey sample (%)
Annual income	0-40,000 (lower incomes)	34.3%
	40,000-80,000 (middle incomes)	29.9%
	80,000+ (higher incomes)	26.9%
	Unspecified	9.0%
Educational level	No education	0.0%
	VMBO/MAVO (lower secondary school)	3.0%
	HAVO/VWO (higher secondary school)	11.9%
	MBO (lower education)	3.0%
	HBO (higher education)	43.3%
	WO (higher education)	38.8%

5.3. Other car driver characteristics

The last section of the survey requested the respondents to provide additional information about their personal driving characteristics in addition to their socio-demographic characteristics described earlier. Table 6 summarizes the characteristics for the group electric and hybrid car drivers. As can be seen, the motives for driving an electric or hybrid car is equally distributed between financial motives and environmental motives. Most of the people driving an electric or hybrid vehicle use public chargers in the neighborhood. Table 7 depicts the characteristics for conventional car drivers. They were asked whether they would consider buying an EV in the upcoming 5 years. As can be seen, about 40% would (probably) consider buying an EV in the upcoming future, and also about 40% would not consider buying an EV, leaving about 20% neutral.

Table 6: characteristics of electric and hybrid car drivers with respect to charging location and motives for driving an electric vehicle (N=20).

Characteristic	Level	Percentage
Most frequent charging place (for electric and hybrid drivers)	At home at a private charger	20.0%
	At the office	17.5%
	In the neighbourhood at a public charger	52.5%
	Other	10.0%
Reason for driving electric/hybrid	Financial motives	45.0%
	Employer offers electric/hybrid vehicle	5.0%
	Environmental motives	45.0%
	Driving comfort/driving pleasure	5.0%

Table 7: characteristics of conventional car drivers whether they would consider buying an EV in the future (N=47).

Characteristic	Level	Percentage
Would you consider buying an EV in the upcoming 5 years	Yes	14.9%
	I think so	25.5%
	Neutral	21.3%
	I don't think so	31.9%
	No	6.4%

In Table 8 characteristics about V2G familiarity and driving frequency are depicted. It is interesting to note that of the electric and hybrid car drivers more than half of the respondents had heard of V2G while of the conventional car driver more than half had not heard of V2G before. It can be concluded that electric and hybrid drivers are slightly more familiar with the V2G concept than conventional car drivers. This may be due to more environmental awareness or more interests in new EV technologies of the electric and hybrid car drivers. Most of the respondents drive at least every week, i.e., 90% of the respondents drive more frequently than 3 to 4 days a week. Furthermore, the electric and hybrid drivers seem to drive more frequently than the conventional car drivers.

Table 8: characteristics of respondents with respect to driving frequency and V2G familiarity (N=67).

Characteristic	Level	Electric/hybrid drivers	Conventional car drivers	Sample (all)
Heard of V2G?	No	40.0%	68.1%	59.7%
	Yes, but is not familiar	15.0%	12.8%	13.4%
	Yes, and is familiar	45.0%	19.1%	26.9%
Driving frequency	(almost) every day	30.0%	27.7%	28.4%
	5-6 days a week	45.0%	14.9%	23.9%
	3-4 days a week	15.0%	29.8%	25.4%
	1-2 days a week	5.0%	14.9%	11.9%
	1-3 days a month	5.0%	10.6%	9.0%
	6-11 days a year	0.0%	2.1%	1.5%

Lastly, the motives for participating in V2G were asked and also if the respondents would consider participating in V2G. As can be seen in Figure 5, respondents are more tended to participate in V2G due to environmental reasons than due to financial reasons. If this is true, this should also be concluded from the Multinomial Logit Model, as the attribute remuneration should not be a strong factor for the total utility.

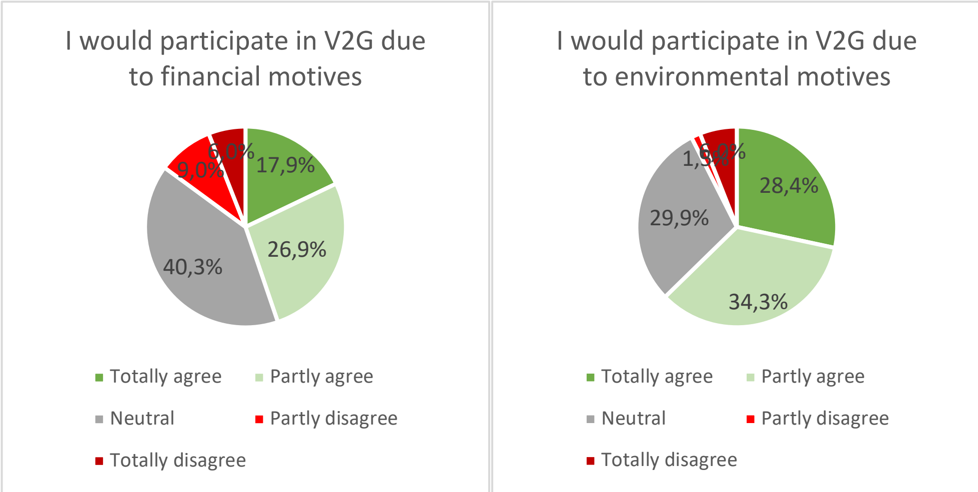

Figure 5: financial and environmental motives to participate in V2G.

Figure 6 depicts the distribution of whether participants would participate in V2G or not. 46.3% would consider participating in V2G, while 38.8% are neutral towards V2G. A relatively small percentage of 14.9% would not consider participating in V2G. It is important to note that this is based on the direct answers given in the last part of the survey and are not preferences elicited from the choice experiment. By comparing the results from the driect queston and the stated preferences elicited from the choice experiment, it is possible to evaluate the extent to which stated preference aligns with actual preference from the direct question. A participation rate of 46.3% seems promising. However, if the results of the MNL model on the stated preference reveals a higher preference for V2G contracts, it is possible that by shaping the V2G contract to the preferences of the participants it will be possible to convince people that are still neutral towards the technology. Naturally, the contract attributes would play a significant role in the willingness of these portion of neutral people.

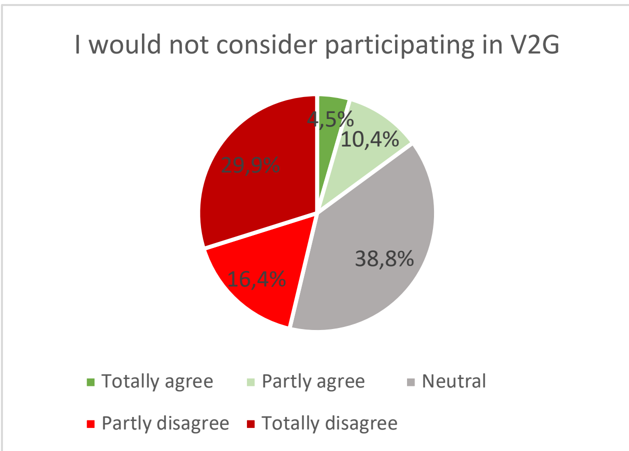

Figure 6: distribution of participants that would not consider participating in V2G.

5.4. Descriptive results of the choice experiment

Every choice task consisted of two types of V2G contracts and an opt out option, i.e., no V2G contract at all. In the case respondents chose “no V2G contract”, they were subsequently asked to choose their preference between the two contracts if they had to choose. This would allow to estimate a model in the case too many people would go for “no V2G contract”. However, as can be seen in Figure 7, for 7 of the 9 contracts, most respondents gave the preference to a contract instead to “no contract”. Only for choice task 3 and choice task 6 the opt-out option was preferred. This indicates that there is relatively more interest in participating in a V2G contract than not participating. This is in contrast with the studies by Zonneveld (2019) and Meijssen (2019) where the rate of "no contract" being preferred was relatively higher. Zonneveld (2019) designed a choice experiment with 12 choice tasks and its sample consisted of only EV drivers. In 10 of the 12 choice tasks, "no contract" was preferred over a V2G contract. Although the survey of this research consisted of both EV drivers and non-EV drivers, in Figure 8 it can be observed that the preference distribution of the contracts is mostly similar for EV drivers as for non-EV drivers, i.e., the most popular option for each choice task is the same for both groups. This suggests that factors other than the type of car may be more influential in determining the willingness to participate in V2G contracts.

A possible explanation for the relatively higher preference for V2G contracts above "no contract" could be the environmental awareness of the people that has been increasing between 2019 and 2023. The general perception of EVs and V2G contracts may have become more positive over time. Another explanation may be the current energy crisis which has led to extremely high electricity and gas prices for households. This can make car drivers more likely to participate in a V2G contract, as it offers them the opportunity to earn extra money by selling the electricity stored in their EVs back to the grid. The compensation of the V2G contracts could therefore be appealing to them.

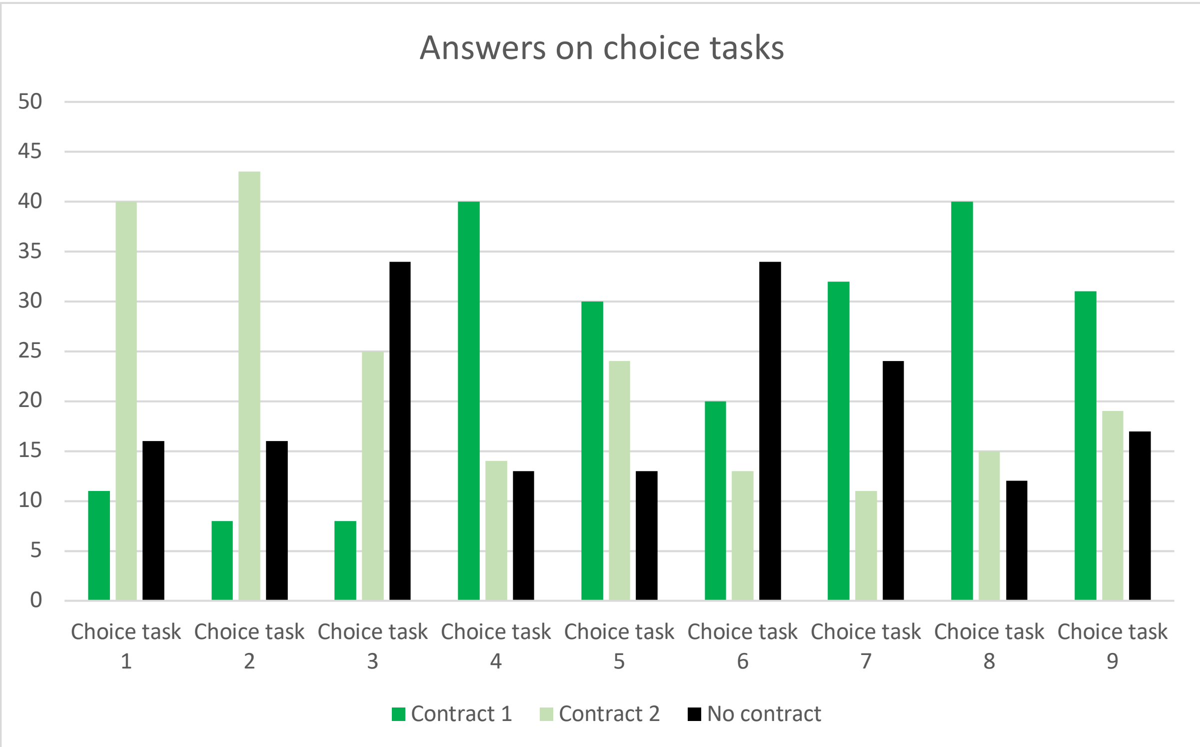

Figure 7: distribution of answers of the nine choice tasks.

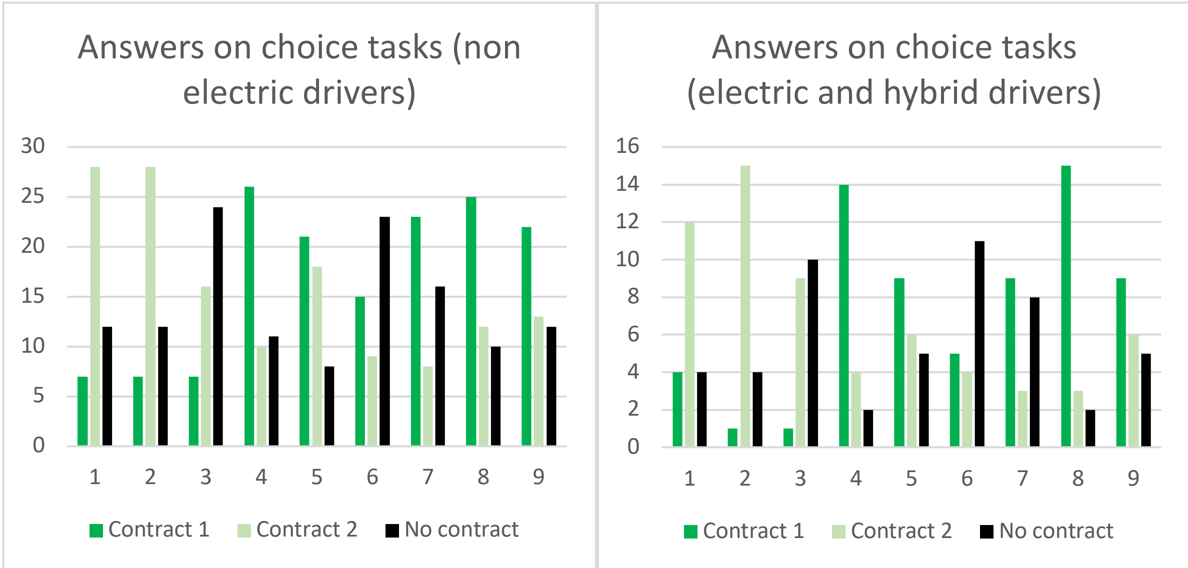

Figure 8: distribution of answers of the nine choice tasks for non-electric drivers (left figure) and electric and hybrid drivers (right figure).

As mentioned, in choice task 3 and choice task 6 most of the respondents preferred the "no contract" option. These two choice tasks are both characterized by relatively high required plug-in hours as can be seen in Figure 9.

Contract Attribute	V2G Contract 1	V2G Contract 2	No Contract
Remuneration	**€100** per month	**€50** per month	–
Daily required plug-in time (weekdays)	**15** hours a day	**10** hours a day	–
Daily required plug-in time (weekends)	**15** hours a day	**15** hours a day	–
Guaranteed driving range	**10** km	**120** km	–

Contract Attribute	V2G Contract 1	V2G Contract 2	No Contract
Remuneration	**€150** per month	**€100** per month	–
Daily required plug-in time (weekdays)	**15** hours a day	**5** hours a day	–
Daily required plug-in time (weekends)	**15** hours a day	**15** hours a day	–
Guaranteed driving range	**65** km	**10** km	–

Figure 9: choice task 3 (left) and choice task 6 (right) of the choice experiment.

This could be an indication that in the MNL estimation the required plug-in time as attribute has a relative higher importance than the other attributes.

5.5. Model estimation results

In this section the results of the Multinomial Logit Model (MNL), as explained in Chapter 4, will be presented. The MNL model gave estimations of the parameters of importance of the attributes included in the choice set and these parameters indicate the relative importance of each attribute in the decision-making process of the respondents.

Basic MNL model with linear components

The basic MNL model consists of three utility function, one for every alternative, i.e., V2G contract 1 in equation (4), V2G contract 2 in equation (5) and No V2G contract in equation (6). For the V2G contract alternatives (V_A and V_B) a constant is added to express the utility differences with the "no contract" alternative (V_C).

$$V_A = C_{V2G} + \beta_{REM} \cdot REM_A + \beta_{DAY} \cdot DAY_A + \beta_{WEEKEND} \cdot WEEKEND_A + \beta_{RADIUS} \cdot RADIUS_A \quad (4)$$

$$V_B = C_{V2G} + \beta_{REM} \cdot REM_B + \beta_{DAY} \cdot DAY_B + \beta_{WEEKEND} \cdot WEEKEND_B + \beta_{RADIUS} \cdot RADIUS_B \quad (5)$$

$V_C = 0$ (6)

Where:

REM_i is the remuneration for contract i
DAY_i is the required plug-in time during weekdays for contract i
$WEEKEND_i$ is the required plug-in time during the weekend for contract i
$RADIUS_i$ is the minimum guaranteed driving range for contract i
β_{REM} is the linear coefficient for the remuneration attribute
β_{DAY} is the linear coefficient for the required plug-in time during weekdays attribute
$\beta_{WEEKEND}$ is the linear coefficient for the required plug-in time during the weekend attribute
β_{RADIUS} is the linear coefficient for the minimum guaranteed driving range attribute
C_{V2G} is the coefficient for choosing a V2G contract.

Table 9 shows the results of the first MNL model. The model did converge, and as can be seen all parameters, except for remuneration, are statistically significant (p-value < 0.05). As expected, the parameters required plug-in time during weekdays and during the weekends have a negative impact on the total utility of the V2G contract. The plug-in time during the weekend has a higher negative effect on the utility than plug-in time during weekdays. Although the difference is not that significant, it indicates that required plug-in time during weekdays is preferred above weekends, as expected. The strongest coefficient is the required plug-in time during the weekend. Respondents experience a relatively lower utility from the required plug-in time. more guaranteed driving range compared to the other parameters. The constant in this first model is not significant. As the constant is the same for V2G Contract 1 and V2G Contract 2, it represents the inherent preference for choosing a V2G contract over not choosing a contract at all. The magnitude can be interpreted as the amount of utils gained from choosing a V2G contract over not choosing one, given that the coefficient is zero, i.e., regardless of the specific attributes of each contract option. However, the estimated value is not statistically significant. The positive sign indicates that there is a higher preference or willingness to participate in these contracts compared to the "no contract" option.

The null log-likelihood, the log-likelihood when all parameters are zero, is -662.46. The final log-likelihood is -609.06. Using McFadden's rho-squared function, the log-likelihood can be used to assess a model's fit with the data. As can be seen in Table 9, the rho-squared has a value of 0.0806. Some studies indicate that a rho-squared lower than 0.1 fits the data quite limited, while a rho-squared between 0.1 and 0.3 indicate a reasonable fit (Zonneveld, 2019). The resulted rho-square of 0.0806 indicate that there is high heterogeneity in the population, i.e., most participants think different about the drivers to participate.

Table 9: estimation results of the MNL model with linear components.

Parameter	Name	Estimate	s.e.	t-ratio (0)	p-value
V2G contract constant	C_{V2G}	0.892	0.415	2.961	0.002
Remuneration	β_{REM}	-0.000	0.002	-0.220	0.413
Plug-in weekdays	β_{DAY}	-0.071	0.024	-3.297	0.000
Plug-in weekend	$\beta_{WEEKEND}$	-0.084	0.017	-4.670	0.000
Guaranteed driving range	β_{RADIUS}	0.012	0.002	8.464	0.000
Number of observations	603				
Estimated parameters	5				
Null log-likelihood	-662.46				
Final log-likelihood	-609.06				

Rho-squared	0.0806				

MNL model with nonlinear components

To check whether there is nonlinearity between the attribute levels, quadratic components are added to the utility function. Since the remuneration parameter was not statistically significant in the first model, this parameter is now tested for nonlinearity. Also the other attributes are tested for nonlinearity. The nonlinearity test is done by adding a quadratic component to the attribute, having for each attribute two coefficients to be estimated, a linear and a quadratic. Equations 7, 8 and 9 show the new utility functions.

$$V_A = C_{V2G} + \beta_{REML} \cdot REM_A + \beta_{REMQ} \cdot {REM_A}^2 + \beta_{DAYL} \cdot DAY_A + \beta_{DAYQ} \cdot {DAY_A}^2 + \beta_{WEEKENDL} \cdot WEEKEND_A + \beta_{WEEKENDQ} \cdot {WEEKEND_A}^2 + \beta_{RADIUSL} \cdot RADIUS_A + \beta_{RADIUSQ} \cdot {RADIUS_A}^2 \quad (7)$$

$$V_B = C_{V2G} + \beta_{REML} \cdot REM_B + \beta_{REMQ} \cdot {REM_B}^2 + \beta_{DAYL} \cdot DAY_B + \beta_{DAYQ} \cdot {DAY_B}^2 + \beta_{WEEKENDL} \cdot WEEKEND_B + \beta_{WEEKENDQ} \cdot {WEEKEND_B}^2 + \beta_{RADIUSL} \cdot RADIUS_B + \beta_{RADIUSQ} \cdot {RADIUS_B}^2 \quad (8)$$

$$V_C = 0 \quad (9)$$

Where:

β_{REML} is the linear coefficient for the remuneration attribute
β_{REMQ} is the quadratic coefficient for the remuneration attribute
β_{DAYL} is the linear coefficient for the required plug-in time during weekdays attribute
β_{DAYQ} is the quadratic coefficient for the required plug-in time during weekdays attribute
$\beta_{WEEKENDL}$ is the linear coefficient for the required plug-in time during the weekend attribute
$\beta_{WEEKENDQ}$ is the quadratic coefficient for the required plug-in time during the weekend attribute
$\beta_{RADIUSL}$ is the linear coefficient for the minimum guaranteed driving range attribute
$\beta_{RADIUSQ}$ is the quadratic coefficient for the minimum guaranteed driving range attribute

The results of the model can be seen in Table 10. Also this model converged. The constant resulted to be negative in this model, but not significant. This would suggest that there is a lower willingness to participate for V2G Contract 1 or V2G Contract 2 compared to the no contract option. As can be seen, now that the attribute remuneration is divided in a linear and a quadratic coefficient, the estimated result is statistically significant. However, the estimated parameters for the nonlinear components of the attributes required plug-in time during weekdays and during the weekend are not significant anymore. Therefore it can be concluded that the effect of these two attributes on the utility is not quadratic, and hence linear. The estimate for the linear and quadratic coefficients of the attribute guaranteed minimum driving range is significant. So, it can be concluded that this attribute also has a quadratic effect on the perceived utility. With this information a new model will be estimated where the attributes required plug-in time during weekdays and during the weekend have a linear coefficient, and the attributes remuneration and guaranteed minimum driving range a linear and quadratic coefficient.

Furthermore, this model shows a better fit than the previous model, the final log-likelihood is now -596.59, resulting in a rho-squared of 0.0994, indicating that the model almost fits the data reasonable according to the previous indication of model fit. However, the number still indicate high heterogeneity in the population.

Table 10: estimation results of the MNL model with nonlinear components.

Parameter	Value	s.e.	t-ratio (0)	p-value
C_{V2G}	-1.183	0.885	-1.337	0.091
β_{REML}	0.019	0.011	1.681	0.047
β_{REMQ}	0.000	0.000	-1.642	0.050
β_{DAYL}	0.047	0.123	0.384	0.350
β_{DAYQ}	0.005	0.006	-0.986	0.162
$\beta_{WEEKENDL}$	0.000	0.107	-0.003	0.499
$\beta_{WEEKENDQ}$	-0.004	0.005	-0.764	0.223
$\beta_{RADIUSL}$	0.033	0.006	5.500	0.000
$\beta_{RADIUSQ}$	-0.000	0.000	-3.913	0.000
Number of observations	603			
Estimated parameters	9			
Null log-likelihood	-662.46			
Final log-likelihood	-596.94			
Rho-squared	0.0989			

MNL model with linear and nonlinear components

As already explained in the previous section. The last MNL model will have a quadratic component for the attributes remuneration and guaranteed minimum driving range. The required plug-in time during weekdays and the weekend will be kept linear. This results in the new utility functions as depicted in equations (10), (11) and (12).

$$V_A = C_{V2G} + \beta_{REML} \cdot REM_A + \beta_{REMQ} \cdot {REM_A}^2 + \beta_{DAY} \cdot DAY_A + \beta_{WEEKEND} \cdot WEEKEND_A + \beta_{RADIUSL} \cdot RADIUS_A \cdot +\beta_{RADIUSQ} \cdot {RADIUS_A}^2 \quad (10)$$

$$V_B = C_{V2G} + \beta_{REML} \cdot REM_B + \beta_{REMQ} \cdot {REM_B}^2 + \beta_{DAY} \cdot DAY_B + \beta_{WEEKEND} \cdot WEEKEND_B + \beta_{RADIUSL} \cdot RADIUS_B + \beta_{RADIUSQ} \cdot {RADIUS_B}^2 \quad (11)$$

$$V_C = 0 \quad (12)$$

The results are depicted in Table 11. In this model all estimated parameters are significant, except for the constant. It can be concluded that hence remuneration and guaranteed minimum driving range have a quadratic effect on the utility, while the attributes required plug-in time during weekdays and the weekend have a linear effect on the utility.

Table 11: estimation results of the MNL model with remuneration and guaranteed minimum driving range nonlinear.

Parameter	Value	s.e.	t-ratio (0)	p-value
C_{V2G}	-0.485	0.607	-0.799	0.212
β_{REML}	0.021	0.011	1.982	0.024
β_{REMQ}	-0.000	0.000	-1.976	0.024
β_{DAY}	-0.073	0.023	-3.241	0.000
$\beta_{WEEKEND}$	-0.078	0.019	-4.080	0.000
$\beta_{RADIUSL}$	0.034	0.006	5.744	0.000
$\beta_{RADIUSQ}$	-0.000	0.000	-4.095	0.000
Number of observations	603			
Estimated parameters	7			

Null log-likelihood	-662.46			
Final log-likelihood	-597.21			
Rho-squared	0.0985			

Furthermore, this model shows a quite similar fit as the previous model, where all the attributes were tested for nonlinearity. The final log-likelihood is -597.21, resulting in a rho-squared of 0.0985, indicating that the model almost fits the data reasonable. The interpretation of this number is comparable with the previous model, and indicates a high level of heterogeneity.

5.6. Model reflection and utility contribution

The final model that will be used is based on the results in Table 11 as it is considered the best model estimated since all parameters are statistically significant, and it has a higher model fit compared to the first model. From this table, a comparison can be made with the hypothesized attribute parameters as depicted in Table 2 in Chapter 4.2.

Table 12: correctness of hypothesis of the V2G contract attributes.

	Hypothesis	Correctness
H_1	Remuneration has a positive effect on the perceived utility	Partly rejected[1]
H_2	Guaranteed minimum driving range has a positive effect on the perceived utility	Accepted
H_3	Plug-in time during weekdays has a negative effect on the perceived utility	Accepted
H_4	Plug-in time during weekends has a negative effect on the perceived utility, and this effect is stronger than the plug-in time during weekdays	Accepted

All parameters are significant, and hence the following utility function for V2G contracts was found:

$$V_{V2G\ Contract} = -0.485 + 0.02118REM - 0.0001389REM^2 - 0.07345DAY - 0.07775WEEKEND + 0.03401RADIUS - 0.0001679RADIUS^2 \quad (13)$$

Remuneration

Remuneration did not have an absolute positive effect on the utility as expected. Figure 10 depicts the utility contribution for the contract attribute remuneration. As explained before, remuneration had a relatively low importance. This can also be seen in the figure. The attribute shows a non-linear effect on the perceived utility. The respondents perceive a higher utility when the monthly remuneration increases from €50. However, after a monthly remuneration of €100 it decreases again. Surprisingly, after €100 remuneration, the utility decreases. Meaning that receiving a remuneration of €150 results in a lower utility than €100. This is counterintuitive, and hence it can be concluded that the attribute remuneration does not have a significant impact on the perceived utility of the respondents for the attribute levels chosen in this research. It could be possible that the respondents did not understand well the differences between the amounts of remuneration. For example, €100 could have a psychological attractiveness since it is a nicely rounded amount.

[1] The remuneration showed a positive effect on the perceived utility for the first phase between €50 and €100, but a negative effect for the second phase between €100 and €150. This is also depicted in Figure 10.

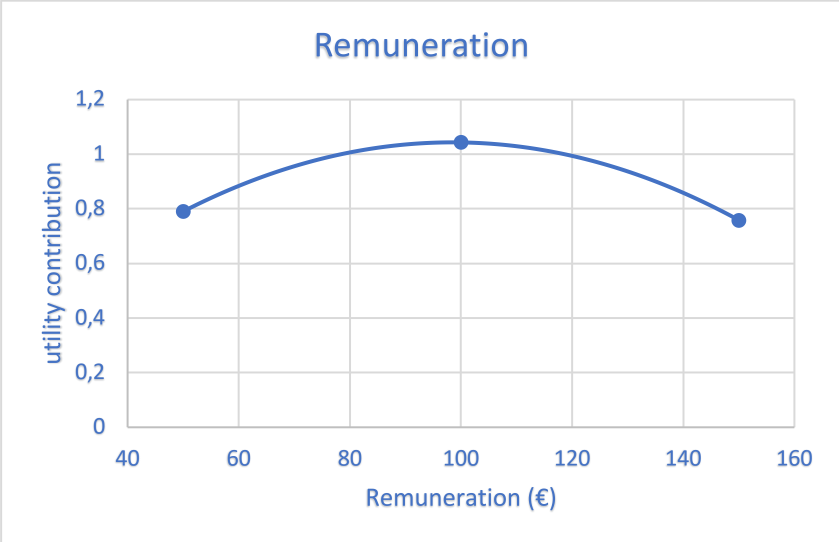

Figure 10: utility contribution remuneration. The utility contribution of remuneration corresponds to the following contribution formula: $V = 0.02118REM - 0.0001075REM^2$.

Required plug-in time

The required plug-in time has a negative effect on the perceived utility of the respondents, as expected. Figure 11 depicts the utility contribution for the required plug-in time during weekdays and weekends. As can be seen in the slope, the required plug-in time during the weekends has a slightly stronger negative effect than the required plug-in time during weekdays. The relative importance is 23% and 25% for plug-in time during weekdays and weekends respectively, resulting both attributes in a substantive importance for the perceived utility. However, it is hard to say whether this difference in slope contributes significantly for the perceived utility, as the difference in slope is rather small.

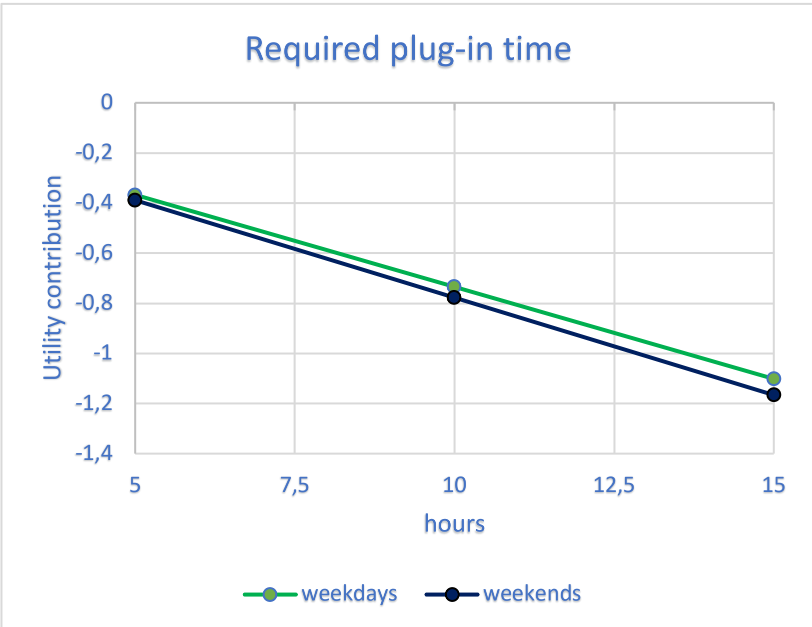

Figure 11: utility contribution required plug-in time. The utility contribution of required plug-in time corresponds to the following formulas: $V_{weekdays} = -0.07345DAY$ *and* $V_{weekends} = -0.07775WEEKEND$.

Guaranteed minimum driving range

The guaranteed minimum driving range has a positive effect on the perceived utility of the respondents, as expected. However, it should be noted that this effect is non-linear. With higher guaranteed driving range, the utility gets saturated. This effect is depicted in Figure 12.

Furthermore, this attribute has the highest relative importance, contributing with 43% to the utility. As can be seen in the figure, when the guaranteed driving range increases from 10 km to 65 km there is a strong increase in utility. While for an increase from 65 km to 120 km of guaranteed driving range, the utility increase is relatively smaller.

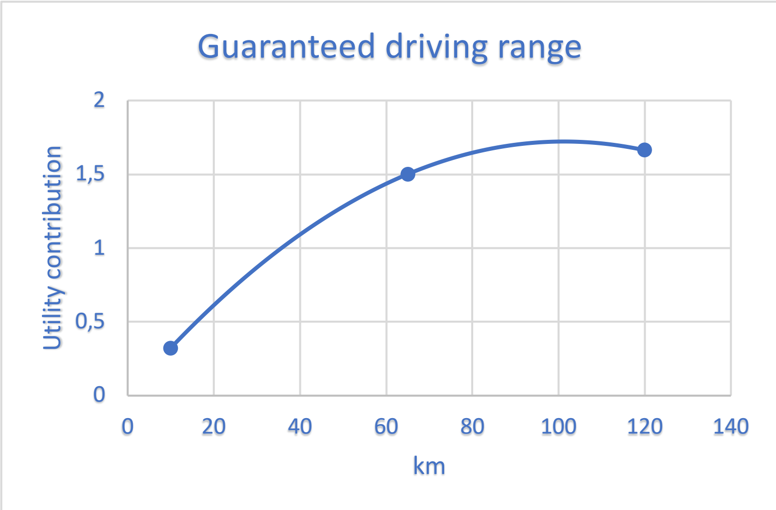

Figure 12: utility contribution guaranteed driving range. The utility contribution of the guaranteed driving range corresponds to the following formula: $V = 0.03401RADIUS - 0.0001679RADIUS^2$.

Relative importance of the attributes

Based on the utility ranges it was possible to calculate the relative importance of the attributes. However, it should be noted that these importance contribution to the utility is dependent upon the attribute levels chosen. As can be seen in Table 13 remuneration resulted to be the least important attribute. This attribute was followed by the required plug-in time during weekdays, which showed a relative importance of 23%, and then the required plug-in time in the weekend, with a relative importance of 25%. The most important attribute resulted to be the guaranteed minimum driving range with 43% of utility contribution. These results indicate that the respondents placed a high importance on the guaranteed minimum driving range in their decision-making process, while remuneration played a minor role.

Table 13: relative importance of the attributes. The utility range is calculated by the absolute difference between the attribute level with the highest and lowest utility contribution. The relative importance is calculated by the contribution of the attribute divided by the summed utility range.

Contract attribute	Utility range	Relative importance	Importance order
Remuneration	0.283	9%	4
Required plug-in time during weekdays	0.735	23%	3
Required plug-in time in the weekend	0.778	25%	2
Guaranteed minimum driving range	1.340	43%	1

6. APPLICATION OF RESULTS

This chapter intends to use the results obtained from the MNL model with linear and nonlinear components as shown in Table 11. Hypothetical contracts for different scenarios will be designed. In order to determine the market share of a hypothetical contract with respect to a base case, the following choice probability formula will be used:

$$P(i) = \frac{e^{(V_i)}}{\sum_{j=1..J} e^{(V_j)}} \tag{14}$$

Where P denotes the probability of the alternative i being chosen over all other alternatives, which correspond to j and includes alternative i. The base case is “no V2G contract”. Due to the constant added in the utility function of the V2G contract, the demand for V2G contract can be calculated. The utility of “no V2G contract” corresponds in this case to 0. This implies that the market share for V2G contract i can be calculated with the following formula:

$$P(i) = \frac{e^{(V_i)}}{e^{(V_i)} + e^0} \tag{15}$$

The market share can say something about the demand in different situations. Three scenarios will be suggested, each based on a different actor’s perspective. The actors that will be considered are the consumers (EV driver), the aggregator and the government. All three have different interest in the outcome of the V2G system which will be elaborated in the continuation of this chapter.

To compare the different cases, revenues of the actor are of importance. Considering that the government is a public entity, only the revenues of the consumers and the aggregator will be considered. The revenues of the consumers are straightforward and follow from the remuneration set in the V2G contract, which can be either €50, €100 or €150 per month. However, as could be seen in the utility contribution per attribute in Chapter 5.6, the highest remuneration does not necessarily lead to the highest utility. Therefore, the highest “profit” for the consumer is assumed to be when the attribute levels are set to the levels that maximizes the perceived utility. The profit for the aggregator is determined in a different way, since they will offer the aggregated storage from the connected EVs on the balancing market. The monthly revenues for the aggregator are dependent upon the following factors:

- Discharge capacity: amount of electrical charge that can be released from the EVs battery in MW [P].
- Hours of discharge: the number of hours the EV is able to offer V2G service according to the contract [t].
- Utilization rate: the fraction of time the EV is actually used for V2G service [u].
- Energy price: price per MWh offered on the balance market [p].
- V2G demand: share of EVs that are connected to the aggregator and provide V2G service. This amount is dependent upon the design of the contract [P(V)].
- Available cars: the available EVs that are capable of participating in V2G. This amount multiplied by the V2G demand market share gives the amount of cars participating [x].

The revenues can hence be calculated with the following formula:

$$revenues = x * P(V) * u * P * t * p \tag{16}$$

The monthly costs [c] of the aggregator consists of the remuneration set in the contract, and is also dependent upon the demand, i.e., the amount of aggregated EVs:

$$costs = x * P(V) * c \tag{17}$$

With these two formulas, the following profit formula can be established for the aggregator:

$$profit = x * P(V) * (u * P * t * p - c) \tag{18}$$

Denoting the profit for the aggregated EVs ($x * P(V)$).

6.1. Consumer's perspective

As already mentioned, the consumer seeks to maximize its perceived utility. According to the utility contributions calculated in Chapter 5.6, the V2G contract depicted in Figure 13 will maximize the consumer's perceived utility. This is when the remuneration is set at €100, the daily required plug-in time (both during weekdays as in the weekend) at 5 hours, and a guaranteed driving range of 120 km.

Contract Element	V2G Contract
Remuneration	**€100** per month
Daily required plug-in time (weekdays)	**5** hours per day
Daily required plug-in time (weekends)	**5** hours per day
Guaranteed driving range	**120** km

Figure 13: V2G contract that results in the highest utility for the consumers.

Using equation (13), the resulting utility for this contract is $V_1 = 1.466$. The resulting demand from this contract is as follows:

$$P(1) = \frac{e^{1.466}}{e^{1.466} + e^{0}} = 0.812 \tag{19}$$

In other words, in the best-case scenario from the consumer's perspective, the V2G demand will result in 81.2%. This indicates that a high share of drivers is willing to participate in V2G, on the condition that the attribute levels are favorable for them.

On the other hand, there is also a worst-case scenario for the consumer. This is when attribute levels are set such that the utility is minimized. This contract is shown in Figure 14. The remuneration is set at €150. Although this is counterintuitive (lower utility from higher remuneration), from the utility contribution resulted that a remuneration of €150 leads to a lower utility contribution than €50. The peak is at €100 remuneration. The daily plug-in times are set at 15 hours, and the guaranteed driving range at its lowest level of 10 km.

Contract Element	V2G Contract
Remuneration	**€150** per month
Daily required plug-in time (weekdays)	**15** hours per day
Daily required plug-in time (weekends)	**15** hours per day
Guaranteed driving range	**10** km

Figure 14: V2G contract in worst-case scenario for consumer.

Using equation (13), the utility that results from this contract is $V_2 = -1.671$. The demand for this contract is:

$$P(2) = \frac{e^{-1.671}}{e^{-1.671} + e^{0}} = 0.158 \qquad (20)$$

As can be seen the demand for V2G contracts drops significantly to 15.8% for the worst-case scenario. However, it is worth noting that there is still some demand in a worst-case scenario. The utility functions can be highly interesting for the aggregator who wants to maximize its profit. This should be a balance of sufficient demand and enough earning on the contract. The above presented formulas can contribute to a design that meets their interest, as will be shown in the following section.

6.2. Aggregator's perspective

As explained before, the aggregator seeks to maximize profit using the profit formula presented in this Chapter. An estimation or assumptions on the parameters should be made in order to make the calculations. For the first scenario, the following assumptions will be taken:

- Discharge capacity: in the first scenario the discharge capacity is set at 11 kW. This is the capacity of most private EV chargers (ANWB, 2013).
- Hours of discharge: since the profit is calculated per month, it will be assumed that a month contains four weeks. So the total hours of discharge in a month is calculated as: 4*(5*plug-in weekdays+2*plug-in weekends).
- Utilization rate: it is assumed that 72% of the time stated in the contract, the EV is actually used for providing V2G service. This assumption is based on an example calculation by Noel et al. (2019).
- Energy price: in the first scenario the energy price on the balancing market is set at €59,94. This was the average price on the Dutch balancing market in February 2019 (TenneT, 2023). In the current geopolitical situation these prices are much higher. But for the first model old prices are considered.
- V2G demand: the demand is based on the contract design. A few contracts will be taken into consideration. Also we will seek the contract that leads to the highest profit for the aggregator.

$P(V)$ represents the market share. This means that when there are x EVs, it is expected that a fraction $P(V)$ is willing to participate in V2G.

Profit aggregator for highest demand
Taken the best-case scenario from the consumer's perspective, the aggregator's revenues are based on the contract design presented in Figure 13. Considering the aforementioned assumptions, the profit for the aggregator is:

$$profit\ per\ EV = x * P(V) * (u * P * t * p - c) = 0.812 * (0.72 * 0.011 * 140 * 59.94 - 100) = -€27.25 * x \quad (21)$$

So, in the case the aggregator would sell the contract presented in Figure 13, given the mentioned assumptions, it will make a loss of €27.25 per EV. Although the demand is high, the potential amount of energy sold on the balancing market does not outweigh the remuneration costs towards the consumers. So this contract would not be profitable for the aggregator.

Profit maximization for the aggregator
To determine which contract attribute levels result in the highest profit for the aggregator, the calculation is made in excel using the Solver option to maximize the outcome. The contract presented in Figure 15 leads to the highest profit per EV for the aggregator. In this case the remuneration is set at €50 per month, the required plug-in time during weekdays at 15 hours per day, the required plug-in time during weekends at 5 hours per day and the guaranteed minimum driving range at 120 km.

Contract Element	V2G Contract
Remuneration	**€50** per month
Daily required plug-in time (weekdays)	**15** hours per day
Daily required plug-in time (weekends)	**5** hours per day
Guaranteed driving range	**120** km

Figure 15: V2G contract that leads to profit maximization for the aggregator.

The resulting utility for this contract $V_3 = 0.478$. And the demand for this contract is:

$$P(3) = \frac{e^{0.478}}{e^{0.478} + e^{0}} = 0.617 \quad (22)$$

The resulting profit for the aggregator for this contract can hence be calculated as follows:

$$profit\ per\ EV = x * P(V) * (u * P * t * p - c) = 0.617 * (0.72 * 0.011 * 340 * 59.94 - 100) = €68.78 * x \quad (23)$$

So, in the case of profit maximization for the aggregator, it should sell the V2G contract as depicted in Figure 15. This will result in a demand of 61.7% for V2G contracts and lead to a profit of €68.78 per EV.

Aggregator's profit in fast charging scenario

As explained before, the profit for the aggregator is partly dependent upon the discharge capacity. When the discharge capacity is higher, the aggregator is able to offer more energy on the balancing market. In the previous example the discharge capacity is assumed to be the same as the average charging capacity in the Netherlands. This example will examine the case of fast charging stations. Most fast chargers have a capacity of 50kW. However, more modern charging stations can already reach capacities of 350kW. In the case this capacity is also available for discharging, and the aggregator would sell the contract that leads to the highest perceived utility for the consumers as depicted in Figure 13, the new profit per EV for the aggregator will be as follows:

$$profit\ per\ EV = x * P(V) * (u * P * t * p - c) = 0.812 * (0.72 * 0.050 * 140 * 59.94 - 100) = 164.19 * x \quad (24)$$

As can be seen, the profit may be really dependent upon different factors such as the discharge capacity. Selling the same contract in with 11kW discharge capacity would lead to a loss for the aggregator while a fast discharge capacity of 50kW leads to a profit. When all charging stations would have a capacity of 350kW, the aggregator can make even more profit.

By applying the solver, a break-even point can be calculated to determine the minimum amount of discharge capacity needed for the aggregator to make a profit. Keeping all other parameters the same, and selling the contract of Figure 13, the discharge capacity should be at least 16.6kW in order to make a profit. This is very promising for the aggregator, as their business as presented is considered to be profitable.

6.3. Government's perspective

The Dutch Government has the ambition to reduce greenhouse gas emissions by 49% in 2030 compared to 1990 levels, and eventually achieve climate neutrality in 2050 (Government of the Netherlands, 2019). As already explained in this report, V2G can enable the integration of more renewable energy sources into the grid by providing a means to balance fluctuations in supply and demand. This is in the Government's interest, since a V2G system can help to reduce the need for expensive infrastructure investments and ensure the availability of electricity. Moreover, V2G can help to reduce greenhouse gas emissions. The Government would have an interest in the V2G deployment. For them, the most important aspect is to ensure availability and affordability of electricity supply. Therefore, the Government would benefit from high required plug-in times. Higher required plug-in times leads to more V2G service and more capacity to balance fluctuations in supply and demand. However, higher plug-in times also lead to lower market share, since it leads to a lower perceived utility for the consumer. Therefore, a contract should be designed where the amount of available V2G hours in a month is maximized. This amount can be calculated as follows:

$$available\ hours\ per\ month = x * P(V) * 4 * (5 * plugin\ weekdays + 2 * plugin\ weekends) \quad (25)$$

Using the solver in Excel, the contract depicted in Figure 16 will lead to the most available hours per month. The contract should have a monthly remuneration of €100, required plug-in time of 15 hours during weekdays and 5 hours during the weekends, and a minimum guaranteed driving range of 120 km. This contract results in a market share of 67.5% and leads to 229 hours of V2G availability per EV per month.

Contract Element	V2G Contract
Remuneration	**€100** per month
Daily required plug-in time (weekdays)	**15** hours per day
Daily required plug-in time (weekends)	**5** hours per day
Guaranteed driving range	**120** km

Figure 16: V2G contract that leads to Government's objective.

The discussed V2G contract would have influence on the profit of the aggregator. By applying the solver in Excel, it is possible to calculate the break-even points for the aggregator when it would sell the contract depicted in Figure 16. In the case the average discharge capacity is 11kW, the average price per MWh on the balancing market should be at least €37.14 for the aggregator to make a profit. While in a fast discharge capacity scenario of 50kW, the minimum price should be €8.17 per MWh.

6.4. Conclusions and reflections on model application

The aforementioned scenarios are very promising for each actor that was discussed. The perceived utility of the different actors is highly dependent upon the attribute levels of the V2G contract. The calculations show that there is room for profit for the aggregator in certain circumstances. Also, if the Government's objective is met, there is still room for profit for the aggregator. Trade-off should be made between the different actors to get to a contract design where there is sufficient benefit for all actors.

It should be noted that the calculations performed in this chapter are highly simplified. In reality the profit model for the aggregator is more complex as presented in this chapter. In the simplification it is assumed that all available hours are sold on the balancing market, which in reality probably would not be the case. Besides, it is also not taken into account the charging behaviour of the EV. Since it is also possible that electricity generation surpluses will be stored in the EVs battery. In this chapter only the discharge is taken into account, and not the charge behaviour. Another side note that is important to mention is that the available hours of V2G is also dependent upon the guaranteed driving range stated in the contract. When the guaranteed driving range is 120 km and the maximum driving range of the EV is 150 km, it is not very feasible that the EV would be available for discharging 15 hours a day. When it gets close to 120 km range during discharge, the system should stop and start charging again to be able to discharge. This implies that if guaranteed driving range in the contract is set to 120 km, while the range is 150 km. It is only able to discharge when above a radius of 120 km.

The price on the balancing market is very volatile, and it is hard to predict revenues from the prices set on this market. The market does not only buy extra capacity for balancing and maintaining the network's frequency, but also sells excess capacity when there is too much supply. These prices may be different, but both can influence the profit of the aggregator.

Another important sidenote, is that if many EVs are aggregated, maybe not all the available energy can be sold, it may be too much. In the calculations it is assumed that all the available energy is also sold. But this is highly dependent upon the demand on the balancing market.

Although, it can be expected that in a future with more renewable energy sources and higher electricity demand, the demand on the balancing market will increase.

Nevertheless, the discussed welfare calculations can give some insights in how a profit model could look like and how the results of the MNL model can play a role in the design of a V2G contract. Having more knowledge about the willingness of (future) EV drivers to participate in V2G contract can give policy makers and market actors like aggregators better insights to shape the design and deployment of a V2G system.

7. Conclusions

This research aims to provide deeper insides on the willingness of Dutch car drivers to participate in V2G contracts. V2G could play an important role in the future, enhancing the energy transition. It can provide a storage solution for future energy systems, enabling the integration of more renewable energy sources into the grid by providing a means to balance fluctuations in demand and supply. Yet, little is known about the willingness to participate in these programs. The literature gave some insides on previous stated preference studies where hypothetical contracts were examined. However, the amount is limited and mostly outdated. Moreover, mostly EV drivers were examined while the amount of EV drivers was really scarce at the time. Currently, the amount of EV drivers has increased, and there is more awareness about EVs and their potential role in the future. Therefore, this study focused on all Dutch car drivers and their willingness to participate in future V2G contracts. To the knowledge of the author, this is the first research that analyzed the effect of differentiating weekdays and the weekend in the contract.

The main research question of this thesis is as follows:

What is the impact of contract attributes on the willingness of Dutch car drivers to participate in V2G contracts?

To answer this question a hypothetical contract was designed based on the literature review. Four contract attributes were chosen, namely remuneration, required plug-in time on weekdays, required plug-in time during the weekend, and guaranteed minimum driving range. The choice experiment was performed through a survey. Both EV drivers as non-EV drivers filled in the survey, as the target group was all Dutch car drivers. From both groups a relatively high willingness was observed towards V2G contracts compared to no V2G contract. For the nine choice tasks presented to the participants, for seven of the choice tasks participating in a V2G contract was preferred over not participating in a V2G contract.

Through the MNL model, the importance coefficients for the contract attributes could be estimated. By adding quadratic components to the utility function, all four parameters resulted to be statistically significant, implying that they all have a significant effect on the perceived utility for a V2G contract. Remuneration had a quadratic effect on the perceived utility, and the curve was not as expected. It resulted that higher remuneration not always led to a higher perceived utility as hypothesized. The required plug-in times during weekdays and the weekend have both a negative linear effect on the perceived utility. As expected, and hypothesized, the negative effect in the weekend is stronger than during weekdays. The guaranteed minimum driving range had a positive quadratic effect on the perceived utility. For lower ranges the increase in utility is relatively high, while for higher ranges, an increase in guaranteed driving range results in relatively lower increase of perceived utility, implying that at a certain guaranteed driving range the utility is saturated.

The relative importance of the contract attributes varies significantly among the attributes. Surprisingly, the remuneration attribute has a low relative importance of 9%, for the attribute levels chosen. The required plug-in time during weekdays and weekends had a higher relative of importance of 23% and 25%, respectively. At last, the highest relative importance resulted from the minimum driving range attribute, with an importance of 48%. This is also in line with the literature, since it is known that driving range is an obstacle for driving an electric vehicle and also for participating in V2G, as it enhances the common barrier of range anxiety.

It was difficult to find heterogeneity in the population. The analysis did not give a clear overview of the characteristics of this group. Therefore, there is no clear evidence that there exists heterogeneity in the population. This is possibly due to the fact that this choice experiment considered all car drivers instead of only EV drivers as some previous studies did. A Latent Class Choice Model could give more insights in this respect.

In order to evaluate the impact of the V2G contracts on other actors in the system, some hypothetical contracts were evaluated for application purposes based on the results obtained from the MNL model. The contract resulting in the highest utility for the consumers leads to a V2G market share of 81.2% while the contract resulting in the lowest utility leads to a V2G market share of 15.8%. The aggregator's profit is highly dependent upon the contract type that is to be sold since it influences the demand. The contract that maximizes the profit for the aggregator lead to a V2G contract market share of 61.7%. In order to maximize the satisfaction of the Government, yet another contract should be sold. It is important for all actors to make trade-offs with respect to their interests in V2G contracts.

The study shows that there is willingness to participate and that certain contract attributes have different impact on the perceived utility of Dutch car drivers. Compared to previous studies is seems that the willingness and towards V2G has increased. This is very promising for the future, as it can be used by different actors to shape V2G contracts in order to satisfy their interests.

8. DISCUSSION

This research presents new insights with respect to the willingness to participate in V2G contract. This chapter intends to elaborate and discuss the results obtained from the research by making a comparison with the literature and discussing shortcomings and limitations of the study. Furthermore, implications for society and avenues for further research are discussed.

8.1. Comparing results with the literature

This study had some similarities with previous stated choice experiments on V2G contract. The contract attributes used in this experiment were based on previous used attributes. The three most important contract attributes that follow from the literature are: remuneration, required plug-in time and guaranteed minimum driving range. Parsons et al. (2014) is one of the first authors known of performing such experiment. Their conclusion was that drivers see high inconvenience cost with signing V2G contracts. It is suggested that a possible reason could be the lack of awareness. It should be noted that for 2014 the EV market was still underdeveloped, let alone a V2G system. More recent publication showed an increase in willingness towards V2G contract. Geske & Schumann (2018) made a similar choice experiment for German car drivers. Of the 611 participants only 14 were EV users. This indicates the low utilization rate for 2018. They concluded that the contract attribute "minimum range" dominates the "remuneration". This is in line with this thesis. Remuneration was not considered a relative important parameter while the minimum guaranteed driving range had the highest relative importance. Zonneveld (2019) and Huang et al. (2021) performed a stated choice-experiment on Dutch EV drivers and included an opt-out option of not participating in V2G. Both studies showed that the willingness to participate in V2G contract was relatively low. For most choice tasks respondents preferred the opt-out option over a V2G contract. However, in a fast-charging context, as Huang et al. (2021) explored, the willingness to participate increases significantly. The minimum guaranteed driving range played an important role in this respect. The barrier "range anxiety" decreases when it is possible to charge your EV as fast as fueling a gasoline vehicle. It is interesting that this thesis showed a relative high willingness to participate in V2G contracts compared to previous studies. This study is most comparable with Zonneveld (2019) and Huang et al. (2021) due to the target group. Although the difference in this study is that also non-EV drivers were included. A possible explanation of the increase in willingness is that there is more awareness and acceptance towards EVs. A substantial group of the non-EV drivers that participated in the survey indicated that they were willing to switch to EV in the future. V2G contract can decrease the costs of driving EV. However, this study also shows that financial compensation is not the main driver of participating in V2G. Most participants agreed that they would also participate in V2G contracts due to environmental motives. A new insight in this study was to differentiate the required plug-in time between weekdays and the weekend. It was expected that participants perceive a different utility for this contract attribute during weekdays and the weekends. Effectively, the results showed that the relative importance was slightly higher for required plug-in time during the weekend than during weekdays. Although this should be taken with caution, as the difference is rather small and not tested for significancy. Possibly participants prefer less required plug-in time during weekends as they probably would prefer to have more flexibility during weekends. Concluding, it can be stated that this study showed an increase in the willingness to participate in V2G contracts among Dutch car drivers compared to previous studies. In line with previous studies, guaranteed minimum driving range seems to have a relative high importance factor compared with remuneration. Range anxiety can still be seen as one of the major social barriers of participating in V2G. However, increased awareness may have led to an increase in willingness, and more openness towards the V2G technology.

8.2. Shortcomings and limitations of this study

This research is subject to various limitations that will be further discussed in this paragraph.

Survey design

The survey design had several limitations. Although after design the survey was tested and many reiterations took place, still it was difficult for some respondents to understand well what the survey was about and how the concept of V2G works. A respondent's feedback was that the numbers were confusing, as the attribute levels for required plug-in time during weekdays and the weekend were the same. It gave the impression that he was only seeing numbers instead of a tangible contract. It is highly important for stated choice experiments that the choices are as realistic as possible in order that it simulates a real-life experience.

There was a large number of incomplete responses which limited the results of this study. The aim was to receive at least 100 completed responses. However, only 67 of the 121 responses were completed. Almost half of the respondent that started the survey did not finish the survey. From the survey results in Qualtrics could be seen that most respondents dropped out after beginning the first-choice set. It was already tried to keep the amount of choice sets to a minimum, but apparently 9 choice sets were found to be intense for a part of the respondents. More effort could have been taken in achieving this target. Currently personal network was used to recruit respondents and social media channels such as LinkedIn. Other means could have increased the final number of respondents. Although, due to time limitations the final 67 answers had to be used to estimate the model. This is an important aspect of the study because the sample size affects the precision and accuracy of the results.

Furthermore, there were some limitations regarding the population, which consisted mainly of older people with high income. This could also be a factor why remuneration was found to be a relatively unimportant attribute. The results could have been different when also younger people were included and people with lower income.

MNL results

In order to obtain statistically significant parameters, some quadratic components were added to the utility function. After some trial and error the best utility function contained a quadratic component for the remuneration attribute and a quadratic component for the guaranteed minimum driving range. Although the parameters for remuneration were statistically significant, they showed a rather unrealistic result. The quadratic relation implied that the perceived utility increases between a remuneration of €50 and €100, which is logical. It was expected that a higher remuneration would lead to an increase in perceived utility. However, the relation also showed that between €100 and €150 the perceived utility decreased significantly. The decrease was so large, that a remuneration of €150 resulted in a lower perceived utility for the consumer than €50. This is counterintuitive and not realistic. Probably this is due to the relative importance of the attributes. The relative importance of the remuneration resulted to be low, as it only contributed with 9% to the total utility. Therefore, the respondents did not care that much for remuneration as other attributes. Since this resulted in a strange parameter for remuneration, it could have been better to use other attribute levels for guaranteed minimum driving range. A guaranteed minimum driving range of 10 km was taken as the bare minimum since it is the minimum distance to any hospital in the Netherlands. However, the gap between 10 km and 65 km is considered high for the respondents. This could also be seen from the utility contribution of this attribute. Between 10 km and 65 km driving range the increase in utility contribution was relatively high compared to the increase between 65 km and 120 km driving range. Between 65 km and 120 km driving range the increase in utility declined. Apparently perceive a feeling of satisfaction reaching a guaranteed minimum driving range of 120 km. For further research it could be wise to use more attribute levels, or see what the results are if all the levels are higher than 65 km. On the other hand, the guaranteed minimum driving range could be designed in a different way. For example, during the night the consumer will probably not drive at all. Agreements could be made between aggregator and consumer on the timing of the guaranteed minimum driving range. During the night this can be for example 10 km, just for emergency rides, while during the day it could be set at 65 km, according to the wishes of the consumer. This will lead to more flexibility for the consumer, but on the other hand also lead to more complexity with respect to the contract. And that while complexity can just be a major barrier to participate. The use of an application could enhance user-friendliness. This could be investigated in future research.

Another shortcoming of the MNL model is the use of the constant C_{V2G} in the utility functions. These constants were crucial to determine the willingness to participate in V2G contract over not participating. Therefore, an opt out option was integrated in the survey which could be interpreted with the constant. However, the estimated constant resulted to be statistically insignificant. Although it is still the best estimate, the null hypothesis, stating that the estimate does not differ from 0, could not be rejected, and the constant could also be interpreted as 0. Therefore, the results from the application chapter should be taken with care. As the calculated market share can differ in reality.

V2G application of results

Chapter 6 gave some insights and examples how the results of the MNL model can be used in practice. However, some of the calculations were prone to several limitations. The calculations were made for application purposes and were based on simplifying assumptions, which may have limited the accuracy of the results. The aggregator's profit model was based on several assumptions. It should be noted that it is very hard to estimate potential profit for the aggregator in advance. The share of electricity that it will sell on the market will not be the same as the all the aggregated storage of V2G. There may be potential competition from other aggregators that will also participate on the balancing market. Besides, the balancing market is prone to fluctuations what can influence the price of the storage sold.

Another important aspect is that it was not taken into account the energy flow in the opposite direction. The business model only took into account energy shortages on the balancing market. But there may also be surpluses for which the aggregator will get energy that can be stored in the aggregated EVs. Therefore, the true business model is more complex than presented in Chapter 6.

8.3. Recommendations and further research

In this section some recommendations are given for the actors involved in the V2G system and also some recommendations for further research.

Aggregator

The aggregator can use the results from this study to shape the contracts that can be sold to new V2G consumers. The results of the remuneration can play an important role, since according to the results of this study, the financial compensation does not have to be that high, which is in favor for the profit of the aggregator. Furthermore, lessons can be taken from the relative importance of the guaranteed minimum driving range. Since this attribute is so strong for the perceived utility of the consumer, the aggregator can consider shaping it into more detail for a V2G contract. A new study could be conducted with a variable guaranteed minimum driving range. Some hours of the day the EV could be able to discharge to a lower level than other moments. In this way the aggregator con profit more of the potential storage solution, while the consumer can be given more flexibility with respect to guaranteed minimum driving range. Also the difference in plug-in time during weekdays and the weekend can better shape the V2G contract, as consumer perceive a difference in utility between those days.

Government

For the implementation of V2G no radical government intervention is needed, as aggregators can join the balancing market on the condition that they offer a minimum of 1 MW on the biddings. However, the government can provide regulatory support by creating policies and regulations. By creating clear regulation for V2G contracts, such as standards for interoperability, data privacy and security, this could help encourage V2G adaption. Besides, it should be noted that this is in the government's interest, since the V2G system can enhance the energy transition and provide flexibility to integrate renewable energy sources to the energy mix. To further explore consumer's preferences to improve the implementation of V2G, the government can work with public-private partnerships to promote the development.

Further research

The results of this research showed that there is an increase in willingness to participate in V2G contracts compared with previous studies. It can be interesting to know what drivers have increased this willingness. For example, this study did not take into account in the survey whether the current energy crisis may have played a role in the willingness to participate. The energy crisis has led to a significant increase in energy prices, which could have affected the results. This can be evaluated through a context variable in the choice experiment where a context is proposed before the energy crisis or after the energy crisis.

The low rho-squared values of the three models indicate that there is high heterogeneity in the population and that the MNL models may not be fully capturing the preferences of the different segments within the population. A higher number of participants and by applying a Latent Class Choice Model, different subgroups or classes within the population that have distinct preferences and behavior can be identified. This would allow the model to better capture heterogeneity and provide more accurate predictions to provide more targeted policy strategies.

Another avenue for further research is by making distinctions between the guaranteed minimum driving range attribute. This could be divided in a guaranteed driving range for different time frames. For example, it could be tested whether consumers perceive a different utility for guaranteed minimum driving range during different days of the week or hours of the day. In this way a better shaped contract can be designed that meets the wishes of the consumer. Also more attribute levels can be explored. However, it is important to take into account that when using more contract attributes and levels, more respondents will be required to achieve statistical significance. Therefore, a the selection of attributes for a new choice experiment should be chosen wisely.

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A. APPENDIX A

A.1 Apollo Syntax – Basic MNL model with linear components

```
rm(list=ls())

### Load Apollo library
library(apollo)
library(data.table)
library(readxl)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="MNL_1",
  modelDescr ="MNL model Exercise 1",
  indivID    ="ID"
)

#### LOAD DATA
database = read_excel("Data_coded.xlsx")


### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(C = 0,
              BETA_REM    = 0,
              BETA_DAY    = 0,
              BETA_WEEKEND  = 0,
              BETA_RADIUS   = 0)

### Vector with names (in quotes) of parameters to be kept fixed at their
starting value in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c()


#### GROUP AND VALIDATE INPUTS
apollo_inputs = apollo_validateInputs()


#### DEFINE MODEL AND LIKELIHOOD FUNCTION

apollo_probabilities=function(apollo_beta, apollo_inputs,
functionality="estimate"){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()

  ### List of utilities: these must use the same names as in mnl_settings,
order is irrelevant
  V = list()
    V[['A']]  = C + REMA * BETA_REM + DAYA * BETA_DAY + WEEKENDA *
BETA_WEEKEND + RADIUSA * BETA_RADIUS
    V[['B']]  = C + REMB * BETA_REM + DAYB * BETA_DAY + WEEKENDB *
BETA_WEEKEND + RADIUSB * BETA_RADIUS
    V[['C']]  = 0
```

```
    ### Define settings for MNL model component
    mnl_settings = list(
      alternatives  = c(A=1, B=2, C=3),
      avail         = list(A=1, B=1, C=1),
      choiceVar     = CHOICE,
      V             = V
    )

  ### Compute probabilities using MNL model
  P[['model']] = apollo_mnl(mnl_settings, functionality)

  ### Take product across observation for same individual
  P = apollo_panelProd(P, apollo_inputs, functionality)

  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}


#### MODEL ESTIMATION
model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities,
apollo_inputs)


#### MODEL OUTPUTS
apollo_modelOutput(model,modelOutput_settings=list(printPVal=TRUE))

apollo_saveOutput(model)
```

B. APPENDIX B

B.1 Apollo Syntax – MNL model with nonlinear components

```
rm(list=ls())

### Load Apollo library
library(apollo)
library(data.table)
library(readxl)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="MNL_1",
  modelDescr ="MNL model Exercise 1",
  indivID    ="ID"
)

#### LOAD DATA
database = read_excel("Data_coded.xlsx")


### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(C = 0,
              BETA_REML   = 0,
              BETA_REMQ   = 0,
              BETA_DAYL   = 0,
              BETA_DAYQ   = 0,
              BETA_WEEKENDL  = 0,
              BETA_WEEKENDQ  = 0,
              BETA_RADIUSL  = 0,
              BETA_RADIUSQ  = 0)

### Vector with names (in quotes) of parameters to be kept fixed at their
starting value in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c()


#### GROUP AND VALIDATE INPUTS
apollo_inputs = apollo_validateInputs()


#### DEFINE MODEL AND LIKELIHOOD FUNCTION

apollo_probabilities=function(apollo_beta, apollo_inputs,
functionality="estimate"){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()

  ### List of utilities: these must use the same names as in mnl_settings,
order is irrelevant
  V = list()
```

```
  V[['A']]  = C + REMA * BETA_REML + REMA * REMA * BETA_REMQ + DAYA *
BETA_DAYL + DAYA * DAYA * BETA_DAYQ + WEEKENDA * BETA_WEEKENDL + WEEKENDA *
WEEKENDA * BETA_WEEKENDQ + RADIUSA * BETA_RADIUSL + RADIUSA * RADIUSA *
BETA_RADIUSQ
  V[['B']]  = C + REMB * BETA_REML + REMB * REMB * BETA_REMQ + DAYB *
BETA_DAYL + DAYB * DAYB * BETA_DAYQ + WEEKENDB * BETA_WEEKENDL + WEEKENDB *
WEEKENDB * BETA_WEEKENDQ + RADIUSB * BETA_RADIUSL + RADIUSB * RADIUSB *
BETA_RADIUSQ
  V[['C']]  = 0


  ### Define settings for MNL model component
  mnl_settings = list(
    alternatives  = c(A=1, B=2, C=3),
    avail         = list(A=1, B=1, C=1),
    choiceVar     = CHOICE,
    V             = V
  )

  ### Compute probabilities using MNL model
  P[['model']] = apollo_mnl(mnl_settings, functionality)

  ### Take product across observation for same individual
  P = apollo_panelProd(P, apollo_inputs, functionality)

  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}


#### MODEL ESTIMATION
model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities,
apollo_inputs)


#### MODEL OUTPUTS
apollo_modelOutput(model,modelOutput_settings=list(printPVal=TRUE))

apollo_saveOutput(model)
```

C. APPENDIX C

C.1 Apollo Syntax – MNL with linear and nonlinear components

```
rm(list=ls())

### Load Apollo library
library(apollo)
library(data.table)
library(readxl)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="MNL_1",
  modelDescr ="MNL model Exercise 1",
  indivID    ="ID"
)

#### LOAD DATA
database = read_excel("Data_coded.xlsx")


### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(C = 0,
              BETA_REML   = 0,
              BETA_REMQ   = 0,
              BETA_DAY   = 0,
              BETA_WEEKEND  = 0,
              BETA_RADIUSL  = 0,
              BETA_RADIUSQ  = 0)

### Vector with names (in quotes) of parameters to be kept fixed at their
starting value in apollo_beta, use apollo_beta_fixed = c() if none
apollo_fixed = c()


#### GROUP AND VALIDATE INPUTS
apollo_inputs = apollo_validateInputs()


#### DEFINE MODEL AND LIKELIHOOD FUNCTION

apollo_probabilities=function(apollo_beta, apollo_inputs,
functionality="estimate"){

  ### Attach inputs and detach after function exit
  apollo_attach(apollo_beta, apollo_inputs)
  on.exit(apollo_detach(apollo_beta, apollo_inputs))

  ### Create list of probabilities P
  P = list()

  ### List of utilities: these must use the same names as in mnl_settings,
order is irrelevant
  V = list()
```

```
  V[['A']]  = C + REMA * BETA_REML + REMA * REMA * BETA_REMQ + DAYA *
BETA_DAY + WEEKENDA * BETA_WEEKEND + RADIUSA * BETA_RADIUSL + RADIUSA *
RADIUSA * BETA_RADIUSQ
  V[['B']]  = C + REMB * BETA_REML + REMB * REMB * BETA_REMQ + DAYB *
BETA_DAY + WEEKENDB * BETA_WEEKEND + RADIUSB * BETA_RADIUSL + RADIUSB *
RADIUSB * BETA_RADIUSQ
  V[['C']]  = 0


  ### Define settings for MNL model component
  mnl_settings = list(
    alternatives  = c(A=1, B=2, C=3),
    avail         = list(A=1, B=1, C=1),
    choiceVar     = CHOICE,
    V             = V
  )

  ### Compute probabilities using MNL model
  P[['model']] = apollo_mnl(mnl_settings, functionality)

  ### Take product across observation for same individual
  P = apollo_panelProd(P, apollo_inputs, functionality)

  ### Prepare and return outputs of function
  P = apollo_prepareProb(P, apollo_inputs, functionality)
  return(P)
}


#### MODEL ESTIMATION
model = apollo_estimate(apollo_beta, apollo_fixed, apollo_probabilities,
apollo_inputs)


#### MODEL OUTPUTS
apollo_modelOutput(model,modelOutput_settings=list(printPVal=TRUE))

apollo_saveOutput(model)
```