GIMA
Geographical Information Management and Applications

Master Thesis

Vehicle to Grid in Utrecht: integrating Electric Vehicles into the Energy transition in Utrecht

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25-02-2020

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Preface

The writing of this thesis has challenged me to combine all the skills and knowledge I have gathered over the years. It was hard work, but structure, discipline and most of all dedication made the writing of this thesis an exciting experience. I did not expect that this topic would trigger my senses the way it did. Tackling societal problems by using geographic information and data is my ambition. This thesis is my first step in making a difference.

I would like to thank Nick Nortier as he helped me to get underway with this challenging subject. V2G is unknown to the public, but also in terms of research. Prior to this thesis, V2G was unknown to me as well. Nick helped me get underway with some helpful meetings and discussions.

Special thanks to my supervisor Dick Ettema who was willing to supervise me during this period. Although he is not as much a spatial data expert, he always knew how to ask the right questions or link me to the right people. Most of all, his expertise and knowledge in transport geography was vital in our cooperation. His suggestions and inputs during our meetings were most worthy and I thank a part of this learning experience to him.

Before you lies my master thesis. The end result of years and years of education, from when I was a toddler until this moment I have been learning. This thesis feels as the highlight of all my educational experiences till date. I present it to you with pride.

Abstract

This research concerns exploring vehicle to grid (V2G) charging station allocation in Utrecht on a neighbourhood level. There are several challenges ahead in the field of energy infrastructure, mobility, energy stability and global warming. V2G could be seen as part of the solution to relieve the stress on these subjects. V2G requires special charging stations, participating electric vehicles and when organized correctly, it would resolve in a series of benefits. But if the municipality of Utrecht would be installing V2G charging stations in the near future, where would they be placed? To find an answer to this problem, this research made use of different methods. An extensive literature review was conducted to understand what V2G is. Next to that a spatial data research was conducted using an multi-criteria evaluation as method. This resulted in the allocation of V2G charging stations over 90 selected residential neighbourhoods in Utrecht. Implementing V2G requires a series of preconditions which need to be met, of which the most crucial ones, apart from the availability of V2G charging stations, are in place. The dispersion of these stations throughout largely followed the pattern of the inhabitants of the city for the three future scenarios in 2025, 2030 and 2035. However, the “Vogelaar”-neighbourhoods which are already disadvantaged neighbourhoods show lower numbers. These are important implications for further research. Questions which arise relate to adding weights to the selected socio-economic variables, or to investigate how policy of governments or businesses play a role in stimulating V2G.

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1. Problem statement

Today's society faces the challenge ~~to limit the effects of~~ the enhanced greenhouse effect. Among other measures, the global Paris climate goals and the European 20-20-20 goals are international guidelines. The Netherlands is a participant in these initiatives and recognizes that action must be taken to curb or even stop climate change (European Union, 2014; United Nations, 2015). The two sectors that account for ~~one of~~ the highest emissions of greenhouse gasses are the energy sector and the transport sector (Centraal Bureau voor de Statistiek [CBS], 2019a). In line with the contemporary challenges and public attention it might be expected that overall energy use will decline as result of the aforementioned agreements. However, the energy consumption is expected to rise up to 50% by 2050. In this case ~~the~~ transport is expected to be the second biggest contributor to this rise. While the largest share of this increase is expected in non-OECD countries, especially in Asia, OECD countries are expected to contribute to this rise of energy use as well (International Energy Agency [IEA], 2019a). In the Netherlands the total energy use only shows minor decline in the past five to ten years (CBS, 2019b). Increase of energy use, however, does not necessarily go hand in hand with increase of greenhouse gas emissions. Sustainable energy generation also shows an increase. For many countries this is the main focus of decarbonizing their energy production. Also, in recent years this increased generation of sustainable energy looks steep, showing a global increment with almost 22% between 2005 and 2015 (World Bank, 2019). This rise is expected to keep going with another 46% energy production in the period between 2018 and 2023 (IEA, 2018a). All in all, the world faces ~~a~~ one of the greatest global challenges ever experienced. The way we deal with our energy generation and use must change. This is all a part of the energy transition (Breyer et al., 2018).

The need for a changing energy system is mostly due to ~~the existing energy system because~~ conventional sources emit greenhouse gasses, whereas the Paris agreement aims at a net zero emission ~~society~~ by the mid-21st century. This is a slow, society wide process and can therefore be viewed as a transition (Breyer et al., 2018). In the Netherlands the need for a policy that handles this challenge emerged. As soon as 2001 the Ministry of Housing proclaimed that the persistent problems with the environment could not be solved by simply intensifying current policies. More rigorous management and policies were needed and transition management theories and models were adopted (Kern & Smith, 2008). As mentioned above, both in energy generation as well in transport large cuts in emissions can be achieved as they are among the largest contributors. So in terms of energy supply, a move from fossil fuels to sustainable energy generation is noticeable. For mobility, on the other hand, another major change is emerging. As a part of the decarbonization of society, recent years show another series of trends. Electric vehicles (EVs) reach new record sales year after year, whereas battery prices keep dropping (IEA, 2018b). There two main types of EVs: Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). In the Netherlands the fleet of all electric passenger cars increased by 26% between 2017 to 2019 (Netherlands Enterprise Agency [RVO], 2019). The future expectations on the growth of EV use vary, but there are several indications that the global EV fleet will be growing rapidly. The IEA (2019b) have scenarios varying between a total of 130 million to 250 million vehicles in 2030, compared to a mere 5,1 million in 2018. This results, among others, in two ~~matters:~~ the emission of EVs will continue to be lower compared to traditional internal combustion engine cars, but on the other hand energy demand will increase. The electricity needed to serve these EVs is, in the higher scenario, 1.100 terawatt-hours (TWh). For comparison: that is more than one third of the total energy consumption of the European Union in 2016 (European Environment Agency [EEA], 2018), or almost ten times as much as the total energy consumption of the Netherlands in 2016 (CBS, 2018a).

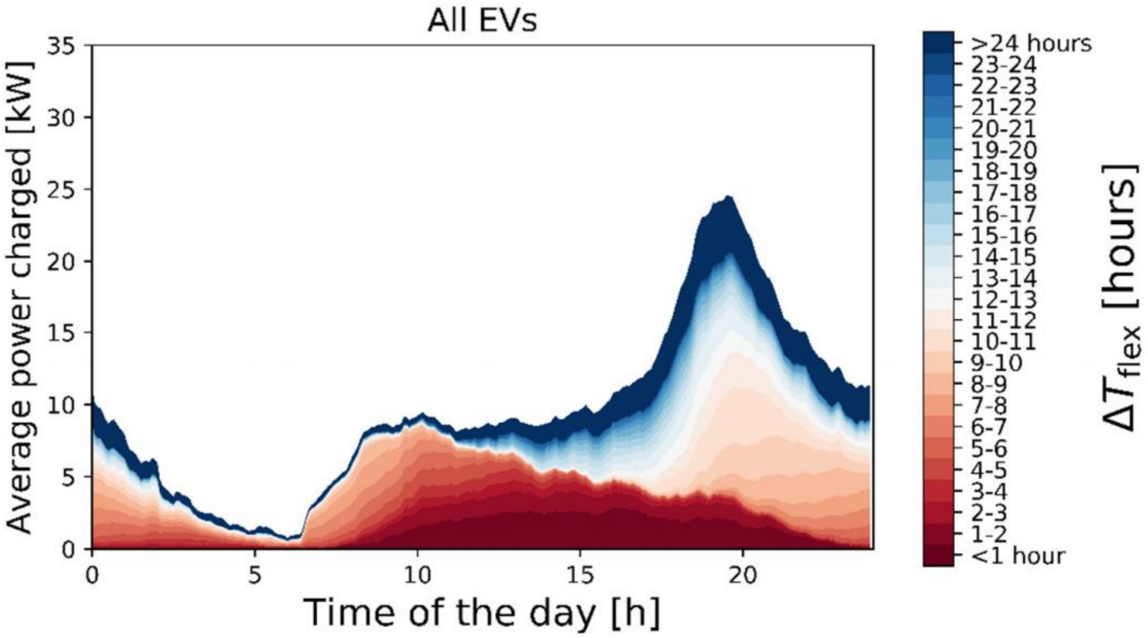
The increase of energy use results in a series of challenges for the existing electricity infrastructure. Where classic internal combustion engine vehicles solely get their fuel from gas stations, EVs obtain their fuel from the electricity grid. This could lead to grid related problems as EV owners generally start charging their cars as soon as they arrive at their homes. That causes a peak in the energy demand at set times (Wackx, & Driesen, 2015). A recent case study in a neighbourhood in Utrecht, the Netherlands, showed that the plug-in times peak at 17.00 until 18.00 for local cars. In the current system of charging there is no balancing of the demand. The current system makes use of the simplest form of charging, namely uncontrolled charging. This means that the EV starts drawing full power from the grid as soon as it is plugged in. In result, this leads to a spike in energy demand. In addition, these peaks are likely to coincide with peaks in household energy demand. It is therefore expected that this might cause grid congestion problems if the number of EVs increases in the future (Gerritsma, Al Skaif, Fidder, & Van Sark, 2019). As mentioned above, the expectations are that this will happen and the increase will reach a significant market penetration. In 2019 the market share of EVs in the Netherlands was 1,6% (CBS, 2019c), but as the Dutch government is stimulating use of EVs, with as goal that 100% of car sales are PHEV or BEV by 2030 (Rijksoverheid, n.d.), in line with the overall expectations that EV sales will increase (IEA, 2019b) and battery prices continue to drop (IEA, 2018b), this market share will increase.

Both (inter-)regional high voltage electricity grids as well as local low voltage electricity grids cope with challenges. Not solely due to the aforementioned increase of EV use, but due to several other factors. To realize renewable energy sources it is important to understand the basics of the existing energy system. There are four types of electricity markets, with potentially a fifth in the near future. First of all there is base load power. This is the round-the-clock energy generation, generally produced by large scale coal, oil or nuclear power plants. The price per kWh is low, efficiency is high, flexibility is low and start up and shutdown is a matter of hours or even days (Kempton & Tomic, 2005; Noel, Rubens, Kempton, & Sovacool, 2019). The second energy market is peak power. Peak power either generated or purchased (from abroad). It must be available at times when demand is unexpectedly high and some flexibility is expected and is covered by power plants which can switch on and off in shorter times. In general gas turbines are used for this. This is, however, a costly business and emits large amounts of greenhouse gasses (Kempton & Tomic, 2005; Noori et al., 2016; Noel et al., 2019). Thirdly there are spinning reserves ~~are energy reserves~~ which are quickly accessible. These reserves usually run continuously and can provide additional power at high flexibility. These are already synchronised to the grid and are constantly ready to respond. These are usually needed in unforeseen events such as power outages. Fourth is frequency regulation (or sometimes called differently, depending on the area of interest). This is a more complex type of market since it is real time and requires some serious maths. In general frequency regulation regards the balancing of the voltage and frequency to a baseline. This is of vital interest to the grid owner because if this is not done properly it could cause damage to the equipment (Kempton & Tomic, 2005; Noel et al., 2019). The last market is a potential market which is energy storage. Noel et. (2019) discuss that this shows synergy with increase of renewable energy sources. The main problem with renewables is that, especially photovoltaic (PV) and wind turbine energy generation is unpredictable. Peaks and dips of energy supply are mainly caused by the intermittency of solar and wind energy. An example of this is that German energy prices drop below zero at times (Reed, 2017). Unlike other, more classic, energy sources, these are not controllable. It is therefore discussed that when there is an imbalance between energy generation and demand this could be resolved by storing this energy (El-Zonkoly, 2014; Noel et al., 2019). This could be done over the course of minutes, hours, days or even seasons (Ibrahim, Ilinca, & Perron, 2008).

The three markets which supply support to the baseline energy supply, namely peak power, spinning reserves, frequency regulation and, in the future storage, are provided by ancillary services. These services ensure the quality of the energy grid and a steady supply of energy. The energy system operator or Independent System Operator (ISO) is responsible for the energy supply. Either these operators or third party energy suppliers can supply these ancillary services. This is, however, costly, both economically as environmentally (Noori et al., 2016; Noel et al., 2019). In addition, the uncertainty of the all growing renewable energy generation and the global trend of growing use of energy combined with the increasingly growing number of EVs in the near future, the existing energy grid faces some serious challenges. This could result in costly grid capacity investments (Tamis, Van den Hoed, & Thorsdottir, 2017).

With regard to the charging behaviour as mentioned above by, among others, Wackx & Driesen (2015), there are innovative solutions which could assist in resolving the charging challenges. While an unambiguous definition lacks, this research will use smart charging as main definition. This can be divided into two types: unidirectional and bidirectional. Both smart charging solutions aim at relieving stress off of the grid among other benefits (Kempton & Tomic, 2005; El-Zonkoly, 2014; Noori et al., 2016; Tamis, Van den Hoed, & Thorsdottir, 2017; Noel et al., 2019). In general smart charging is “smart” because “smart charging can be seen as a charging strategy that takes the power grid condition and parameters into account, in order to avoid potential power grid conditions” (Tamis, Van den Hoed, & Thorsdottir, 2017, p. 3). In other words, the charging synchronises with the quality of the grid at any given time as long as the car is connected to the charging station. Instead of directly charging the vehicle, the smart charging system will automatically decide when and how much the EV will be charged, based on an algorithm with a continuous feed of relevant information (Tan, Ramachandaramurthy, & Yong, 2016). Unidirectional smart charging means that the EV can start and stop charging at different times, whereas bidirectional charging has the ability to make the EV battery available to the grid to use. The latter is also known as Vehicle to Grid technology and offers a wide range of applications for future energy stakeholders (Noel et al., 2019). However, these novel technologies are still innovative niches and have therefore mainly been subject to theoretical and technical research to date. Where for example the potential benefits for its users and the decrease emissions of greenhouse gasses are calculated (Noori et al., 2016), technical algorithms attempt to find the most suitable location and/or time of charging for smart charging systems (El-Zonkoly, 2014; Tan, Ramachandaramurthy, & Yong, 2016), or the technical way of how combined EV fleets can be made of use (Sortomme & El-Sharkawi, 2011), are all technical or theoretical approaches. A recent research concerned a more practical analysis of the charging behaviour of EV owners in a neighbourhood in the Netherlands. Figure 1.1 shows why smart charging is feasible and that it may aid in decreasing the stress on the grid. The figure shows in blue the flexibility (in colours) as function of time (in hours) of the connected EVs in a 24 hour cycle, and the amount of demanded power. The researchers suggest that a shift of the charging session could be realized where the EVs would make use of the solar power production peak of the next day. It could therefore relieve grid congestion and increase local PV self-consumption (Gerritsma et al., 2019). Whereas this is a more practical approach of the possibilities of smart charging, large scale smart charging (unidirectional) nor V2G are in place yet.

Figure 1.1: Flexibility of EV charging times of EVs in Lombok, Utrecht. Adopted from Gerritsma et al. (2019).



Vehicle to grid is a feasible but challenging innovation which could solve some of the energy challenges listed above. Several pilot programs are being launched since the start of 2019. Two of these are in Utrecht. Combined under the name Smart Solar Charging they initiated a series of V2G projects. With multiple partners including, among others, the municipality of Utrecht, the University of Utrecht, Utrecht Sustainability Institute, Renault and We Drive Solar, led by LomboXnet and partially funded by the EU, many facets of society have been linked together (Smart Solar Charging, n.d.). In order to make V2G work, the challenge must be tackled using a sociotechnical approach which combines stakeholders from all different aspects: technical, social, financial, political, energy sector and others. These must all fulfil their share in achieving the V2G transition (Noel et al., 2019). So it is known what should be done to incorporate renewable energy sources into society, what the challenges for the grid are and that V2G could contribute in solving the problem, both practical and technical. One of the main questions that remains is where the future V2G charging stations must be placed. The goal of this research is therefore to locate suitable locations for V2G charging stations. The focus area of this research is the municipality of Utrecht.

1.1 Societal problem statement

Based on the different challenges for society as mentioned above, there are a couple of main societal problems which will be addressed in this research. Global warming stresses the need for contemporary society to change way energy is used. Not only global warming, but also the nitrogen crisis caused by emissions of other gasses is a problem for society (Minister van Landbouw, Natuur en Voedselkwaliteit, 2019). One of the solutions is to shift from internal combustion engine [ICE] vehicles to electric vehicles [EV], but this may cause an overload of the energy infrastructure. The upgrade of the existing energy network is a very time and capital expensive investment (Kempton & Tomic, 2005; El-Zonkoly, 2014; Noori et al., 2016; Tamis, Van den Hoed, & Thorsdottir, 2017; Noel et al., 2019). Besides that, V2G offers a synergy in the need of using renewable energy. Occasional surplus of energy as mentioned above could be stored in the batteries of EVs. As both development of renewable energy as well as the boost of emission free EV driving benefit from this, so does society in general. If the Dutch society want to change the way they use cars to aid reduction of greenhouse gasses, new solutions which affect both cars and the electricity infrastructure must be explored and applied. Finally, electric driving is still considered expensive, whereas the environmental benefits are known. V2G could be an incentive to lower the barrier for owning an EV.

1.2 Scientific problem statement

As described above, when exploring vehicle to grid as a solution to the current day's societal problems, the general approach is mainly technical (El-Zonkoly, 2014; Tan, Ramachandaramurthy, & Yong, 2016) or hypothetical scenarios (Noori et al,. 2016). More practical applied researches still theoretically approach practical implications (Sortomme, & El-Sharkawi, 2011). Finally, there is a societal approach to the V2G challenges (Noel et al., 2019). So there is a gap between technical and hypothetical literature and how this would benefit for society. This research aims to fill that gap by providing a applicable solution and bringing the technical possibilities and the societal benefits together. ~~The solution is based~~ on a literature research to both technical and societal challenges and benefits, as well as data about technical variables and socio-economic variables. In addition, the research aims to tackle the problem in such a way that it bridges the gap between social needs and technical possibilities.

~~The research contains seven chapters in total if which the introduction is the first~~. This is followed by the research objectives wherein the main goals are explained and introduces the research questions. The third chapter reviews ~~contemporary~~ scientific literature to explore the common theories, threats and strengths, and challenges concerning V2G. Chapter 4 is dedicated to describe the methods used to come to an answer of the research questions. The used data are justified as well. Chapter 5 contains the results of the research, accompanied by maps and tables. This chapter is supplemented by the appendix. The end of chapter 5 holds the interpretation of the results as well. Chapter 6 concludes the research by answering the research questions. The last chapter, chapter 7, discusses the outcomes and suggest further research, and is ended with a reflection on the research process.

2. Research Objectives

2.1 Research objectives

The main goal of this research is to find suitable locations for a sufficiently large number of charging stations which allow for bidirectional charging. In order to find these locations this main objective must be broken down into several more workable objectives. When all of these objectives are fulfilled, the main goal will be reached as well. These objectives are used to resolve the technical challenges which are needed to answer the research questions.

Define and explain why bidirectional charging is a solution to the existing problems
Before starting the data research, this objective defines what the solution could be. V2G is a complex technological innovation and must be understood before extensive data analysis can be conducted. A series of assumptions will be the result and is needed to complete the other objectives. These assumptions concern the feasibility of V2G. This is a literature objective.

Find out what a suitable location is and define suitability
This objective helps to define what kind of locations is sought for. The advancement of V2G in society does not happen in a vacuum and does not start from a zero state. This objective will investigate the socio-economic situation of the research area. Based on this, the neighbourhoods in Utrecht can be classified on suitability. ~~In other words, suitability will be based on the literature.~~ This is a literature research.

Collect data
This is a clear but crucial objective. This research aims to work with available data to create new information. Therefore the collection of data sets is vital. This clearly is a data collection objective.

Define how many charging stations are needed
To assist the existing energy grid a minimum number of V2G participants is needed. This number can be calculated from multiple angles. For example, from the viewpoint of the energy grid, the expected number of available EVs or the grade of participation of EV owners. Different scenarios will be created and with different outcomes. An EV centric approach will be applied where the V2G demand is based on the requested EV or charging points. These are sought for in literature. Different scenarios are based on different future prospects. This is a literature and data analysis objective.

Combine analysed data and create final output in the form of a series of maps
The main goal of this research can be fulfilled by combining the research questions into one final data set. This includes both statistical and EV prospect data as well as the spatial data. This combination results in the allocation of the charging stations based on all the variables as stated in the previous objective. The outcomes of the data set can be visualized in a final series of maps to elaborate on the findings. This is the final objective and includes concluding the research. Once this objective is completed, the research is completed. This is a data analysis objective.

2.2 Research questions

The problems with the current EV and electricity are mainly researched theoretically or technically in scientific literature, the goal of this research is to find a practical, geographical solution to the EV charging challenges. Therefore, finding an answer to the following research question will be the key in solving these problems:

How are suitable locations within the municipality of Utrecht allocated to realize public vehicle to grid charging?

The research questions is subdivided into sub-questions on which the structure of this research is based. The exact methods of research will be discussed in the methodology chapter.

What are crucial preconditions in order to implement Vehicle to Grid in Utrecht?
The first research question aims at finding the conditions which need to be fulfilled in order to implement V2G in Utrecht. The different stakeholders will be reviewed to identify different limitations or opportunities. Contemporary pilots will be inspected to find known challenges or successes. The information of the first sub-question will result in a series of technical, political or societal conditions which need to be fulfilled. When this question is answered, the basic preconditions which are crucial for implementing V2G on a city-wide scale are known. These can be used to find the most suitable locations.

How can the distribution of future EV ownership be calculated for the different residential neighbourhoods in Utrecht?
The second sub-question explores the spatial components in relation to the main question. This question explores the existing charging infrastructure in Utrecht. This concerns, for example, the distribution of charging stations. In relation with other known data like socio-economic statistical data on neighbourhood level a spatial data set can be created for the whole municipality of Utrecht. In combination with local data about the built environment, the sub-question can be answered. The result is a cross section of the existing infrastructure in Utrecht and an overview of the relevant socio-economic characteristics of each neighborhood. This is a crucial sub-question and involves extensive spatial calculation and makes use of existing data sets to.

What are the prospects for EVs and EV charging in Utrecht in 2025, 2030 and 2035?
The third sub-question is devised because the contemporary developments like V2G are still niche and are part of the energy and mobility transition. In addition, the proposed infrastructure cannot be installed instantly and will take time. Therefore this will used future prospects of the EV fleet in Utrecht. ~~So the final output is based on a future prospects on how many EVs there will be around in Utrecht.~~ To add to that, the renewable energy supply will grow as well and as later will be explained in more detail, a minimum amount of EVs is needed in order to contribute to the energy system. A calculation will be ma to find out how much V2G charging stations are needed to make sure that there is enough storage capacity to be used as backup. This is an important calculation which will contribute to answering this sub-question as well as the main research question.

What can future spatial allocation of Vehicle to Grid charging stations in the municipality of Utrecht look like?
This final question will combine all collected data into a final output. The different scenarios will have different outcomes. These outcomes will be visualized in the form of maps with explanations. This sub-question will explore the exact neighbourhoods which are suitable to place the V2G charging stations in the municipality of Utrecht. The prospects are distributed among the neighbourhoods based on the previous sub-questions shown in tables and maps. These maps can be used by third parties, like the municipality of Utrecht. These maps can also be used as a motive for further research, for educational purposes or as a basis for policy.

As listed above, several choices have been made to make this research feasible and provide a scope so a high level of detail can be achieved. Technical algorithms are purposely left out of scope because these have been subject of previous research. These algorithms exist, for example in El-Zonkoly (2014) or Noori et al. (2016) to name a few. The outcomes and implications of these algorithms will be used, but the analysis and technical details are out of scope. Next to that, the research will be focussed on the municipality of Utrecht. As mentioned above, this is a municipality where V2G possibility is being explored at this very moment. To make use of this momentum, the research is aimed at this municipality alone. ~~Other regions are out of scope.~~ However, the results for Utrecht and methods used in this research can be used in other regions. The research focuses only on public charging stations because of several reasons. Firstly, because home charging is subject to other registrations and work charging is offered by companies, and secondly because recent developments show that home charging leads to more and more societal problems such as fights over charging wires on the pavement (NOS, 2020). Finally, a series of assumptions must be made in order to conduct spatial research. In this matter there is a time constraint which limits the testing and analysis of a series of these assumptions. The assumptions regard, among others, charging behaviour, political willingness, EV owners' participation and overall participation willingness of stakeholders. These assumptions will be based on existing literature.

3. Theory

Vehicle to Grid has only emerged recently as a way of charging and discharging electric vehicles. It is a not commonly known charging method. For example, a survey conducted by Noel et al. (2019) showed that less than 10% of the participants of the survey had ever heard of V2G prior to the survey. As mentioned above, the current knowledge of V2G remains to be highly academic. In addition Sovacool, Noel, Axsen and Kempton (2018) found that the vast majority of researches conducted up until that moment was in the field of science and engineering. This chapter will therefore elaborate on the principles and concepts which are involved with V2G. As Noel et al. (2019) indicate, the decarbonization of the transport sector is not an isolated subject. So approaching the challenges which come along with the decarbonization of this sector from one single discipline could be counterproductive or even dangerous. Therefore the following literature review attempts to find a balance between social and technical factors of V2G. Eventually in the analysis chapter these factors will all come together and the concepts made in this chapter are the basis of the geographical research.

3.1 V2G overview

V2G is a complex system with various social and technical factors which should all align. To get an understanding of what V2G means and offers, the system is broken down below. The technical and social aspects of current EVs and charging behaviour is combined with the technical mechanism and social benefits of V2G.

3.1.1 Electric Vehicle basics

Before exploring the concepts of V2G it is crucial to understand the basics of an electric vehicle. There are three main types of EVs. The numbers of cars in the Netherlands are found in table 4.1. Hybrid Electric Vehicles [HEV] make use of a battery to accelerate on battery power. This battery is charged using the internal combustion engine [ICE] which runs on fossil fuels. The battery in this car is mainly used in city traffic, traffic jams or other flows of traffic which requires a lot of starting and stopping. This battery cannot be charged using a plug and is therefore not suitable for V2G application as it cannot be charged or discharged (Lake, 2001). More than half of the EVs in the Netherlands are this type of EV as if 2018. The second category of EV is the Plug-in Hybrid Electric Vehicle [PHEV]. As the name suggests, this car is similar to the HEV but the battery can be charged using a plug. The main motor remains to be an ICE and the electronic driving range is limited (Emadi, Lee, & Rajashekara, 2008). However, since this car has a fairly large battery with an electric range of approximately 35 km or 10 kWh of usable battery capacity it has a decent amount of usable battery capacity for V2G. In addition these cars can use their ICE to increase their range. The last category involves the Battery Electric Vehicles [BEV]. These cars are solely powered by batteries and do not have an ICE. These are charged using a plug and have an average usable battery capacity of 58,5 kWh and the average range is about 300 km (Electric Vehicle Database, 2019). These cars are obviously suitable for V2G application as well. For the remainder of this research, the term Electric Vehicle only concerns cars which allow for V2G. These are cars which can be charged and discharged using a plug. So this research will only include PHEVs and BEVs. The term EV therefore only regards the PHEVs and BEVs unless they are specifically mentioned.

So the first requirement to join V2G is the possibility for the vehicle to be plugged. There are three other, technical requirements which must be met in order for EVs to be used in a V2G system. Currently the most used chargers only charge unidirectional (Gerritsma et al., 2019). These must be replaced by V2G chargers which allow for bidirectional charging. The charging stations differ in several ways. First of all, they allow for electricity to flow in two ways. Secondly, there must be a means of communication between the grid and the battery of the car. This communication either happens on-board of the car or in the charging station (Noel et al., 2019). These preconditions in order to make V2G work will be discussed in more detail in chapter 3.3.

Table 3.1. Number of EVs in the Netherlands in 2018 (BOVAG-RAI Mobiliteit, 2019)

Type of car	2018
HEV	153.794
PHEV	92.765
BEV	21.032
Total EV	267.591
Total vehicles	8.594.600

3.1.2 Charging behaviour

Regarding the behaviour of charging a distinction is made between different types. For example, Gerritsma et al. (2019) look at a residential area in their research. They used data based on the cars' owners. They found that there is a difference in behaviour between visiting EVs and local (residing) EVs in that neighbourhood. Other research made a distinction between residential and industrial/commercial land use areas (Verzijlbergh, 2013). The problem statement addresses the peak load times in the early evening. This is the period where the grid experiences intensified stress. This stress is found in residential areas. This is recognized by multiple scholars (Dallinger, Gerda, & Wietschel, 2013; Yong, Ramachandaramurthy, Tan, & Mithulananthan, 2015; Gerritsma et al., 2019). That is what this research will be investigating, the allocation of EV charging stations in residential areas.

With regard to the mobility behaviour, a profile can be made on whom the average EV owner is. Sovacool et al. (2018) argue that a sociotechnical approach of the transition to a decarbonized mobility system is a crucial approach. In their research they research what socio-economic characteristics are linked to interest in, or ownership of an EV. The choice for a vehicle is based on consumers' behaviour and therefore the old behaviour of driving ICE's must be changed or even broken in order to establish new behaviour. In this case the new behaviour concerns owning an BEV instead of an ICE. Bockarjova and Steg (2014) even use the analogy that BEV integration is similar to quitting smoking in terms of behavioural change. The behaviour of potential EV owners can be important in policy making. So knowing the potential owners of EVs could be crucial. Sovacool et al. (2018) researched a series of demographic factors which are of influence on ownership or interest in EVs. First of all they agree on previous findings which state that the transition to a decarbonized or low-emission mobility system is challenging. The approach is that an alternative must be at least equally attractive or better than the status quo in order to be successful.

The research by Sovacool et al. (2018) was based on both a qualitative literature review as well as a statistical research based on a survey in the North European region. The findings are listed below. They indicate a relation between demographics and, among others EV ownership, EV interest and/or EV experience. The following demographic statistics are in positive relation with EV potential.

- **Gender** seems to be of an influence on the EV potential. They way in which this is significant is remarkable however. Whereas women typically show more interest in the factors on which electric cars generally score good: smaller cars, environmental impact, fuel economy and ease of operation to name a few, women score lower in the potential interest and "are less likely to have an EV or even to have tested one" (p. 89). The statistical research shows that men are both significantly more likely to own an EV and show significantly more interest in EVs than women.
- With regard to the highest level of **education** of the participants of the statistical research there is a significant positive correlation with both interest, experience and ownership of EVs. The higher the highest level of education is, the more interest they show in EVs. Other factors such as comfort and EV range do not seem to be of significant influence when looking at education level. However, the literature research showed that although highly educated people show more interest in EVs, they are also likely to exhaust more greenhouse gasses.
- **Employment** shape travel patterns and are, based on the literature review, of influence on the potential for EVs as well as on negative travel patterns. This is caused because of the current travel system. The survey resulted in the same findings. The survey broke employment down into sectors. The results show that mainly academics show interest and non-profits owning the most. The researchers indicate that, based on the numbers of car owners and driven kilometres daily, the biggest potential EV market lies within the private sector, but the figures of interest

and current ownership show different numbers. Remarkably enough, retirees are seen as a prime group of potential EV owners. They have a a high car ownership rate, drive short kilometers, low car demands, high budgets and are likely to benefit from the ease of driving an EV.

- **Age** is also of influence on the current and potential EV ownership. There are two main groups who are significantly of influence here. First of all there is the group of middle aged people ageing between 25 and 34. They peak at both EV experience and environmental awareness. This is both concluded from the literature review as well as from the survey. The second group, as mentioned above under the employment segment, the elderly also have a great potential. Conclusions from scientific literature prove that elderly (65+ or 65-75) “prefer the personal, conventional automobile” (p. 92). Although they have a low interest, the strong points of EV do coincide with the preferences by the elderly.
- The final demographic factor which is tested is **household size**. Based on literature review, larger household sizes do not show more interest in EVs, whereas household size is of influence in relation with car ownership as well as daily travel distance. However, in contrary to the literature, larger household sizes show both more EV experience and ownership. For larger families the preferences for car quality and concerns about EV infrastructure increase.

In addition to the demographic data gathered by Sovacool et al. (2018) make a final remark about the V2G subject in their research. They conclude that V2G is not perceived the same way as EVs. There is an overall lack of interest and knowledge in V2G and there is no differentiation between the tested demographics. This indicates that “there is an overall lack of consumer knowledge about the product, making it difficult to properly design policies for V2G implementation” (p. 97).

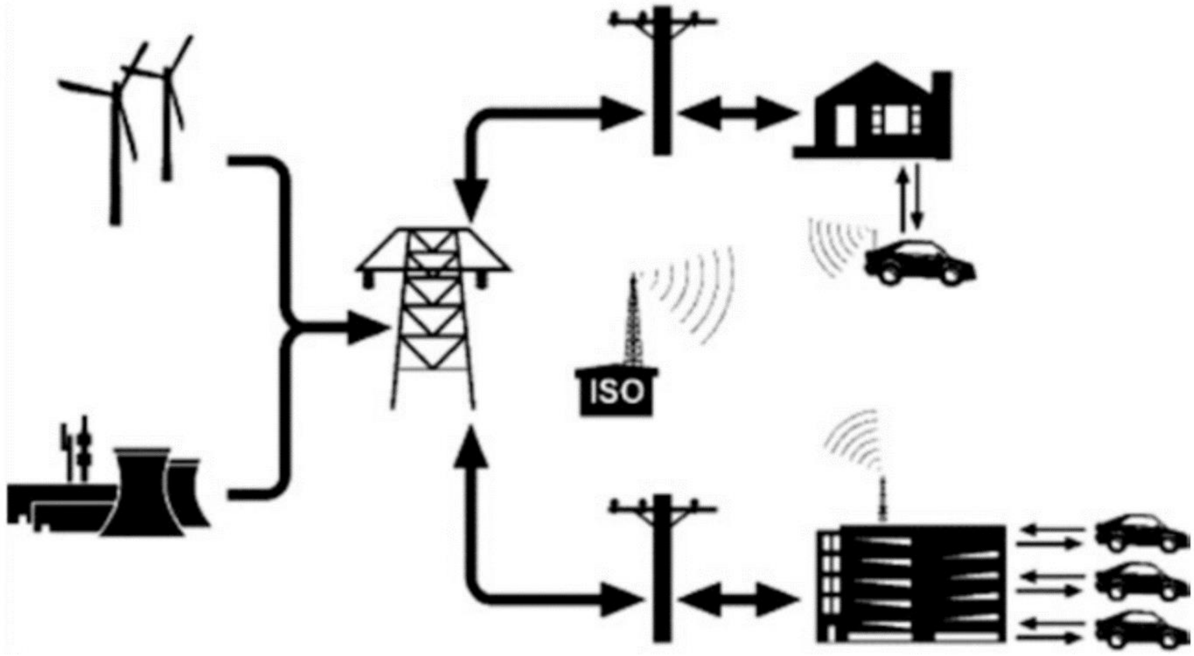
3.1.3 Basic technical mechanisms

Vehicle-to-Grid, Vehicle-2-Grid, vehicle to grid or simply V2G is a newly researched and to lesser extent applied technology (Sovacool et al., 2018; Noel et al., 2019). As mentioned in the introduction, V2G is a type of smart charging. This technology can regulate the power flow of the charger into the car. Unidirectional smart charging has the ability for the charging device or the charging component inside the car to start charging on a set time, instead of directly charging when plugged (Tamis, van den Hoed, & Thorsdottir, 2017). The latter form of charging is currently used most commonly in the Netherlands with over 90% of the charging station having no smart charging options (Gerritsma et al., 2019). V2G consists of several crucial technical components. Among others Sortomme & El-Sharkawi, (2011) Noori et al., (2016) and Noel et al. (2019) indicate that there are three main components:

1. A connection to the energy network;
2. A communication device/system which can control the (dis-)charging of the EV;
3. A measurement system so that the power flow can be audited.

The V2G technical basics will be explained using figure 3.1. From left to right multiple components are found: energy supply from, in this case, either base load non-renewable or renewable sources via a high-voltage network through a low voltage network to the private car or the fleet of EVs. The ISO operates the communication in the system (in this case) and stands for Independent System Operator (not to be confused with International Organisation for Standards). The ISO is the regional energy supplier. Details about the energy supplier will be discussed in chapter 3.2. The different components will be broken down below (Noel et al., 2019).

Figure 3.1. Schematic of a V2G system. Copied from Noel et al. (2019, p. 2).



Firstly, V2G needs an EV and a power connection to the energy grid. This is possible using a specialized electric vehicle supply equipment [EVSE]. This is the link between the battery of the car and the charging in/output, or in other words, the charging station. These devices allow for the power to be charged or discharged to/from the battery via the plug. In order to make V2G work, both the EVSE as well as the on-board charging system of the car must allow for discharging. This is not standardized in all EVs (Noel et al., 2019). The current system of charging does not have the required EVSE's to establish discharging of the EVs batteries.

Secondly, the system can only operate when proper communication systems are in place. Technical literature explains how this allows for optimal charging and discharging in, among others, Sortomme & El-Sharkawi (2011) and Tan, Ramachandaramurthy, & Yong (2016). This handles the regulation of the physical flow of power between the battery of the EV and the energy grid. This relatively simple addition to the vehicle communicates when the EV and EVSE need to charge or discharge. Although this is a simplification of what the communication does, it is an essential part of the technical details of the V2G system. The chip which is located on-board of the EV is called the vehicle smart link [VSL]. Although it is a relatively simple and cheap chip, not all current day new EVs have such a chip. Once this part of the system is installed, the V2G system has the physical ability to charge and discharge and can be told when and how much to do so. The communication happens between the EV and the grid (the energy supplier) directly, or with the intervention of an aggregator (Noel et al., 2019). The role of the aggregator will be discussed in paragraph 3.2, as well as the role of the grid or network operator.

Finally the last step is to manage and measure the flow of power. The different ways in which V2G can be used require monitoring different electrotechnical aspects of the energy system. These will be elaborated on in the next paragraph (3.1.4). The final step in the V2G system is the so called Advanced Metering Infrastructure [AMI]. Since the system needs the ability to react very quickly to the signals of the aggregator or the ISO, this AMI can provide near-real time data. This allows for the system to react on the supply and demands of the network within seconds. This is one of the major benefits of V2G since this allows for a huge boost in flexibility compared to conventional network assisting services. The AMI measures to what extend the requested service demanded by the system operator is fulfilled (Noel et al., 2019). This is the final step in the technical domain of the operability of the V2G system. When these subsystems are installed, the EV can be charged and discharged, it can communicate how and when to do so and a means of measurement can log and provide feedback to the system on a near-real time basis.

3.1.4 Possible ways to use V2G

In general there are several ways of how V2G could be used as a means of relieving the energy network. In general, the main energy supply is by means of the baseload power supply. This is a cheap way of generating power but is not flexible. The main sources of energy for the base load supply are coal-, oil-, and nuclear power plants. Starting up and shutting down may take hours or even days and sudden changes to the power output are therefore not possible. So sudden changes in demands need to be absorbed by other facilities (Noori et al., 2016; Noel et al., 2019). In addition, as explained in the introduction, the future holds a more intermittent supply of energy due to the nature of the most common renewable energy sources in the Netherlands, namely wind turbines and photovoltaic [PV] panels. Note, Biomass is a renewable energy source but it is not climate neutral as it emits CO2 (CBS, 2019d). V2G offers several kinds of assistance to this grid which could assist in mitigating these problems. Some of these solutions can only be applied in fleets by making a bid with multiple EVs via an aggregator. This will be explained in further detail in chapter 3.2. Another side note is that the possibilities to use V2G below are currently mainly covered by assisting services for the electricity operator. These are called ancillary services and will be explained per type of assistance which could potentially be overtaken by V2G. Ancillary services are based on contracts with the suppliers and are therefore forced to cover the deficit in power supply of the baseload. On the other hand, the power price is higher when these services are used (Hirst & Kirby, 1996). There are different kinds of ancillary services and operate in different parts of the energy system:

The first market for these ancillary services is peak power supply. Whereas base load power suppliers do not have the flexibility to drastically or flexibly change their supply. So in order to provide for peak power demands, additional services will come into play. These peak times are generally predictable, so more flexible but still bulky power supply currently covers this supply. These are generally gas turbines. The energy price is high and emits large amounts of greenhouse gasses (Noori et al., 2016). The battery of the EVs could assist in this situation by discharging the car when it’s plugged at home. This has great synergy with especially PV as this is generally available off peak hours. The car battery can be loaded during daytime and discharged during peak hours which are generally during 17.00 and 21.00 in the evening. This would resolve three problems at once: firstly, the pressure of new EVs onto the grid and energy demand currently coincides with this peak power demand. By introducing V2G this could be spread. Secondly, the intermittency and unpredictability of renewable energy sources can be used more efficiently (Noel et al., 2019). In addition, the existing peak power demand can be partially covered by available EV batteries. The EVs will then automatically start charging when peak demand times are over based on optimization algorithms (Sortomme & El-Sharkawi 2011; El-Zonkoly, 2014; Tan, Ramachandaramurthy, & Yong, 2015; Noori et al., 2016).

The second form regards a more technical means of assistance. The frequency of power supply can rise or fall at times of increased or decreased demand of power. This could potentially damage electricity equipment as these items are built to operate on a frequency of the system, either 50hz or 60hz (Energy Storage Association, 2019). Frequency regulation requires quick response, high power capacity but limited energy capacity. It is continuously needed and requires a high flexibility. In addition, the amount of withdrawn power is lower than with peak power supply. Noel et al. (2019) therefore define frequency regulation as the most suitable ancillary service market for the V2G system.

Spinning reserves, being the third possible market for V2G is a service related to the peak power service, but must be available for unexpected power outages or other unexpected events. The ancillary service must be available at all times and is financially compensated for this. Response times are generally quick, but not as quick as the frequency regulation market. However, the batteries of the EVs might be drained for a large amount. This could decrease battery life, which will be elaborated on later in chapter 3.3 (Noel et al., 2019).

In addition to these ancillary services, V2G and the use of the batteries offers a synergy between the increase of the use of EVs and the increase of the use of renewable energy sources. Both in the introduction as in chapter 3.3.1 the potential energy storage capacity is mentioned. This is potentially a huge battery capacity. The main upside is that these batteries already exist and used. Instead of investing in new storage systems, these batteries can directly be used (Ibrahim, Ilinca, & Perron, 2008; Noel et al., 2019). The relation with the intermittent nature of the renewable sources PV and wind turbines, V2G would assist in resolving the storage problem. Simply said, the two technologies go hand in hand together really well (Dallinger, Gerda, & Wietschel, 2013; Wang et al., 2016) However, as the investment in renewables is currently rising, the development of an active V2G system lags behind.

3.2 Involved parties

Referring back to figure 3.1 the different parties who are involved in the V2G system are explained. The two main participants on a purely technical basis are the ISO and the EV owner. For practical means though, it is suggested that a aggregator is involved as well. This is a third party which operates as link between the network operator and the EV owner or V2G participant (Noori et al., 2016; Noel et al, 2019).

In addition proper regulation must be in place, facilitated by the government. EV industries may need to adapt (Noel et al., 2019).

3.2.1 Participant

The most crucial role within the V2G system is the role of the “V” standing for vehicle. More importantly is the battery of the electric vehicle. Unlike the importance of the EV in this system suggests, the role of the EV owner is quite passive. There are a several things the EV owner in particularly participates in. First of all, the EV owner needs to have a contract with either a network operator directly (3.2.2) or with an aggregator (3.2.3). These will take over the purpose of the cars battery as long as it is connected to the bidirectional EVSE (Noel et al., 2019). The owner can influence the charging behaviour of the car and should be able to communicate with the system about minimal charged capacity in case of an emergency as well as the departure time for when the vehicle must be at the requested state of charge. State of charge is the percentage of battery capacity that is charged (Mozafar, Amini, & Moradi, 2018). In return for the use of the battery of the EV, the owner will receive a financial compensation. Noori et al. (2016) argue that this is the most fundamental incentive to make EV owners participate. They found, using agent based modelling, that the financial compensation could be in the tens of thousands of dollars in a EVs lifespan. In this calculation the average decrease in EV battery lifespan is taken into account. In addition, the decrease in greenhouse gas emissions could be in the thousands of tons per researched region. This could lead to an incentive to change behaviour and also relates to the synergy named in paragraph 3.1.4.

3.2.2 Network operator

Next to the importance of the “V” is the “G” in V2G. The G stands for the grid or the energy network. The grid itself is, from a technical perspective, seen as a complex system. When simplified there are two main actors: the national or larger regional energy supplier and the local energy distributor (Noel et al., 2019). In the Netherlands the high voltage network is owned by the Dutch state company TenneT (TenneT, 2019). The lower voltage network from the high voltage power lines to the end users like offices, homes, factories. This regards all power networks with voltages of 110.000V and lower. Subsequently the Netherlands have a system of responsibility within these networks. In addition to the energy supplier and the network administrator there is the Program Responsibility Party (programmaverantwoordelijke partij). They are the link between the supplier and the network. They account for the purchase of enough energy to supply the end user. In short, this Program Responsibility Party is responsible for the purchase of energy when there is increased demand (TenneT, 2002). So when ancillary services need to get paid, they will be paid by the Program Responsibility Party. That makes them play an important role in the V2G system (Noel et al., 2019). So ancillary services like the services named in 3.1.4 are purchased and managed by this party. Therefore, in the framework of network operators, the Program Responsibility Party is the operator who is crucial to V2G as they will be the party who will need to be in contact with the EVs to communicate what kind of service is needed, for how long and when.

3.2.3 Aggregator

Noel et al. (2019) argued that a V2G system might technically be possible directly with only the network operator and the EV, but they themselves and other scholars conduct their research integrating an aggregator into the system (Sortomme & El-Sharkawi, 2011; Tan Ramachandaramurthy, & Yong, 2014; El-Zonkoly, 2015; Noori et al., 2016; Mozafar, Amini, & Moradi, 2018). The role of an aggregator can be seen as the “2” in the V2G system and therefore the link between the EV and the grid, hence V2G. This is due to the way ancillary services work. They have a minimum participation capacity. In the US 1 Megawatt or 100.000.000 Watt is a typical amount to join the ancillary market. For BEVs this means approximately 20 cars with an average battery of 58,5 kWh or approximately 100 PHEVs. That means that for the Netherlands the current fleet of 77.392 BEVs there is an available capacity of 4.527 MWh. If that is calculated for the two most common BEVs the Netherlands the Tesla Model 3 (13.903 cars and 50 kWh battery) and the Tesla Model S (12.671 cars and a 95,5 kWh battery), that means a total of 1.905 MWh is available. Compared to the annual energy consumption by households in 2016 in the Netherlands, that is almost two thirds. In other words, the total available EV battery capacity in 2018 was almost twice as much as the annual households’ energy consumption (CBS, 2018a; RVO, 2019). Electric vehicles have a huge potential as temporary energy storage. The batteries already exist (Ibrahim, Ilinca, & Perron, 2008), EV battery prices drop (Nukvist & Nilsson, 2015) and, as mentioned in the introduction, the number of EVs is likely to explode within the coming decades (IEA, 2019b). An important remark here is that this assumes that all current and future EV owners participate with V2G. There are several perspectives which indicate that this is not likely. This will be elaborated on in chapter 3.3.

In this scenario the role of the aggregator has several important meanings and in the implementation and execution of the V2G system plays a crucial role. In general the third party has to combine the EV owner with the network operator. To start with, the aggregator can play an important role in facilitating the usable EVSE's which allow for bidirectional charging. Since these are costly charging stations, the aggregator could be seen as the party who does this initial investment. The return profit can be made by bidding for the ancillary service. Partially the money made by contributing to the energy network can be a return over investment for installing the infrastructure (cables, EVSE's, fuses and other local power infrastructure upgrades), and partially the EV owners can be paid for their participation. As mentioned in the sections in 3.1, the communication between the car and the network and auditing the power flows are vital. This could be arranged directly back and forth between the grid operator and the EV owner, but it is suggested that this is the role of the aggregator (Noel et al., 2019).

3.2.4 EV market

A simple precondition which must be met is the minor involvement of the car production industries. As mentioned above in section 3.1 the EV itself must allow for bidirectional charging as well. Only two items must be installed in an EV, which are relatively cheap. These are a suitable connection between the battery and the socket of the car and a means of communication with the EVSE and/or the aggregator (Noel et al., 2019).

3.2.5 Government and legislation.

When all of the facets of the V2G system are in place, there is one last participant which needs to be mentioned. This regards the government. The national or local government can play a role in the V2G development in several ways. Noel et al. (2019) argues that legislation can be either a boost for V2G by means of subsidization or investments or it could be a counteracting factor. On the other hand, the municipality of Utrecht seems to be investing together with several entrepreneurs and the Utrecht University is participating as well (Smart Solar Charging, n.d.). In addition, the national government is already investing in Smart Solar Charging. This fund is specifically intended for V2G. Although the 20 new charging squares in Utrecht are intended for shared vehicles, the intentions are there. To increase its media attention and stress the importance, the first opening of the V2G square in the neighbourhood of Lombok was opened by the king of the Netherlands (De Utrechtse Internet Courant [DUIC], 2019, 2 September). Another example of the EV incentives by the municipality of Utrecht is that they offer to build a public charging station near the home of an EV owner if there are none in the near vicinity. They share this information on the specially opened website Gemeente Utrecht (n.d. a). These are examples of the willingness of the municipality to participate in the growing number of EVs and even show interest in V2G.

3.3 V2G Challenges

The different possibilities of V2G integration showed a series of potential benefits of V2G. Also the different stakeholders could benefit from participating and stimulating V2G implementation. On the other hand, there are challenges to V2G too. Before researching the allocation of V2G, a series of challenges must be named. V2G is not developed in a closed system and is a part of vibrant society. The sociotechnical approach which is widely used to approach both the technical challenges and possibilities as well as the social and societal impacts (Kern & Smith, 2008; Noel et al., 2019).

3.3.1 Technical challenges

Some of the technical challenges have already been named in sections 3.1 and 3.2. To elaborate on them in further detail, they are discussed below. These challenges are not insurmountable and as the interest of different pilots (Kane, 2018; Electrive, 2019; Smart Solar Charging, n.d.) as well as the participation of the municipality of Utrecht suggest, V2G may be feasible. However, the technical challenges need to be addressed.

One of the main challenges on a global scale concerns energy storage. Not only for V2G, but energy storage in general is a challenge (Ibrahim, Ilinca, & Perron, 2008). Regarding V2G, the battery of a car is the main factor of influence. Batteries are subject to degradation. There are many kinds of degradation and a vast number of factors is of influence on the speed at which this degradation takes place. A battery with a 25% capacity fade loses 25% ability. So an EV with this degradation can cover 25% less distance on one battery (Noel et al., 2019). Calculating how the different factors are of influence on the degradation of a battery is very complex. Weather conditions, depth of charge (how far the battery is (dis-)charged), average state of charge (how much % of the max capacity is in the battery), number of charges and battery age are all of influence. In addition, these factors may also influence each other. Although the V2G services explained in 4.1.4 put extra stress on the battery, the battery degradation remains small or even insignificant in comparison to battery ageing and degradation due to normal use (Wang et al., 2016). In addition to the challenge of battery degradation, two important notes must be added. In the modelling of revenues for V2G participants by Noori et al. (2016), the replacement price of a battery was calculated. Next to that, Nukvist and Nillson (2015) found that EV battery prices fall rapidly.

Next to the challenges of battery degradation, there are other power related issues. In general, all energy conversion actions cost energy due to efficiency. Noel et al. (2019) argue that the V2G system has an overall high efficiency of 70-80%. This raises the concern of the system efficiency as well as the cost efficiency as a part of the losses are caused within the V2G system. Most of the energy losses happen inside the EVSE where power is converted from the grid to the battery. Although the efficiency rates remain higher than other energy transfer systems like hydrogen storage, it remains a challenge. Researching and experimenting with solutions may lead to an optimization for the efficiency of the system, resulting in an even more beneficial system. Changing the power flows from and to the EVSE are named as a solution, as well as making use of optimization algorithms. For power flow efficiency similar factors are of influence as for the battery capacity degradation named above. If the factors concerning efficiency at the EVSE are measured an algorithm could optimize this as suggested by Apostolaki-Iosifidou, Codani, & Kempton (2017).

One other challenge for the V2G system is the willingness of the vehicle industries. EVs must be compatible to both charge and discharge at the charging station. It is not seen as a major challenge, but important to note that not all EVs by default are able to plug into a bidirectional charging station. Implementing such a change is only a minor intervention (Noel et al, 2019).

The last challenge for V2G is of a different type. The three challenges named above are mainly hardware related, whereas communication techniques are more software related. Without going too much into detail, it is a common problem within data sciences. There is a wide variety of how data, software and systems are designed and used. Standards are invented to ensure that communication of (geo)data is harmonized so different actors can communicate flawlessly (Open Geospatial Consortium, 2012). Data standards are also designed to protect the data from theft or hacking. As the V2G will be making use of a (near) real time data communication system between the EVSE, the EV, the aggregator and the network operator, a system of secured fast and harmonized data is essential. It is crucial that one standard is used to communicate between the involved parties in order to make the V2G system work. As this is a highly detailed data management challenge, this may take some time. It is crucial that all the actors of V2G come up with a combined solution (Noel et al., 2019).

3.3.2 Societal

V2G technology is not only subject to challenges in the technical domain, but also in society. Sovacool et al. (2018) found that most of the literature is focussed on technical aspects of V2G. However, societal aspects and impacts cannot be neglected. The first of these societal challenges concerns the technical barriers described above. Two main aspects are involved here. The actual challenges and downsides for V2G participants as well as consumer knowledge. Regarding the consumer knowledge, V2G can be viewed as niche. Noel et al. (2018) found that less than 10% of the respondents had ever heard about V2G prior to participating in their survey. They even note that they expected that their respondents are more than average interested in V2G or EVs. This is one of the indicators that people are not known with V2G and therefore lacks consumer awareness.

However, Noel et al. (2019) suggest that consumers have knowledge about some of the technical challenges without knowing the exact up and downsides. Some of the major issues relate to the fear of battery degradation and the high costs of EVs compared to classical ICE vehicles. Next to consumer knowledge, the status quo of stakeholders in the existing ICE infrastructure could impose a barrier as well (Sovacool & Hirsh, 2009). Some suggestions which have been made to decrease scepticism towards V2G and increase consumer knowledge are varying. First of all, tackling and solving the problems in the technical domain. Besides that, gaining interaction with the consumer, set up targeted information campaigns, involving users in pilot projects and promoting V2G technology as an outstanding innovation are seen as solutions. This can contribute to overcome fear of technical barriers and increase consumer knowledge towards V2G (Noel et al., 2019).

One particular societal challenge relates to the vast amounts of data. Communication of data, storage and operability security to name a few. With regard to V2G the concerns towards data relate to a series of things. First of all, societal concerns are raised about privacy and security. These concerns are specifically related to the travel patterns of V2G users since they are tracked when they plug their car into the V2G charger. Next to that, the V2G system requires data from the grid and therefore certain parts of the operational details of the energy grid must be opened up. This may therefore also include real-time and real life energy use of households. These data could indicate certain habits and patterns relating to households as well. Habits and privacy sensitive data may be distilled from these patterns. These and other types of data will be in possession of third parties. Next to these grid related data challenges the accuracy and the crucial temporal component of V2G when it comes to providing ancillary services are crucial. So to conclude, there are two main aspects to this data issue: authenticating the EV when it is plugged in and securing the anonymity of the individual EV owners when different kinds of data are gathered (Noel et al., 2019). More specifically, the risks named above appear in different forms. These are forms of deliberately hacking, stealing or breaking into the system. Impersonation, eavesdropping, system hacking or other forms of cyberattacks are among the risks (Bekara, 2014). Since most of the data are owned and used by the aggregator, they are the actors who have most influence on the security of these data. For both securing the flow of data and energy between the EVSE and the EV, installation of secured communication standards are part of the solution. Including digital certificate systems and other authentication methods, the communication between the aggregator and the EV can be secured. This also help to secure the anonymity of the EV owners (Open Geospatial Consortium, 2012; Noel et al., 2019). The final challenge regarding data is a more general data challenge. As the possibilities of acquiring and using data increases, storage and securing these immense amounts of data is a global dilemma and needs a suitable and secure solution. This field of data security is constant subject to research on a global scale.

Based on the literature review the energy network operators, other participants and basic principles are shown in figures 3.2 and 3.3 to give a brief overview of the situation. Figure 3.2 shows a scheme of the existing energy network. The energy generation is broken down into three categories, being renewable energy, baseload energy and ancillary services. Renewable energy goes to waste from time to time because the energy supply is higher than the energy demand and there is not enough energy storage available. Baseload energy is either nuclear or fossil fuel and not flexibly adjustable to demand. Ancillary services are demanded by the network operator to fill gaps between renewable and base load supply and actual use. As mentioned, these ancillary services are both expensive and some services emit large amounts of greenhouse gasses. Below, the energy use is divided into households and EVs. Other forms of energy use are not included in the graph as they are not part of this research. In the current system both household energy use and EV energy use coincide in the early evening and both contribute to the energy peak demand (in the red box), with all the consequences mentioned in the problem statement and in chapter 3.1. The graph between the household and the EV shows a schematic of the energy use over one day's cycle with the hours of the day on the X-axis and the a visualization of energy use on the Y-axis.

Figure 3.3 is a scheme of the situation when the V2G system will be integrated. The main differences are found with the influence of the EV and the V2G aggregator on the right side of the figure. In this situation the ancillary services are still demanded by the network operator but this is communicated via the aggregator. This party will the distribute the ancillary service demand over the participating EV fleet. Both communication lines are bidirectional and mainly handled by algorithms. Eventually the main difference is found in the ancillary services as they are now provided by the EVs. This results in several main benefits:

- Surplus of renewable energy can now be stored in the EV battery to be used later instead of going to waste. This is the synergy between V2G and renewable energy sources;
- The graph of energy use shows that the peak demand can be lowered (or even flattened). This results in decreased grid pressure and lower energy price;
- As EV owners will be compensated for their contribution in the ancillary services, owning an EV will be less expensive. This could result in a boost for EV ownership and a decline of the ICE vehicle fleet;

- Other ancillary services such as frequency regulation can be provided by EVs so that expensive grid investments can be prevented.

Figure 3.2: Overview of energy in residential setup, including EVs

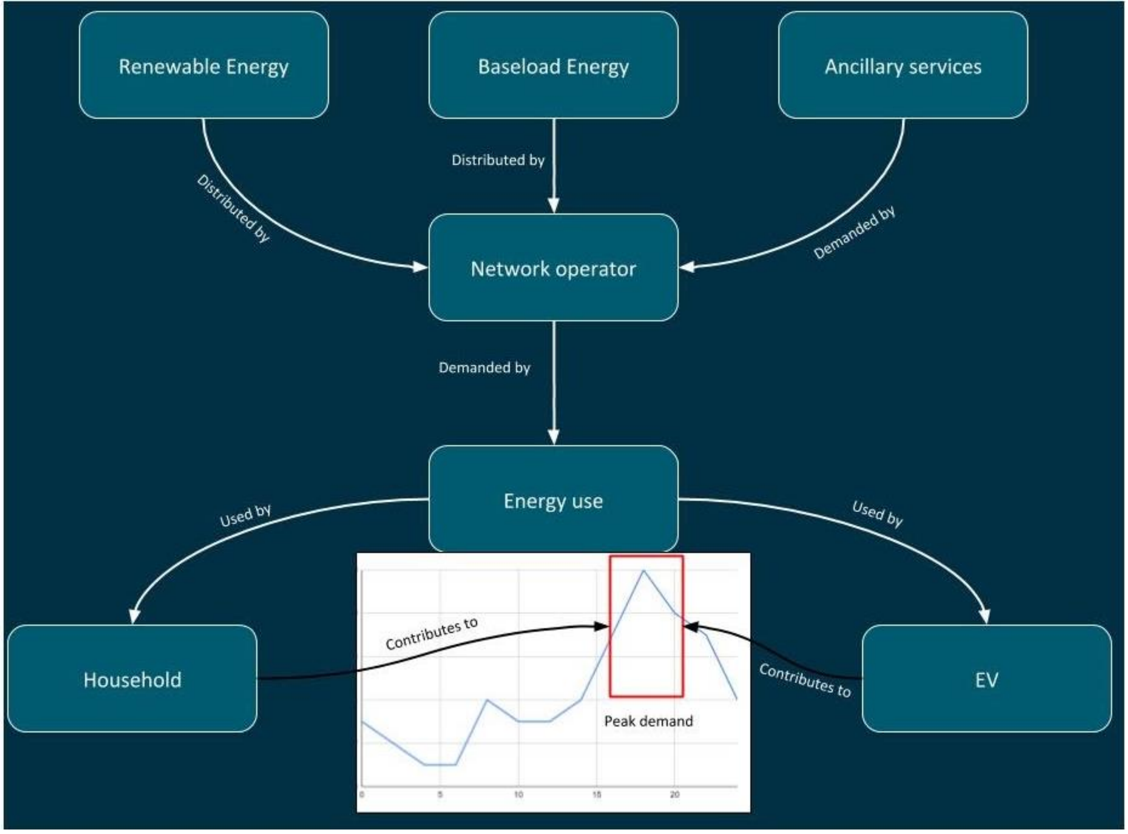
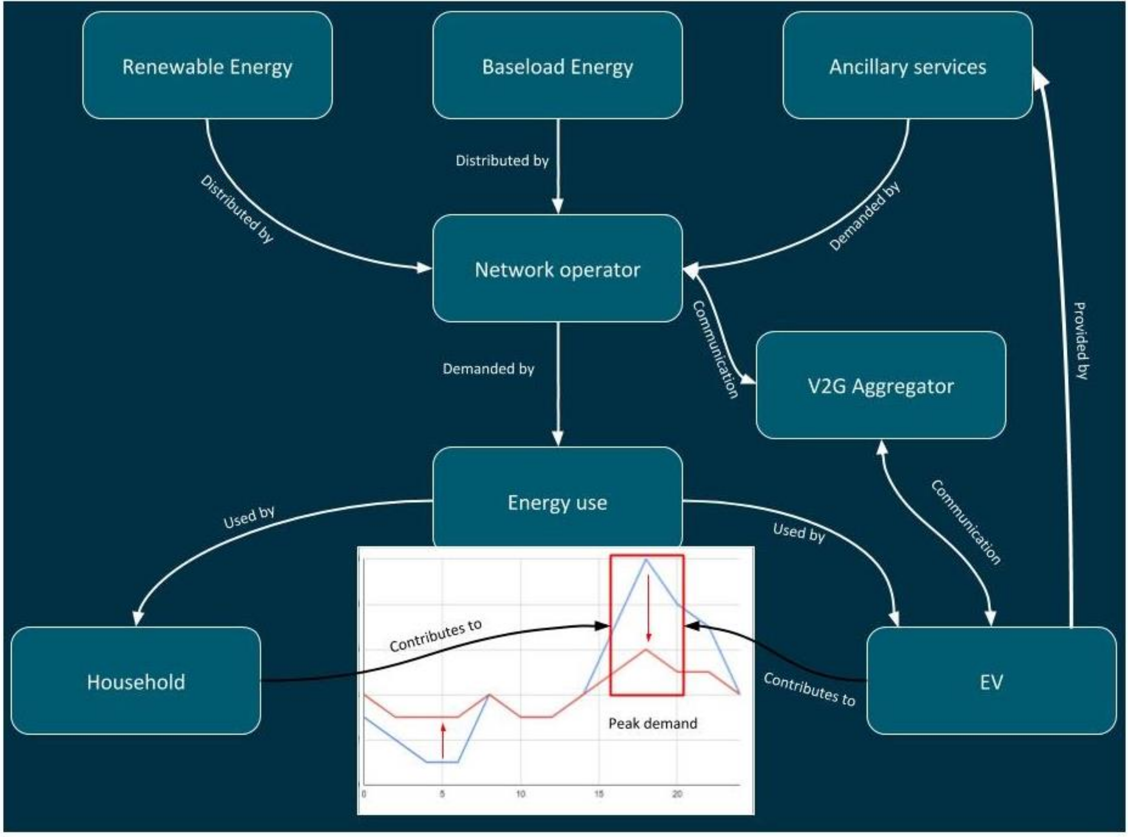


Figure 3.3: Overview of energy system with V2G installed

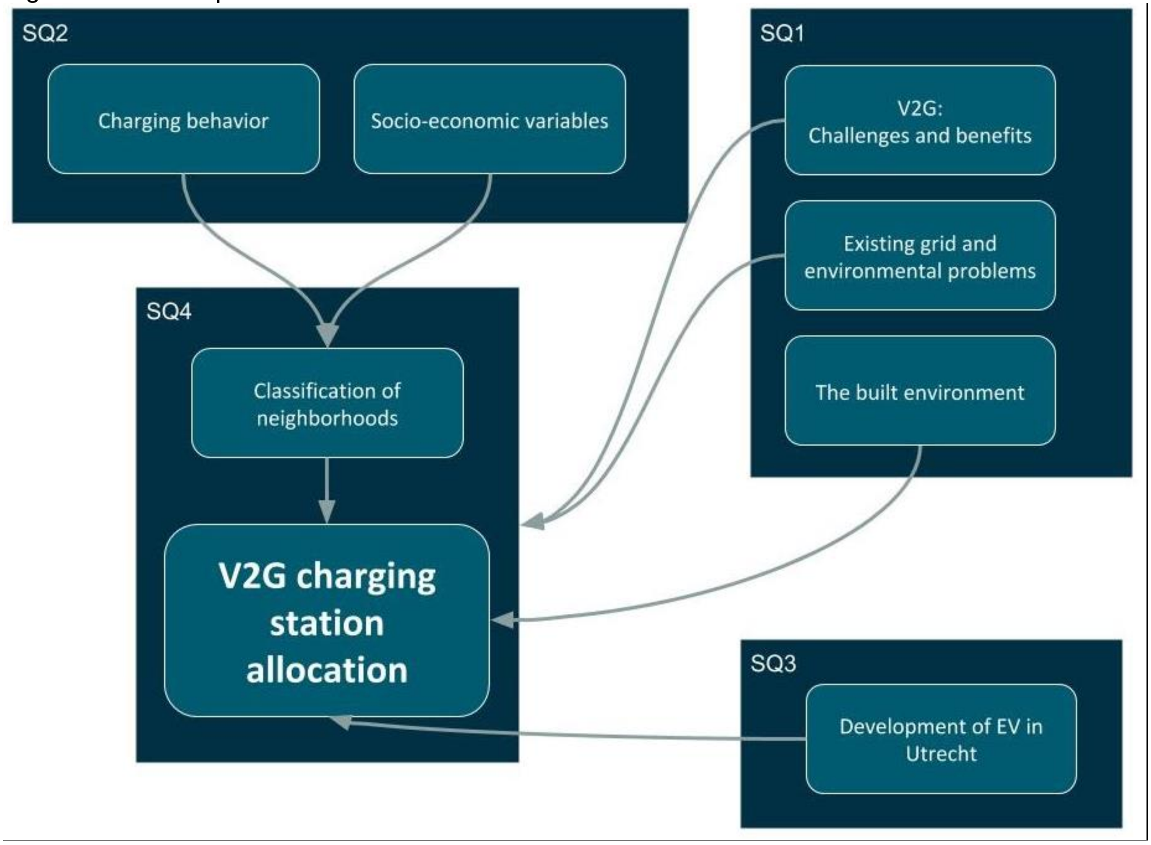


3.4 Conceptual model

Chapters 2 and 3 include the research setup, the prevailing theories and concepts are captured, whereas chapter 4 contains the used methods, and finally the way data are collected, converted and analysed. Before continuing to the methodology chapter, the research setup and the literature chapter are recapped in the conceptual model. The model contains the theories and concepts which are directly line with the research questions. This is visualised in figure 3.4.

The overview starts with the general information about V2G. In order to understand the connection between following steps in the research and what benefits and challenges exist for the niche technology, the basic principles must be known. Besides that, knowledge about what the impacts could be in the form of solving problems is of importance. Finally, several assumptions must be made based on the gathered knowledge about V2G. This part of the research will be the basis of the research and the answers to sub-question 1 will be used in the classification of the neighbourhoods. Another series of variables and concepts which are of influence on the classification of neighbourhoods relate to sub-question 2. In contrast to the information found in sub-question 1, these concepts are more data based. Although the influence of the existing EV infrastructure and socio-economic circumstances of EV owners are retrieved from the literature review, this sub-question is mainly focused on gathering, combining and converting data. The outcomes of the data analysis of these inputs will also contribute to the classification of neighbourhoods. Sub-question 3 is not an input for the classification but directly influences how the charging stations are distributed. This is also a data review variable which involves a calculation provided of the hypothetical number of EVs to provide Utrecht from energy in a scenario. The outcomes of this question is of direct influence on the number of charging station per classified neighbourhood. Finally in the centre box, the two main subjects of research are found including the ultimate goal of the research. Firstly, the data conversion as explained in chapter 4 mainly aims at creating classifications of the neighbourhoods to indicate how many V2G charging station need to be placed in that neighbourhood. So this and the final computation of the built environment gathered in SQ2 and the future prospects from SQ3 are direct input for the final allocation question, sub-question 4. In bold the expected final outputs are listed and when the steps of the conceptual model are fulfilled it will result in the allocation. More details about the methods of research and data computation are described in the next chapter.

Figure 3.4: Conceptual model



4. Methodology

This chapter will elaborate on the methods used in this research. The different choices will be justified and more specific information concerning the approach of the different sub-questions will be explained.

4.1 Research approach

The setup of this research is subdivided in three main parts. Firstly, a literature research will be conducted to determine the basic principles of V2G. This first part will create the basis to continue with the quantitative part of this research. The collected data will be analysed, converted and combined and finally visualized in a final output. The second part will investigate what socio-economic variables are of influence to predict likeliness of inhabitants to own an EV in the (near) future. This will based on statements found in literature. The hypotheses will be based on Sovacool, et al. (2018). This will eventually result in a classification of neighbourhoods. The allocation is based on this classification. The third and final part approaches the allocation of the V2G charging stations. The chosen method is Multi-Criteria Evaluation [MCE]. MCE is a suitable data evaluation method within a geographic information system [GIS]. It is an overlay analysis method where several inputs can be combined to create one output model. This model holds information about research subjects such as site location determination (Carver, 1991). There are two main types of MCE used in GIS research: one converts the criteria to Booleans. In other words, the criteria become a 1 or a 0, or a true or a false. Both applicable in raster and vector methods. The second MCE method has a more quantitative nature. This more modern application of MCE where the input for the MCE are not Booleans but continuous variables. This way a degree of suitability can be implemented in the evaluation of the spatial data. This suitability is applied to the variables using scores. The scores impact the influence of the variables on the model. The value of the scores are based on assumptions concerning suitability (Eastman, 1999). These assumptions are retrieved from existing literature such as peer reviewed articles or pilot projects. The second, more modern type of MCE will be used in this research. This type of MCE makes use of raster data type, or directly from data recalculation and reclassification. Several computational methods are available, both with and without weights in ArcGis Pro (ESRI, n.d.), or non-spatial calculations are made in Excel.

Table 4.1. Data sets and sources. *Not acquired.

Data type	Title	Source	Year of publication/ year of collection
EV prospect	Elaad Outlook	ElaadNL	2019/2019
Existing charging stations	Laadpalen.nl	Laadpalen.nl/Utrecht University	2020*/?
Energy demand calculation	Energy use in Utrecht	Staat van Utrecht	n.d./2016
	V2G and the Energy Transition	Utrecht University	2019/2019
	Wijken en buurten 2018	CBS	2017 and 2018/ 2017 and 2018
Socio-economic data	Wijken en buurten 2018	CBS	2017 and 2018/ 2017 and 2018
	Wist u data	Municipality Utrecht	2019/2019
Built environment	BGT	CBS	n.d./2018
	Verbruiksgegevens	Stedin	n.d./2018
	BAG	PDOK	2019/2019

For this research, the subject is V2G charging stations for EVs. The second MCE type as described above will result in a spatial raster model as final output. This model will resemble the municipality of Utrecht. The different inputs will eventually result in data combined using the MCE into this model. The final model shows a number of places which are suitable. What suitable locations are is based on literature. To calculate these locations, several input data need to be selected. These data sets are retrieved from the internet sources and from within the Utrecht University listed in table 4.1. The different data sets are discussed below. The different scores will be determined based on the literature as described above as well as the input data. The literature is key in finding data which fit the research area, the scale and the content. Eventually the scores will be based on data which are in line with the theories found in literature

4.2. Data collection

The use of existing data to come to new insights is key in this research. Therefore existing data sets need to be collected from different sources. The information retrieved from these sources during the execution of the research will be elaborated on. There are three main subjects: EV related data, socio-economic data and existing built environment data of the research area. The different data and sources are listed in table 4.1.

4.2.1 EV related data.

The first type of data required to aid the allocation problem relate to EVs themselves. Firstly, it is important to know what the distribution of the existing charging station of the research area looks like. Therefore, the data set of Laadpalen.nl will be used which has information about all public charging station in the area. Next to that, research needs to be done to determine what the (near) future prospect for the EV fleet in Utrecht looks like. The recently published Elaad Outlook (2019) will be used for this as well as the older Utrecht *Strategisch Plan Laadinfrastructuur* (Kok, 2018). This is needed because the implementation of the V2G charging station is a process that will roll out in the future. In addition, the Utrecht University has made a calculation on how many V2G charging station are needed to provide a certain threshold. This recalculation has been redone based on other sources such as Staat van Utrecht (n.d.). This results in an indication of the impact V2G can have in a hypothetical scenario in Utrecht. With this information, a clear overview of the existing and future needs for EVs can be made.

4.2.2 Socio-economic data

The second type of data that is of influence regards the socio-economic data. Combined with the data regarding EVs, a new data set can be created. Combining the spatial information of the neighbourhoods with the relevant socio-economic data results in a series of categories. These categories can be calculated for the whole municipality. In combination with the assumptions retrieved from the literature review this aids in understanding where the increase of EVs ownership may take place. The data are collected from CBS (2017; 2018b). Both have several data sets about the neighbourhoods of Utrecht. The CBS (2017) hold information about income, education and work, whereas these data are missing in CBS (2018b). The latter is more up to date and therefore used for the other variables: elderly, young adults, men and large households. How and why these variables are chosen and retrieved from the data set will be explained in paragraph 4.3.

4.2.3 Existing built environment

The third kind of data then will be used in the MCE concerns public space. More specifically, the existing parking area. Cars park on parking spots when they charge, so the charging stations must be built alongside parking areas. Other variables, like for example the vicinity of homes, which are of influence can be retrieved from either literature or derived from the existing non-bidirectional chargers in Utrecht. Data sets with data about built up areas are for example the Basisregistratie Grootschalige Topografie [BGT] or in English, the Key register Large-scale Topography (CBS, n.d.) or the Basisregistratie Adressen en Gebouwen [BAG] or Key register Addresses and Buildings in English (Publieke Dienstverlening op de Kaart [PDOK], 2019). In addition, the energy network will be reviewed to find potential congestion points or areas with increased pressure on the existing grid. In Utrecht the MV and LV network operator is Stedin. They have data sets concerning the grid infrastructure (Stedin, n.d.).

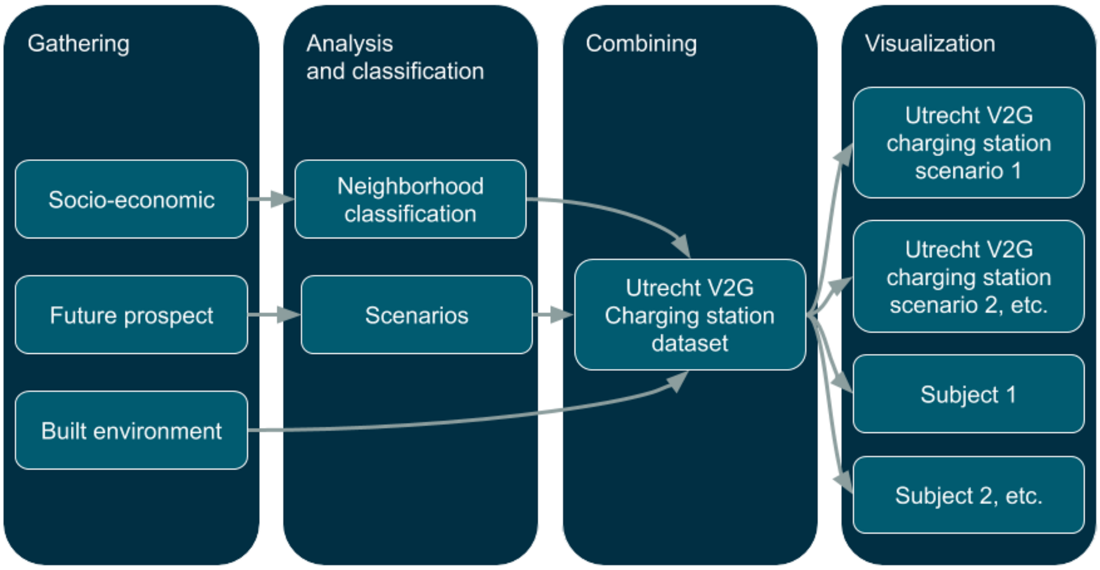
4.3 Operationalization

The different sub-questions all have a different approach. This subchapter will explain how the answers for each of the sub-questions will be found. Finally, the way data are used to come to a final output is visualized in a scheme in figure 4.1. This scheme is a rough overview of how the data are analysed, combined and converted to new information.

SQ1: *What are crucial preconditions in order to implement Vehicle to Grid In Utrecht?*
The subject of this sub-question are the required preconditions. As explained above this concerns the preconditions which need to be in place for V2G to be installed. The preconditions will be found by means of an extensive literature overview. The problem statement mentioned that there is a gap in research between social and technical approach in scientific literature. However, in both fields of research these preconditions are mentioned. Scientific literature has identified challenges which have to be overcome before V2G could work. These challenges will be sought for. Because it is a new system it is important to look for solutions to these challenges. Whether or not these challenges need mitigation will be mentioned. Surpassing insurmountable challenges and how this can be done is part of the preconditions in order to implement V2G. Another, more specific subject of preconditions is in the field of legislation. This question will investigate whether Utrecht is a feasible municipality to implement V2G as a city wide system. Answering this sub-question also involves exploring the basics of V2G, identifying the challenges of V2G and what the benefits of V2G are.

Another precondition regards parking availability. Where charging stations are placed, cars will need to be able to park. So for each neighbourhood the number of parking spots is calculated and combined with the outcomes of the research. This gives insight in whether or not the implementation of the V2G system on a neighbourhood level is feasible. The parking spots are calculated by using the surface of the parking areas per neighbourhood divided by the average size of a parking spot.

Figure 4.1: Scheme of data analysis.



SQ2: *How can the distribution of future EV ownership be divided over the different residential neighbourhoods in Utrecht?*
The scheme of how data are used in this sub-question is shown in figure 4.1. This sub-question researches the existing situation in Utrecht regarding the charging stations. The answering of this question regards a data research. There is a series of steps involved in finding an answer to this question. There are different data types involved which are both spatial and solely numerical. These will have to be combined into a one single data set to come to an answer to the sub-question above.

Based on the objective of defining suitability, the first step in the process is to find out what suitable locations are. The answer to this objective is sought in terms of likeliness for inhabitants of the research are to be owning an EV in the (near) future. So to predict the expected distribution of future EV owners in Utrecht, the research of Sovacool et al. (2018) will be leading. The socio-economic variables they have found will be the basis for the remainder of the research.

The second step is to collect the data concerning these variables on a neighbourhood level in Utrecht. This research focuses on residential areas so non-residential areas will be defined as unsuitable and will therefore be filtered out. The parameter on which this filtering works is the share of dwelling surface used for residential purposes of the total dwelling surface derived from the BAG (PDOK, 2019). So the remainder of the research will concern neighbourhoods with a significant share of residential areas. The spatial neighbourhood data set will be complemented with data from other sources listed in table 4.1 above. The socio-economic variables are now combined into a spatial data set containing solely the neighbourhoods with residential characteristics.

To make the input data mutually comparable the data are recalculated to a comparable 1-10 scale. Firstly, all input variables will be calculated into percentages of the population. Since these percentages all hold different kinds of information they cannot directly be compared. The data are recalculated using a formula which provides the highest percentage of a positive variable with a 10 and the lowest percentage of this variable with a 1. For the negative variables this process is inverted. This leads to grades from 1-10 for all variables which allows them to be compared mutually and allows for recalculation and combining the different variables. The last step herein is calculating the average score for each neighbourhood.

This grade hold information about the grade every inhabitants get in terms of likeliness to own an EV in the (near) future. So multiplying this grade with the number of inhabitants results in a number per neighbourhood which is the total score for all inhabitants combined. The share per neighbourhood of the total score of all neighbourhoods combined can be multiplied with the prospected number of EVs or charging points in the future. This is the basis for the allocation in the future.

Based on the variable by Sovacool et al. (2018) and the available data on neighbourhood level from the CBS (2017, 2018b), the socio-economic variables in table 4.2 are selected to use as data input. The research aimed at using data which is actual on the one hand but complete on the other. Due to lacking numbers in 2018, the data were supplemented with data from 2017. Variables 1 through 4 do not need further explanation. The data concerning employment was not available at the time of research so in order to use this variable, as explained in paragraph 3.1.2, is computed using the percentage of people who receive unemployment benefits (WW-uitkering) as percentage of the working population (aged 15-64). Because it is a negative influence, it was inverted in the MCE. The variable “high income” is interpretable in many ways. In this case, the research made use of the percentage of inhabitants who earn the top 20% of national average incomes. In other words, if the national population was divided into five classes based on income, this variable counts the percentage of the neighbourhood population who has an income which fits in that highest national class. Finally the large households are based on the households with kids. This category is most similar to the statement by Sovacool et al. (2018).

Table 4.2: Socio-economic variables of influence on likeliness of future EV ownership (Based on Sovacool et al., 2018).

Name	Characteristics	Influence	Source year
Percentage men	Percentage of men in the neighbourhood	Positive	2018
Percentage young adults	24-45 years	Positive	2018
Percentage elderly	65+	Positive	2018
Percentage highly educated	People with a Bachelor degree or higher	Positive	2017
Percentage unemployment benefits (ww-uitkering)	People with an unemployment benefit as percentage of the working population, aged 15-64	Negative	2017
Percentage high income	% of people have an income in the 20% group of highest national incomes	Positive	2107
Percentage large households	Households with children	Positive	2018

SQ3: *What are the prospects for EVs in Utrecht in the future?*

This sub-questions focuses on the future of EVs. As explained in chapter two, this question is raised because developments do not initiate instantly and in a vacuum. Therefore this research works with future prospects. The prospects are based on:

- Future number of EVs for Utrecht in 2025, 2030 and 2035
- Energy storage demanded by the current energy system in Utrecht

There are several variables of influence. Since these variables are based on future prospects it hosts a level of uncertainty. Therefore the prospects will be broken down into scenarios. The data flow (figure 4.1) requires these prospects to be broken down. There will be three future scenarios: 2025, 2030 and 2035. These will be calculated from the perspective of the EV. This means that the V2G charging stations which are to be installed follow the growth of the EV fleet in Utrecht. This means that the neighbourhoods which are likely to show the most growth in terms of EVs will be foreseen of a relative high number of V2G charging stations. This is based on socio-economic variables as explained in SQ2. For comparison a null situation will be shown as well where the input variables are solely the distribution of the inhabitants. These different scenarios will result in different outcomes. The calculations of these inputs will have their effect on the expected number of V2G charging stations. Therefore these will all be calculated in the eventual data set which is created for this research. These scenarios will also be visualized in the final outcomes. The number of allocated V2G charging stations is based on the share per neighbourhood of the total score of all neighbourhoods combined multiplied by the prospected number of EVs or public charging points in Utrecht in all three future scenarios. The control group or null scenario is used to analyse the impact of the different variables against the number of inhabitants. This is done by calculating how much the difference between the MCE differs from the control group is. This difference is then transformed to percentages showing the how much the outcomes of the MCE are explained by the number of inhabitants.

SQ4: *What can future spatial allocation of Vehicle to Grid charging stations in the municipality of Utrecht look like?*

This fourth sub-question concerns the combining and visualization blocks of the data scheme in figure 4.1. The last sub-question involves the visualization of the final outputs. The data computation and combination into one data set will be laid out over the research area in a raster grid. This is where the MCE as mentioned above will be visualised and analysed. The visualization part of the research is where the actual allocation of the V2G charging stations will be taking shape. All the relevant input variables will be added to the spatial data set. The scores of the different variables will be defined and added, and a spatial calculation will be executed using ArcGis Pro. Once again, the different scenarios will all have their own output. These spatial calculations will be visualized using a series of maps. Alongside these maps, the relevant tables with their numbers will give a visually appealing, as well as a substantive image of the allocation of the V2G charging stations in the municipality of Utrecht. The maps will also include analysis of the data and outcomes.

4.4 Available Soft- and Hardware

During the research use of a desktop computer will be required for this research. The data analysis and visualization process are data intensive procedures. The execution of this research makes use of a personal desktop. This desktop computer has the computing power needed. In addition, several licenced software programs will be used as well. These include ArcGIS Pro by ESRI and Excel by Microsoft. Data calculations and transformations are mainly done using Excel and spatial calculations and visualizations are executed in ArcGis Pro. Data will be copied between both programs. The researcher has full licences covered by the Utrecht University for both programs.

4.4 Reliability and validity

With regard to the measuring instruments used in an investigation, there are two guidelines: precision and accuracy. The precision determines the validity and the accuracy determines the reliability. Because it is not always possible to repeat a quantitative study, the value of the study can be increased by justifying the way in which the study was conducted (Boeije et al., 2009). To guarantee reliability and validity, several research methods were applied during the execution of this research. The use of multiple methods: content analysis using literature research and existing data such as policy documents and the use data analysis, results in a more reliable investigation. The literature and the additional sources of research that have already been carried out in this context benefit the validation of the results (Baarda et al., 2013, pp. 115-116).

To guarantee the accuracy of the investigation, the investigation refers to the sources used and the data sets. The justification of the sources and the data are already justified for this in section 4.2. The results of the data transformation and recalculation are included in the appendix (Boeije et al., 2009).

5. Analysis

The analysis chapter is subdivided in four main subjects. Before continuing with the analysis it must be clear that V2G is bound to a series of limitations and constraints. These limitations and constraints are discussed in chapter 3 as challenges. These challenges lead to a couple of crucial preconditions which must be met before V2G can be implemented in Utrecht. This is the first part of the analysis chapter. Secondly, the variables found in chapter 3.1 are recalculated for the existing charging structure in Utrecht. The data themselves and the results of the analysis are reviewed extensively. This will create a basis for understanding the current situation and this can be extrapolated to the desired future V2G infrastructure. Finally, the allocation of the V2G charging stations will take place. First the results of the input data are shown and discussed. As these are the basis for the final outputs of the MCE, the most important input factors will be shown separately before continuing with the remainder of the analysis. After this, the control group will be shown and analysed. Next, the MCE for all three future scenarios are shown and discussed and interpreted. This combines all the different data and creates a general overview of the V2G charging station locations as well. The results will be discussed using visual representations, numeric representations and textual explanation of the findings. The most important findings will then be overviewed in a broad context and be combined to create an understanding of the V2G charging stations allocation problem. Finally the results and interpretations are discussed.

5.1 Preconditions

The previous chapter extensively reviewed the literature concerning EVs and V2G. This resulted in several challenges and other crucial changes which must occur before V2G can be implemented and used in Utrecht. These are discussed in the next sub-chapter. Whether or not these preconditions are already in place, they will still be discussed below. The chapter is subdivided into four different subjects. They relate to different kinds of preconditions which must be met. Firstly, the requirements concerning EVs are listed. Secondly and thirdly, the V2G system is pulled apart into technical preconditions and the preconditions of involved parties and society.

5.1.1 EV related preconditions

There are two main preconditions which need to be met for V2G to work in Utrecht. The first one is derived from Noel et al. (2019) and relates to the communication possibilities of the EV. The first precondition which must be in place is the installation of a Vehicle Smart Chip (VSL). They described that without this chip, smart charging is not possible as without the VSL the charger cannot know the battery status of the battery. It then simply fulfils the physical demand. As the VSL allows the car for communicating with the charger, this is a crucial precondition which needs to be met.

Secondly the full, large scale V2G system, a minimum number of vehicles is required (Noel et al., 2019). This is due to the ancillary services (Noori et al., 2016) and the more EVs can be used for storing energy, the better the system works (Ibrahim, Ilinca, & Perron, 2008). So as the generation of renewable energy grows, it's crucial for the V2G system to operate as efficiently as possible, it is crucial that the number of EVs keeps growing until 100% in the near future. Therefore, in order to make the V2G system successful, this research assumes that the precondition of growing abundance of EVs in Utrecht is met. This is feasible based on the Elaad Outlook (2019), RVO (2019), IEA (2018b), and others.

5.1.2 Technical preconditions

The V2G system consists of many different mechanisms which must all operate in harmony. The basics of the system are extensively discussed in chapter 3.1.3. All three components; the connection to the grid, communication possibilities (as named in 5.1.1) and control of charge and discharge, and finally the measurement system must operate properly. The grid connection is crucial for both the existing infrastructure as well as for the V2G system itself. Expansion of V2G is inherent in grid connection as this is one of the pillars of the system. This is not seen as a precondition, but it is crucial for the system to operate and relieve the existing grid pressure (Gerritsma, Al Skaif, Fidder, & Van Sark, 2019). In addition to the communication inside the EV as described above, the communication with the aggregator, the control of (dis-)charging and auditing of power flows and ultimately the bidirectional connection to the grid is arranged in the EVSE or the charging station. Installing those is subject of this research. The installation is a precondition which must be met, but as the presence of these EVSE's is currently not there, this precondition will be fulfilled by installing them as final step in the V2G system.

In chapter 3.3.1 several technical challenges are listed. The current main technical challenges are battery degradation, energy efficiency and data security. As mentioned, battery degradation is generally less than expected and of an insignificant impact compared to for example battery ageing and normal battery use (Wang et al., 2016). Whereas battery degradation remains a challenge, for this research it is assumed that battery degradation is not an insurmountable problem. For the energy efficiency, Apostolaki-Iosifidou, Codani, & Kempton (2017) identified this as a drawback, but opted that further algorithm optimization could be key in increasing the efficiency. However, noting that the energy efficiency of the energy transfer between the EV and the grid is between 70% and 80%, this is significantly higher than for example for hydrogen energy transfers. In addition, the energy efficiency of an ICE is about 25% (Noel et al., 2019). Therefore, the efficiency issue is not seen as an insurmountable drawback. The last addressed challenge, the privacy and standards issue, is not seen as surmountable either. This due to the fact that it must be taken care for. As this is managed by large companies like the Open Geospatial Consortium and the International Organization for Standardization (ISO) who have extensive experience in this field, this challenge is crucial to take care of, but not an insurmountable challenge. To conclude, V2G has its technical challenges and points of improvement. However, there are already several solutions which take care of this. In addition, V2G can still be seen as a niche development and according to the multi-level perspective when this system is growing, more investments will be made which will benefit these challenges. (Geels, 2006).

5.1.3 Involved parties and societal preconditions

The V2G system is dependent on the involved parties in order to make it work. The different parties are mentioned in chapter 3.2. Several preconditions must be met before the V2G system in Utrecht could work. Some preconditions are already met, whereas others are assumed to be met as soon as the implementation of the system is executed. These preconditions are based on developments which already occur in technology or society at this very moment. The five involved parties will be discussed below.

As described in 3.2.1, the most crucial participant in the system is the EV owner. In this lies a challenges whereas the preconditions which are needed to make V2G work are in place. Consumer participation is crucial and currently seen as one of the major challenges (Noel et al., 2019). There are several challenges to be overcome in order to increase private participation. First of all, there must be enough cars who are able to participate. As mentioned before, the number of EVs is expected to increase rapidly which is in favour of the system. However, there is an issue with estimating participation grades as there are only pilot studies without actual private EV owner participation. Gerritsma et al. (2019) solved this in their study by assuming 100% participation grade and therefore neglecting consumer resistance to participate. The main factors which play a role in participant resistance include lack of consumer and the high initial cost of the EV, whereas the ICE infrastructure may impose a barrier as well (Sovacool & Hirsh, 2009). An incentive to persuade current and future EV owners is the financial benefit of participating in V2G. Increasing consumer knowledge about the technical up- and downsides of the system as well as tackling the actual technical challenges both aid in increasing participation grade. Another option to increase consumer knowledge is an incentive which is of a more forceful nature: the main existing stock of charging stations in Utrecht are public. They are placed by the municipality (Gemeente Utrecht, n.d. a). Whereas this research aims at replacing these charging stations by bidirectional charging stations, the EV owners who want to make use of public charging will automatically be connected to a V2G station. Because there are no real life studies implying an expected participation grade and the existing challenges relating to consumer participation are not insurmountable, participation of consumer is assumed to pose no threat for the V2G implementation. This research therefore assumes a participation grade of 100%.

Secondly, the network operator must participate in order to make the system as a whole function. The V2G part wherein the network operator is influenced will mainly be in the ancillary services, which are currently a very costly business for the network operator (Noori et al., 2016; Noel et al., 2019). They will benefit from V2G because V2G is designed to be cheaper financially and in addition benefits the environmental aspect as it replaces the existing greenhouse gas ancillary services (Noori et al., 2016). Therefore it is assumed that the network operators is willing to join.

Thirdly there is the aggregator as involved party. In terms of participating parties, this party is the only party which doesn’t exist yet. We Drive Solar does have V2G running, but since they own and operate their own fleet, there is no aggregator involved. For public V2G an aggregator is crucial. This third party is needed to arrange all technical arrangements. The aggregator will play the central role in the V2G system as explained in chapter 3.2.3. Flows of energy, communication and money will be managed by this aggregator. This could either be a government body or a third party business. It is assumed this role will be fulfilled as V2G offers a business model. Noori et al. (2016) found that potentially sums of financial benefits are to be made. The example of We Drive Solar who, with help of the municipality of Utrecht, who started with V2G as a shared car company shows that there is a business opportunity as they keep growing (We Drive Solar, 2019). Although V2G is still in development this research assumes that the role of aggregator will be fulfilled. Either by the municipality, by a third party or a combination.

Fourthly, the EV market must integrate the relatively cheap VSL as well as a socket which allows for discharging next to charging (Noel et al., 2019). These are no major or costly additions to electric vehicles and some even already have them. However, it is crucial for the EV market to apply this minor addition to the vehicles in order to allow the EV owner to participate with V2G. As this is not a major addition, this research assumes that this precondition will be met.

Finally the government has an important role to play. They can arrange legislation, subsidies or impose charges. As mentioned in chapter 3.2.5, the municipality approaches both electric driving and V2G as a subsidizing role and so does the national government (DUIC, 2019). The only precondition which is important is that legislation is not an obstacle in developing V2G (Noel et al., 2019). In Utrecht the government is actively participating and therefore seen as a positive contributor. That means that this precondition is met. Finally it is worth noting that the eventual benefits of, among others, decreased greenhouse gas emissions, more efficient usage of renewable energy sources and relieved pressure on the existing grid are benefits for the whole society. The active stimulating attitude to V2G may be a great incentive to increase awareness about V2G in Utrecht. With the multi-level perspective approach by Geels (2006) in mind, the new developments of V2G can be intensified and accelerated.

5.2 Descriptives

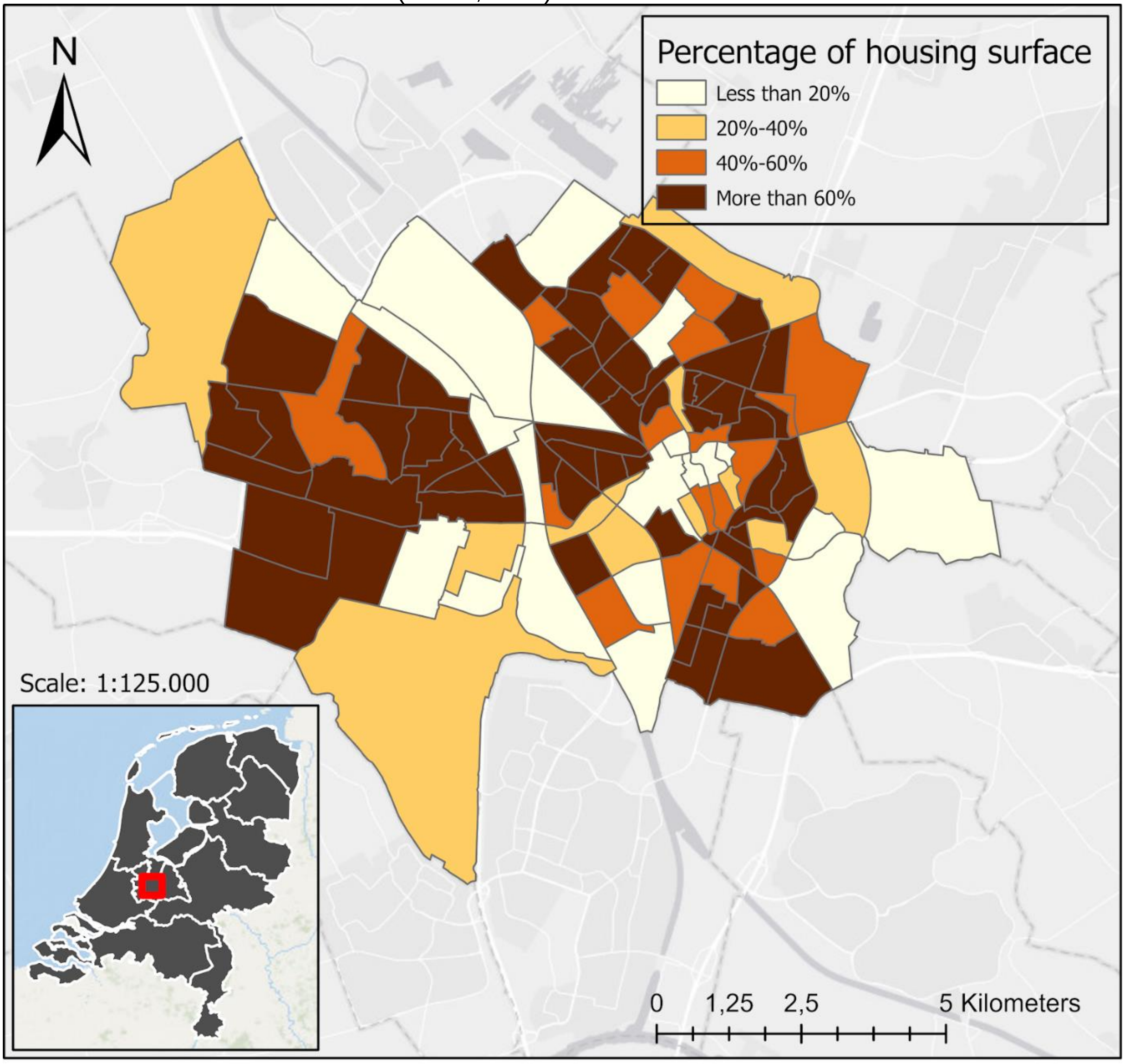
The research area is the municipality of Utrecht. The following subchapters are dedicated to explore the current data concerning this area. This is crucial to understand where the outcomes of the V2G charging station distribution is based on. As mentioned before, the subdivision of the region is based on a neighbourhood scale. The spread of the neighbourhoods and the corresponding neighbourhood names are listed in Appendix A. The locations of the different neighbourhoods are shown in Appendix B. The exploration of the research area is subdivided into five different parts. These are the basis of the allocation of the V2G charging stations and concern data gathering and data transformation. The most crucial maps and tables are shown accompanying the text.

5.2.1 Residential neighbourhoods in Utrecht

The distribution of offices, industries and residential areas are of influence on the type of charging which is used Gerritsma et al. (2019). Whereas this research solely focuses on areas with residential characteristics, several neighbourhoods have been excluded from the analysis. These neighbourhoods are listed in Appendix A and shown in figure 5.1. The threshold for the areas has been set at lower than 20% of the used surface for residential purposes based on the BAG dwelling surfaces in 2019 (PDOK, 2019). A total of 21 neighbourhoods have been filtered out this way. Obvious neighbourhoods like De Uithof (Utrecht Science Park), all neighbourhoods which are called business parks and shopping centres like “Zamenhofdreef en omgeving“ with shopping center Overvecht and “Leidsche Rijn-Centrum” are excluded, but also a series of neighbourhoods in the city centre. Many shops, offices, meeting centres and university buildings are located here.

The exclusion of these non-residential neighbourhoods is done with two main reasons. First of all, because charging behaviour is different in visiting or working areas, compared to residential areas. Secondly, in the following analysis steps these neighbourhoods cause flaws in the data accuracy due to misleading figures in the socio-economic data, or on the car-inhabitant ratio. The result is a data set with 90 neighbourhoods, with an average of 68,7% of residential surface. The selection of the residential neighbourhoods is part of the MCE.

Figure 5.1: Percentage of housing surface of the dwellings in Utrecht per on neighbourhood scale in Utrecht in 2018. Based on the BAG (PDOK, 2019).

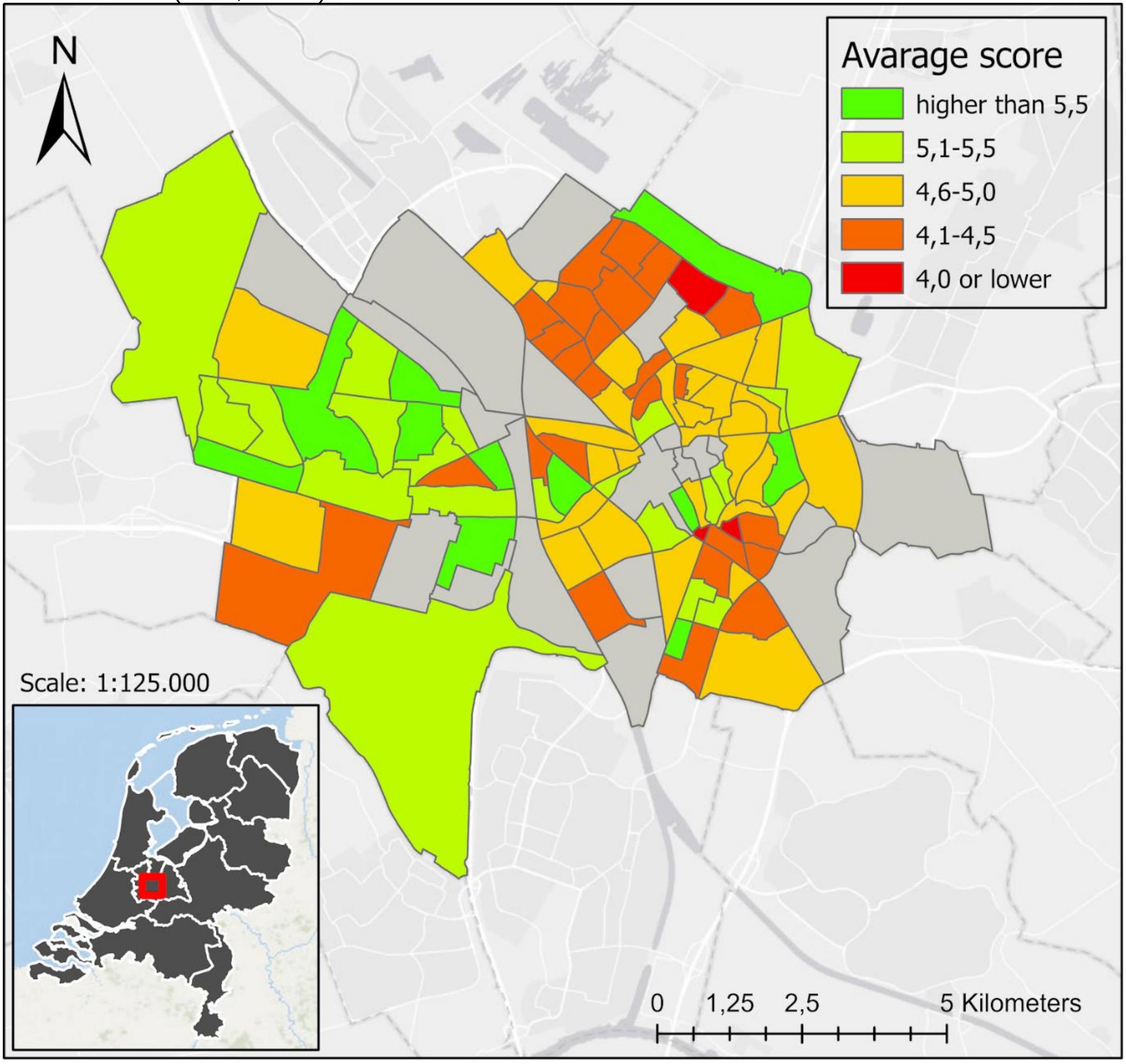


5.2.2 Socio-economic classifications

As explained in chapter 3, the socio-economic variables are a basis for the allocation of V2G charging stations in Utrecht. A total of six characteristics, containing seven variables are considered positive and one as negative factors to predict EV ownership (Sovacool et al., 2018). These variables are combined on the basis of a 1-10 scale in order to make them mutually comparable. The scores indicate the likeliness of every inhabitant of the neighbourhood to own an EV in the (near) future. Without adding weights, the total score is combined which holds information about the likeliness of people who live in those neighbourhoods to own an EV in the future. The input variables are explained on page 21. The data on which they are based are derived from two data sets, both retrieved from CBS (2017, 2018b). The different variables are listed in table 4.2. Please note that the variable of unemployment benefits is the only applicable data type available which allowed for spreading over the neighbourhood scale. The score has been inverted to be comparable, so a higher score is a lower percentage of people with unemployment benefits. This is done to cover the employment factor found by Sovacool et al. (2018). The average scores are found in Appendix A. Chapter 5.4 will explain the details of the final scores in more detail, as it is not clear to review all scores of the 90 neighbourhoods.

To overview these scores, the averages are shown in figure 5.2. The average of all 90 neighbourhoods is 4,82. The highest score is 6,76 in Máximapark whereas the lowest is found in Sterrenwijk with a score of 3,79. In general the pattern is similar to the pattern found at the cars/inhabitant. However, looking at the highest and lowest scores throughout the results of the variables, no real pattern stands out. Many young people live in and around the city centre, but elderly people not so much, which are on the basis of the mainly average scores there. For neighbourhoods in De Meern and Vleuten mainly large families, higher income and a large number of young adults are in line with the high average grades in these neighbourhoods. These scores are used in the MCE to allocate the V2G charging stations. The maps of the separate scores are found in appendix C. Rijnvliet and Rijnenburg have missing values in the income score and the employment score.

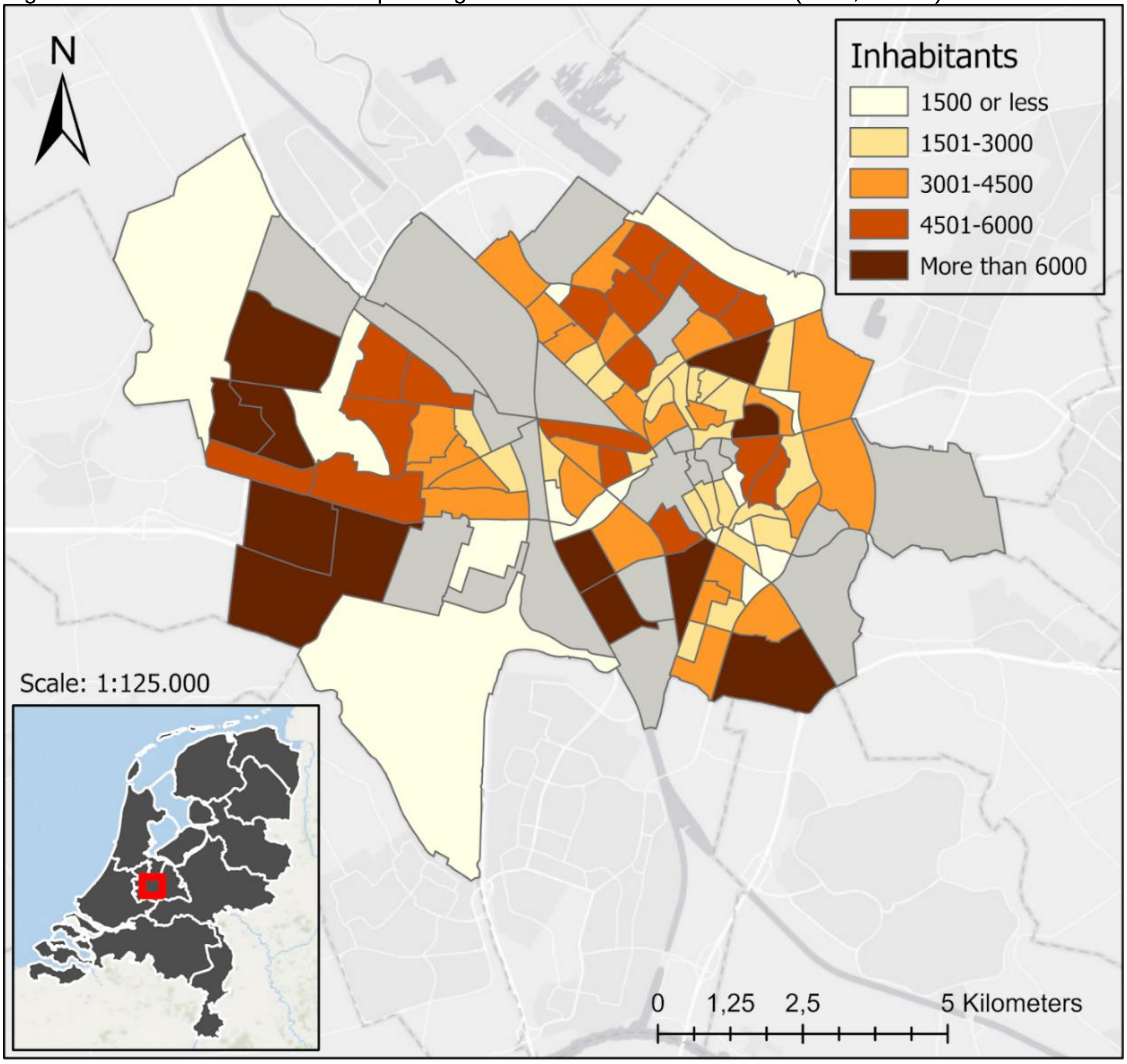
Figure 5.2: Average final scores of the socio-economic variables per neighbourhood in Utrecht in 2018. Based on CBS (2017, 2018b).



5.2.3 Inhabitants

The distribution of inhabitants is the neighbourhoods in Utrecht varies. In total the municipality of Utrecht houses 347.483 inhabitants. After removing the non-residential neighbourhoods, a total of 327.060 inhabitants remain in the research area. With an average of 3.634, and a high of over 9.000 and a low of 135, differences are big. The number of inhabitants per neighbourhood are listed in Appendix A and shown in figure 5.3. The neighbourhoods with the larger number of inhabitants are generally the larger neighbourhoods in terms of size. The number of inhabitants is a basis on which the MCE will be executed. The inhabitants are of influence on the outcomes of the MCE because the eventual number of charging stations is computed using a multiplication of the score (figure 5.2) and the number of inhabitants. Every inhabitant has a likeliness to own an EV in the (near) future based on the average score the neighbourhoods has. In addition, it serves as a means of control what the impact of the socioeconomic variables is.

Figure 5.3: Number of inhabitants per neighbourhood in Utrecht in 2018 (CBS, 2018b).



5.2.4 Prospects

In order to allocate the V2G charging stations it is necessary to anticipate on the expected number of EVs in Utrecht. This research makes use of three scenarios of 2025, 2030 and 2035. As if 2030, all newly sold cars must be sustainable, so no ICE cars anymore (Rijksoverheid, n.d). At the time of writing there were two available prospects. Elaad Outlook (2019) is a nationwide calculation based on an S-curve model approximating the expected number of EVs in the future scenarios named above. Another prospect is retrieved from a policy document of the municipality of Utrecht: Utrecht laadt op voor 2030 (Kok, 2018). The results of these prospects are listed in table 5.2 below. A difference between the prospects is that the Elaad Outlook approximates the number of EVs, whereas the municipality of Utrecht lists the number of expected charging points (please note, a charging point is the a connections, whereas charging stations can have multiple charging points).

This research is conducted, based on theories concerning global warming and the need to reduce emission of greenhouse gasses. In addition, the estimates by the municipality of Utrecht are more precise and retrieved by the municipality itself. By using the municipality based estimates, a possible misunderstand concerning the definition of EV, as explained on page 7, is avoided. The “high” scenario in table 5.2 will therefore be the input for the MCE.

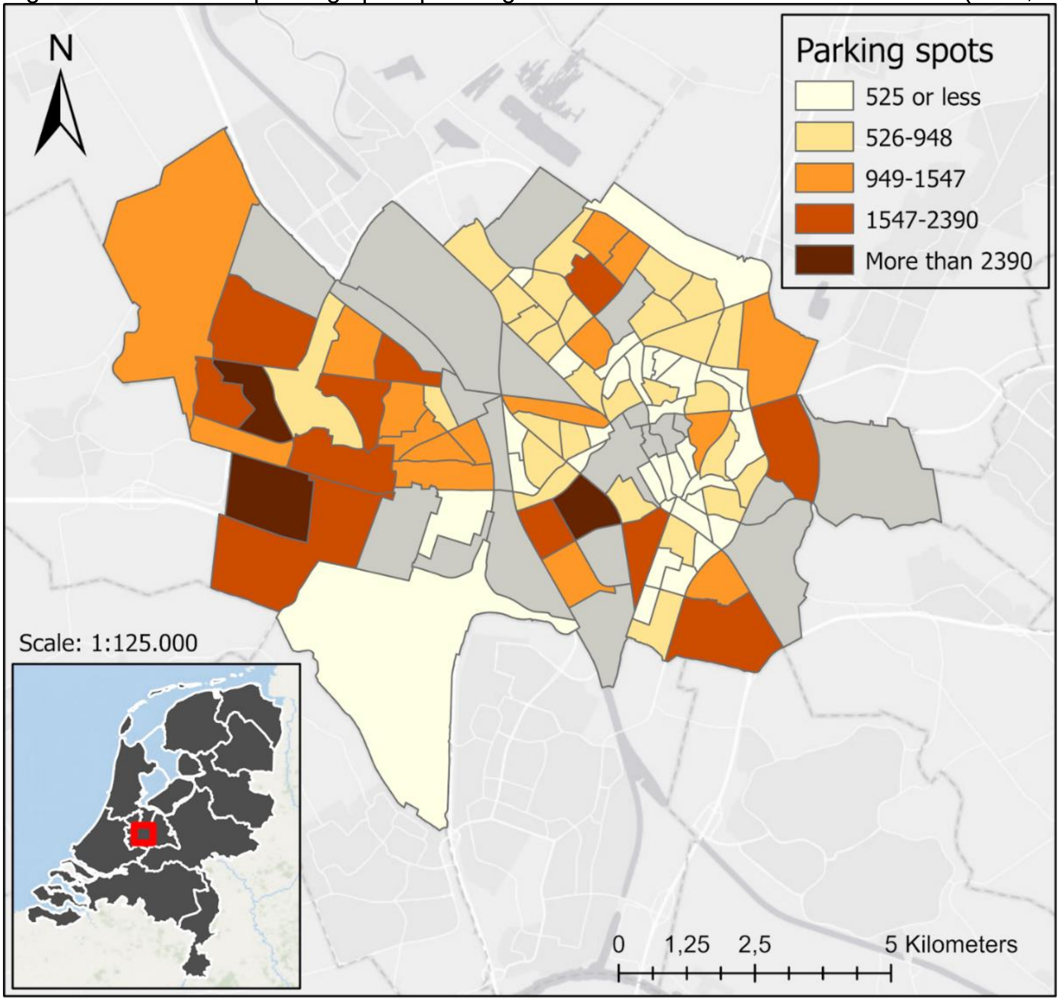
Table 5.2: Prospects by Elaad and municipality of Utrecht.

Source	2025	2030	2035
Elaad Outlook (2019)	10.000-20.000	20.000-30.000	more than 30.000
Municipality of Utrecht, normal (2018)	2.764	8.989	14.920
Municipality of Utrecht, high (2018)	11.132	20.835	27.915

5.2.5 Parking

If the allocation is completed, the number of charging points must be placed in public space where cars can be parked. Therefore, the number of parking spots per neighbourhood is estimated based on a series of input data. The charging stations must not be placed too far from residential dwellings. The municipality of Utrecht uses a rule of thumb where the distance limit is set at 200 meters (Gemeente Utrecht, n.d. a). All parking spots of a maximum of 200m from a residential dwelling are included. The estimation of the number of parking spots is done using NEN 2443:2013 which is a guideline for parking and roads. The average public parking spot size of both angled and square parking. This is 12,9 m2 per parking spot. The parking spaces are retrieved from the BGT (CBS, n.d.). Note that road side parking is not included in the data. The results are listed in Appendix A and shown in figure 5.4. The average number of parking spots per neighbourhood is 908, but the differences are large. The lowest number of parking spots is found in Halve Maan-Zuid with 76 spots and the largest number is in Transwijk-Noord with 3.892 parking places. The estimates of the to be placed charging stations compared with the parking availability are discussed in paragraph 5.3.4.

Figure 5.4: Available parking spots per neighbourhood in Utrecht. Based on BGT (CBS, n.d.).



5.3 Allocation

The basic data on which the allocation is based are displayed and explained in the previous subchapters. The next three paragraphs will be dedicated to distribute the V2G charging stations throughout the selected neighbourhoods in Utrecht. Firstly a calculation on how many EVs are needed to provide enough energy for common use. Secondly the distribution of the control group, the inhabitants, is displayed and explained. Finally the outcomes of the distribution of V2G charging stations based on the socio-economic variables is displayed. Differences between the control group and the MCE results will be discussed as well. In the appendices A through E, additional information is found. The subjects are referred to in the text but hold extra information about the who paragraph.

5.3.1 V2G prospect and calculation Map

One of the objectives of this research is to use V2G because of two of its main benefits. Firstly, it aids in relieving grid pressure and secondly because EV batteries can be used as temporary energy storage. As explained in chapter 3, there are multiple ways in how this storage could aid the existing system. An estimation of the number of needed EVs is made to assist the energy use of Utrecht. This is based on a graph provided by Van Sark & Van der Ree (2019) and the energy use derived from Staat van Utrecht (n.d.). In the municipality 1.411.713.000 kWh is used in 2016, equal to an average of 3.867.706 kWh per day. The use by the households is lower, with approximately 2560 kWh per year per household. This means that, looking at residential areas only, a total of 418.854.400 kWh is used annually for all 163.615 households. On a daily basis that relates to an average of 1.147.546 kWh. The average BEV battery has a capacity of 58,5 kWh (Electric Vehicle Database, 2019). So for a full day of energy consumption, a total of 19.616 fully charged cars are needed to provide enough power for all households. This is not a realistic nor preferable scenario because a 100% discharge is not good for battery life (Noel, 2019). However, this shows that in the extreme case, st ill a relative small number of EVs could already provide a significant amount of energy.

A more realistic scenario is on a winter’s day where the power demand peak in the Netherlands is after sunset, so PV’s do not generate any energy. The power demand is approximately 50% higher than the average demand, estimated on 71.721 kW. If the charging stations allow for a 7 kW discharge rate, a total of 10.245 V2G connected cars would sustain. Another approach would be the energy consumption in this winter’s night which is about 50% of the total households energy use. So a total of 573.773 kWh is needed which could be provided by 19.616 average capacity EVs, but only discharged for 50% to prevent battery degradation. These figures are estimated based on current day energy use. The households energy use is expected to increase. This partially due to electric driving (Gerritsma, 2019). The energy consumption and therefore the number of required EVs connected to the grid will be higher. The calculations above show that a day of energy generation and storage in the EVs has enough potential to provide a full night of energy without causing energy degradation. Related to the prospects shown in table 5.2, if all of the charging stations are V2G capable, there would be a sufficient number of V2G charging stations in Utrecht to relieve grid pressure, prevent costly ancillary services and prevent energy waste due to overproduction because of the intermittent nature of renewable energy sources.

5.3.2 Allocation based on inhabitants

The prospect discussed in 5.2.4 are distributed throughout the research area. The three selected prospects are listed in table 5.3 below. The first method of distributing the charging stations is based on the inhabitants of the neighbourhoods. So in these three cases the likeliness of an inhabitant to purchase an EV in the (near) future is equal and the distribution is based on only one variable. This is calculated by multiplying the total number of to be placed charging stations with the share of each neighbourhood by the share of inhabitants of the total inhabitants stock. This for all three prospects results in three different outcomes.

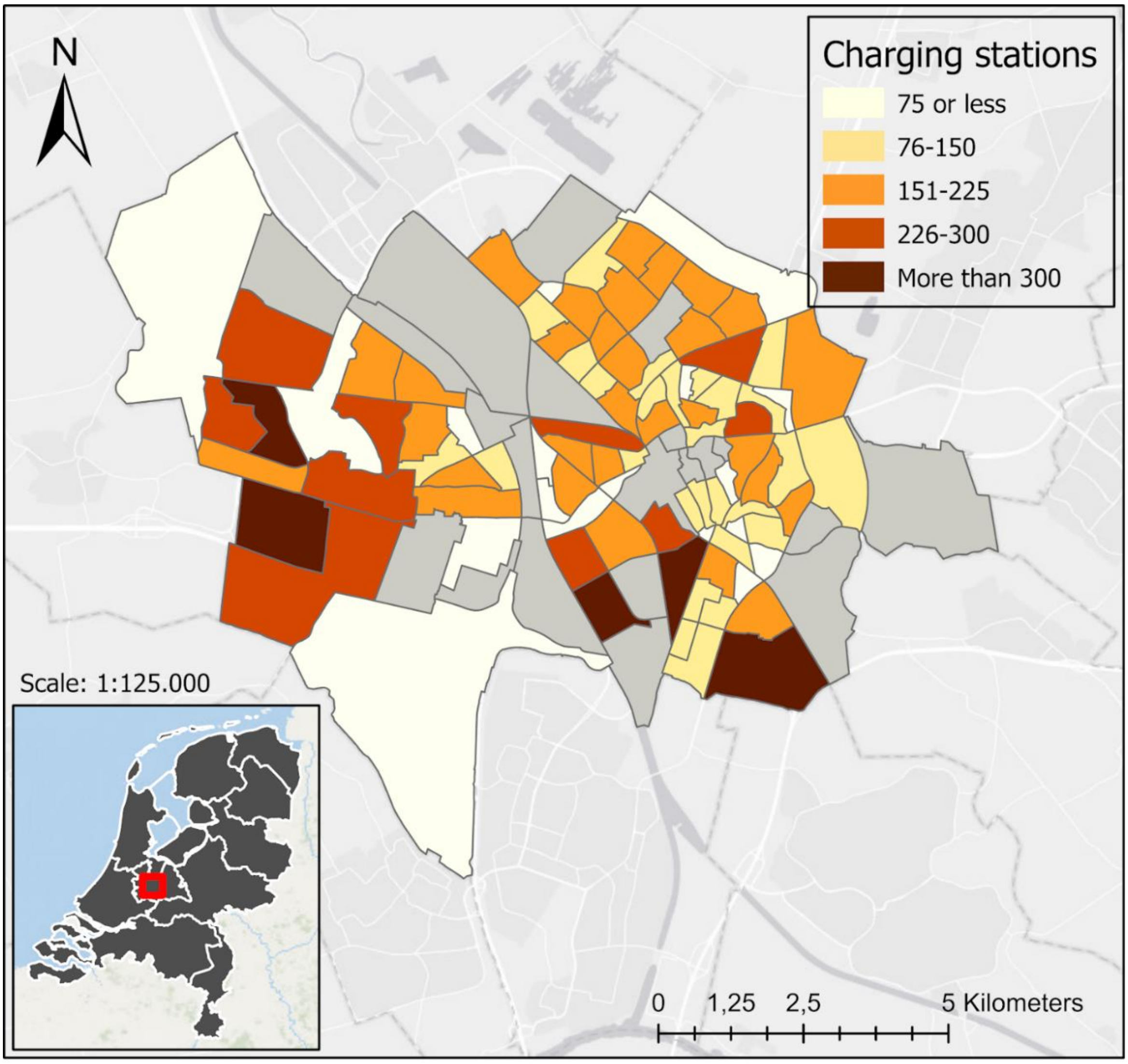
The results shown in figure 5.5 are the results for 2035 and visualize the outcomes of the allocation based on the number of inhabitants. The other two prospects can be found in Appendix C. The numbers of V2G charging stations per neighbourhood are derived from the number of prospected EVs per neighbourhood which are listed in Appendix E. The number of inhabitants is listed in Appendix A. The outcomes of figure 5.5 show a similar pattern as figure 5.3 above, the map showing the distribution of inhabitants. This is caused by the fact that it is a recalculation of the number of inhabitants and is lowered to fit the number of prospected charging stations. The number of charging points is the prospected number of EVs divided by two, because a standard charging station has two connections. The neighbourhood with the most charging stations is Terwijde-Oost, with 403 V2G charging stations to be placed in 2035. This is due to Terwijde-Oost being the neighbourhood with the most inhabitants. The lowest number of charging stations is placed in Langerak, with only 6. On average, the neighbourhoods get 155 charging stations, and combined result in a total of 13.985. This is half the number of the 27.915 expected charging points in 2035.

There is a series patterns noticeable. The first one being that the size of the neighbourhood generally influences the number of charging stations. The larger the neighbourhood is, the more charging stations are allocated. In addition, there are three neighbourhoods with peripheral characteristics. The BAG dwellings show hardly any built-up areas and for their size there are only few inhabitants. The neighbourhoods with more high rises in Kanaleneiland, Transwijk and Overvecht have higher numbers of charging stations appointed to them, whereas these are relatively small neighbourhoods.

Table 5.3: Prospects of expected charging points in Utrecht

Year	Expected charging stations
2025	11.132
2030	20.835
2035	27.915

Figure 5.5: Allocation of V2G charging stations based on inhabitants per neighbourhood in Utrecht in 2035.



5.3.3 Allocation based on socio-economic scores

This third subchapter holds the final results of the research and analyses and interprets the outcomes in three different ways. Firstly, the V2G charging station allocation for all three future scenarios are shown and described. The numerical results can be found in appendix E. Secondly, the results are compared to the control group where only the number of inhabitants is of influence on the allocation. This is done to underscore the importance of the socio-economic variables on the allocation outcomes and to come to a better understanding of the data. Finally, the data are compared to the parking availability to analyse if some neighbourhoods might experience pressure on the existing built environment. Due to missing values, Rijnvliet and Rijnenburg have been excluded from the analysis and interpretation below.

5.3.3.1 MCE 2025

The scenario in 2025 with the allocation of the V2G charging stations is visualized in figure 5.6. The total of 5.562 charging stations seems to be evenly distributed throughout the research area. Since inhabitants are a leading part of the MCE, the neighbourhoods with many inhabitants still receive a large number of charging stations and vice versa. The differences between the neighbourhood with the highest number of allocated charging stations, Veldhuizen with 168 in 2025, and the lowest, Poldergebied overvecht with 4, is relatively small. With an average of 62, these number do not differ much. 64 of the 90 neighbourhoods get less than 75 charging stations and only two of them receiving more than 151. For both these neighbourhoods the number of charging stations is mainly caused by the large number of inhabitants, as their average scores are only slightly above average.

Figure 5.7 shows the difference between the control group based on solely the inhabitants and the allocation based on both inhabitants and the socio-economic variables for the scenario of 2025. The blue colours are neighbourhoods where the MCE allocate more V2G charging stations, whereas the orange neighbourhoods have fewer charging stations allocated. The white areas only show minor differences with a total of 10 or less. In the scenario of 2025 the differences are not extreme and are below 25. There is a total of seven neighbourhoods which show higher numbers and seven neighbourhoods which show a lower number of allocated charging stations. The neighbourhoods which show a significantly higher allocation number all have an average grade well above 6, almost one mark higher than average. They generally score high in the variables work and big households and at least one high score at either education or income. In addition they initially had around 100 charging stations allocated based on the inhabitants only, which increases rapidly if they have a good socio-economic score. As for the neighbourhoods which receive a lower number of V2G charging stations based on the scores of the socio-economic factors, five out of seven are found in Overvecht. They are among the neighbourhoods with the lowest grades on high income, where none of them reaches above “2”. Education is very low as well. On the other grades they generally do not score high what leaves their averages among the lowest. In combination with a high number of inhabitants, the difference between the two methods expands rapidly.

Figure 5.6: Allocation of V2G charging stations based on the MCE per neighbourhood in Utrecht in 2025.

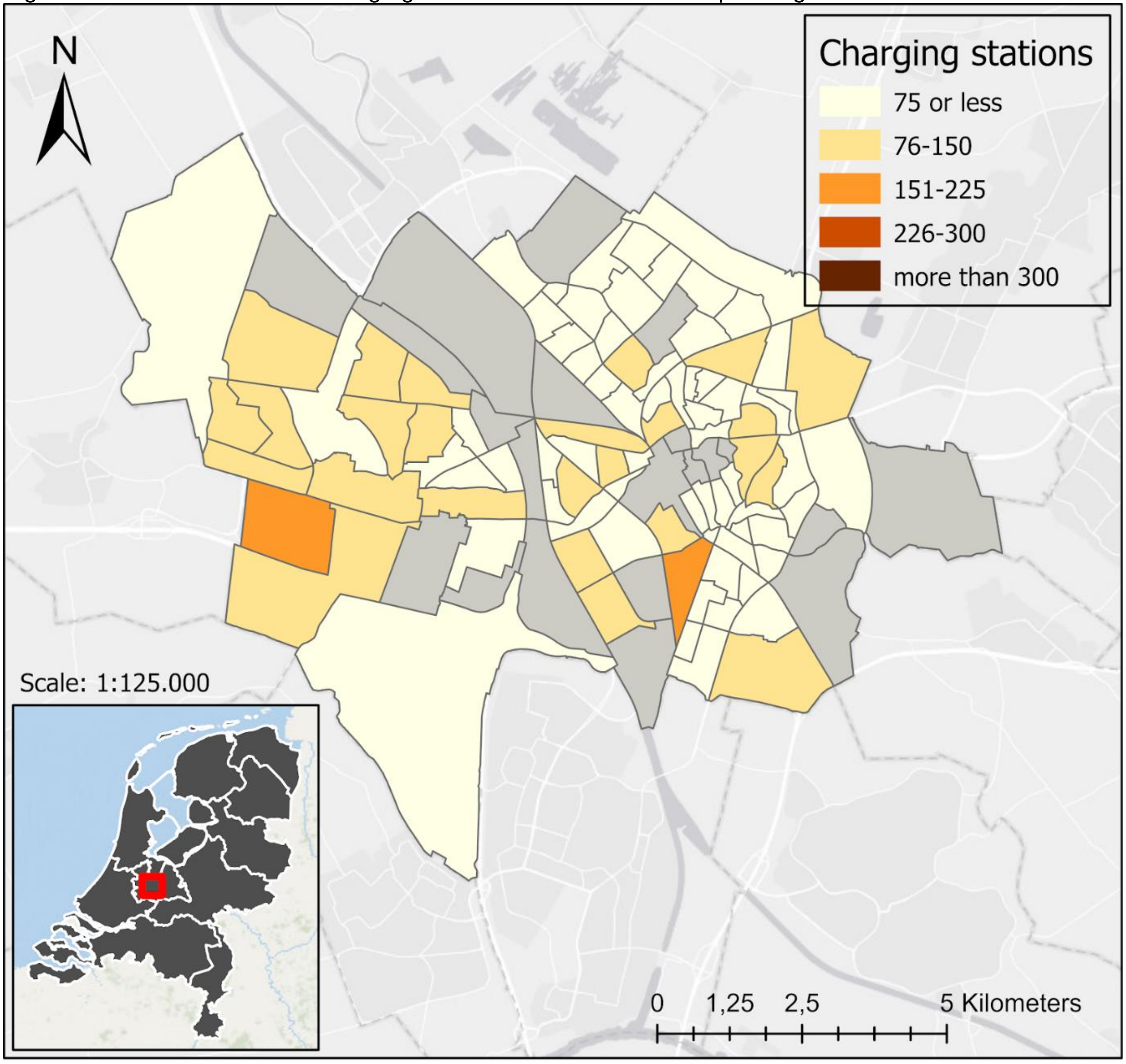
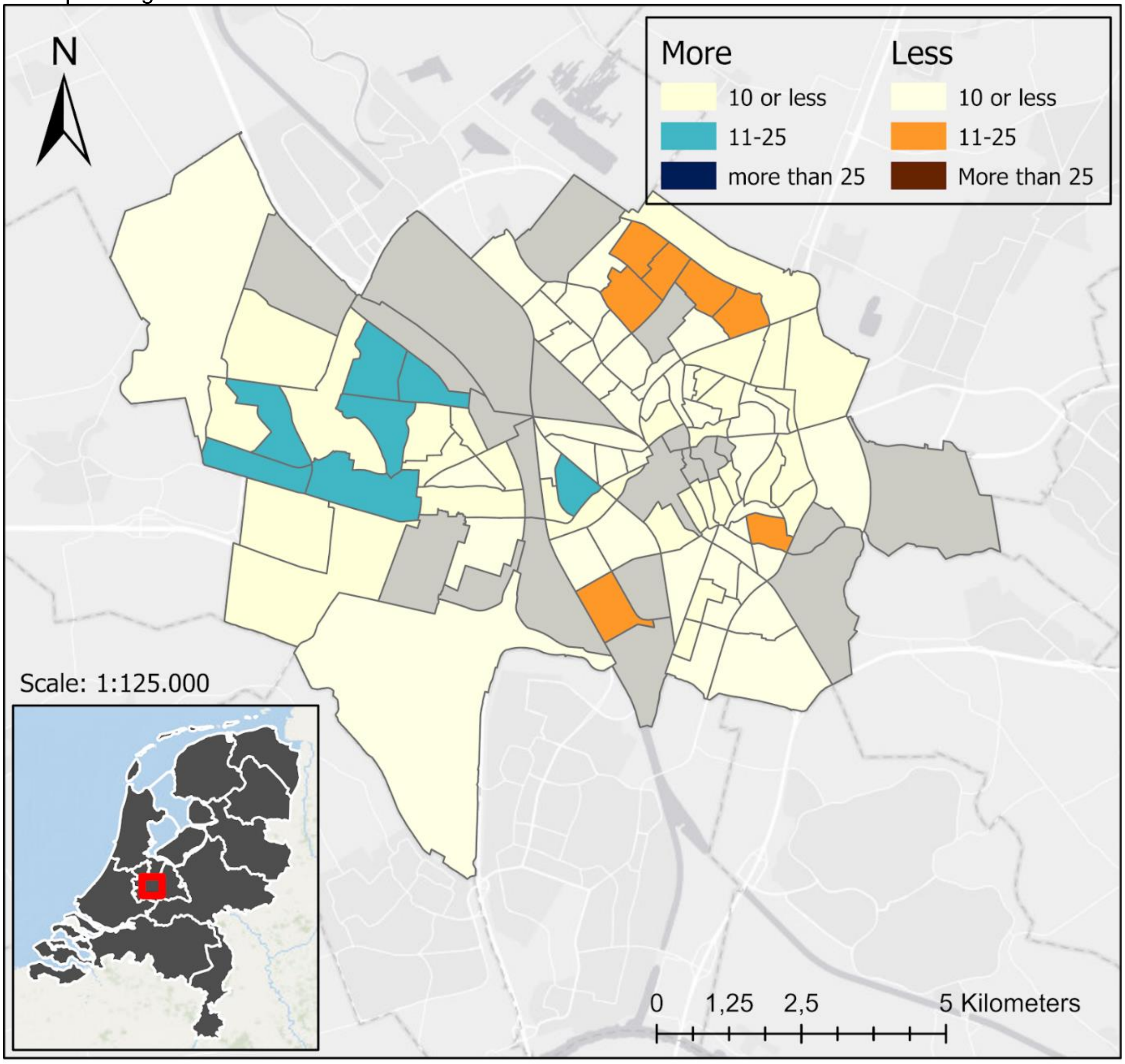


Figure 5.7: Differences between the allocation method based on inhabitants and the outcomes of the MCE per neighbourhood in Utrecht in 2025.



5.3.3.1 MCE 2030

When looking at the prospects in 2030, larger local differents start to emerge. The V2G charging stations shown in Appendix E indicate that the increased expected number of EVs leads to a more differentiated allocation of V2G charging stations. The outcomes are visualized in figure 5.8. The number of neighbourhoods with less than 75 V2G charging stations allocated is decreased to 28, whereas the difference between the lowest, Poldergebied Overvecht with 8, and highest, is Veldhuizen (just as in the 2025 scenario) with 315. The average number of the to be placed charging stations increased from 62 in 2025 to 116 in 2030. This is more than double the number of charging stations compared to only five years before. That means that in some neighbourhoods a rapid development of these stations must be realized in order to achieve the set number. The map in figure 5.8 shows that the neighbourhoods with a higher number of inhabitants generally have more than 75 allocated charging stations. Both the table and the figure show that the allocation is closely related to the number of inhabitants.

However, figure 5.9 does show that there are significant differences between the allocation based on the control group, the inhabitants, and the MCE outcomes. The socio-economic variables are magnified by the number of inhabitants and show a pattern in Utrecht. The method using the generally positive socio-economic variables favours the neighbourhoods where these are generally higher. So Overvecht and Zuilen will be lagging behind the Utrecht average more in 2030 whereas the neighbourhoods with more kids and higher education in the west of Utrecht show increased values. This pattern is amplified by the increased prospected number of charging stations.

Figure 5.8: Allocation of V2G charging stations based on the MCE per neighbourhood in Utrecht in 2030.

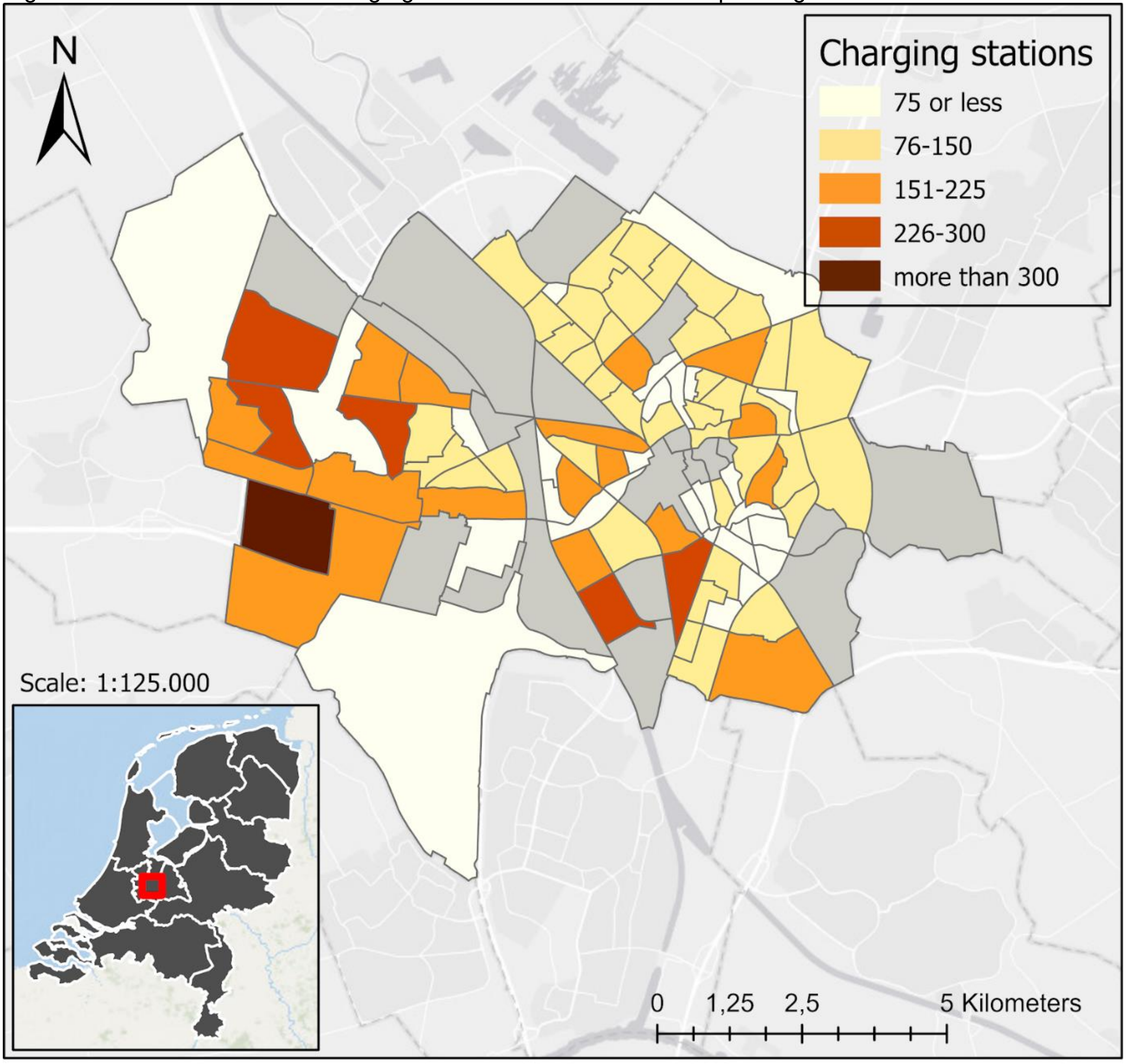
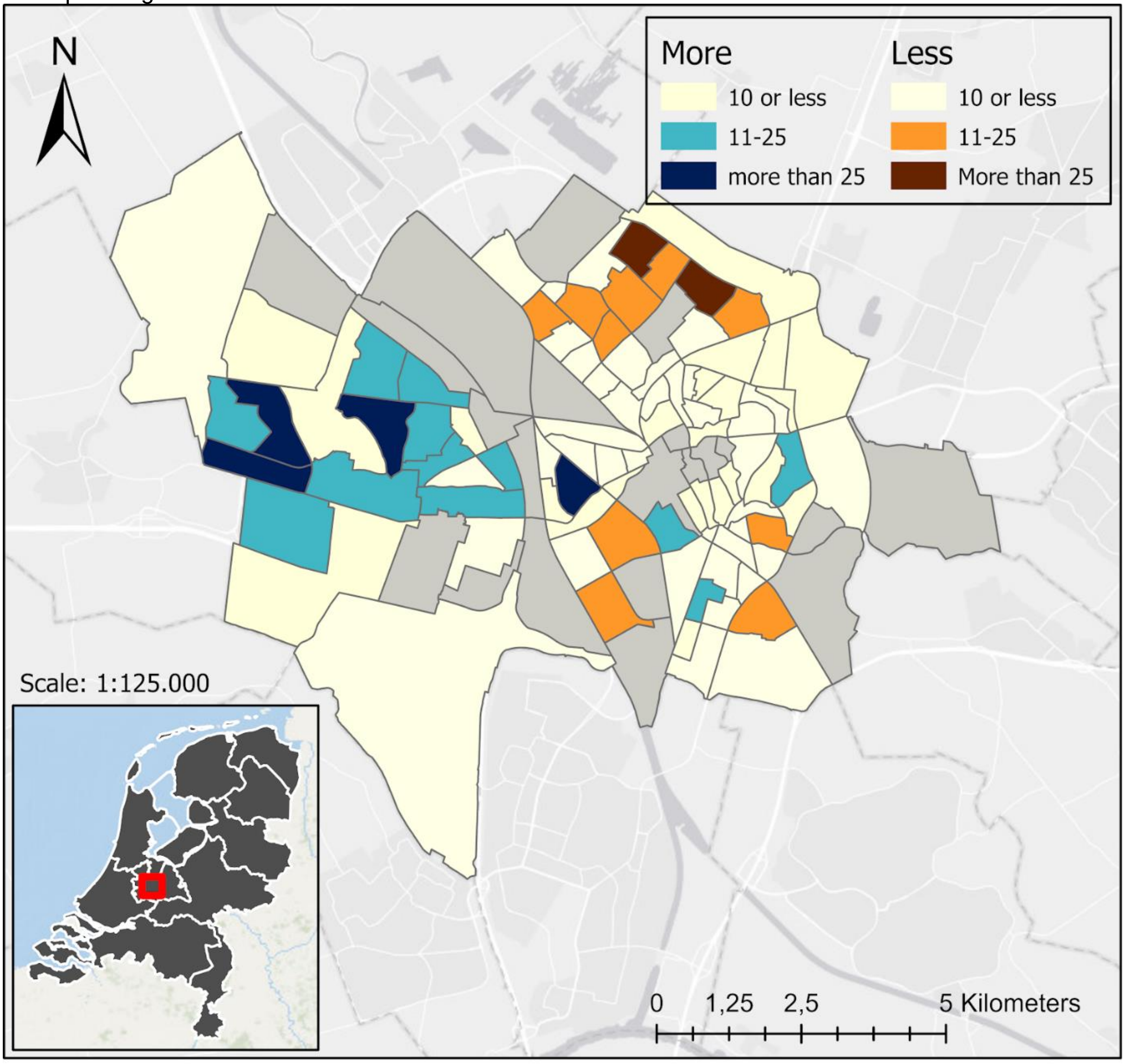


Figure 5.9: Differences between the allocation method based on inhabitants and the outcomes of the MCE per neighbourhood in Utrecht in 2030.



5.3.3.1 MCE 2035

Finally the most extreme outcomes of the MCE are the combination of the selected variables combined with the 2035 prospect where 27.915 charging points are predicted. Figure 5.10 visually shows similarities with the figure 5.3 on page 29, with some exceptions. The neighbourhoods with only few inhabitants remain below 75 charging stations per neighbourhood, even with almost 14.000 divided over the 90 neighbourhoods. There are 19 neighbourhoods with such low numbers, where the lowest will only have 11 charging stations in the neighbourhood. This is partially related to the number of inhabitants or the low number of inhabitants in combination with a low average score. With an average of 155 per neighbourhood, there are 13 neighbourhoods which have significantly more with over 250 charging stations. These are mainly found in the western neighbourhoods and in the south. All of them have more than 5.500 inhabitants and have average or above average grades.

As the total number of prospected EVs increases, so do the differences between the neighbourhoods. The number of inhabitants remains a significant factor in the allocation of the V2G charging stations. The last map in figure 5.11 shows the socio-economic differences in Utrecht and how they influence the distribution of V2G charging stations. Where the differences between the neighbourhoods positively influenced neighbourhoods in blue and negatively influenced neighbourhoods in brown were only marginal in the prospect in 2025 (figure 5.7), the differences in 2035 are more evident. It seems that there is a clear distinction between the more wealthy neighbourhoods and the less wealthy. As in 2025 and 2030, the neighbourhoods in and around Zuilen and Overvecht show large differences of up to 44 charging stations less than the control group. For example in Neckardreef en Omgeving and Tigrisdreef en Omgeving, both in Overvecht, that is more than 20% less. On the other hand, the neighbourhoods with higher incomes and higher educations, who are more likely to buy an EV are encouraged even more by purchasing an EV if more is invested in the V2G infrastructure.

Figure 5.10: Allocation of V2G charging stations based on the MCE per neighbourhood in Utrecht in 2035.

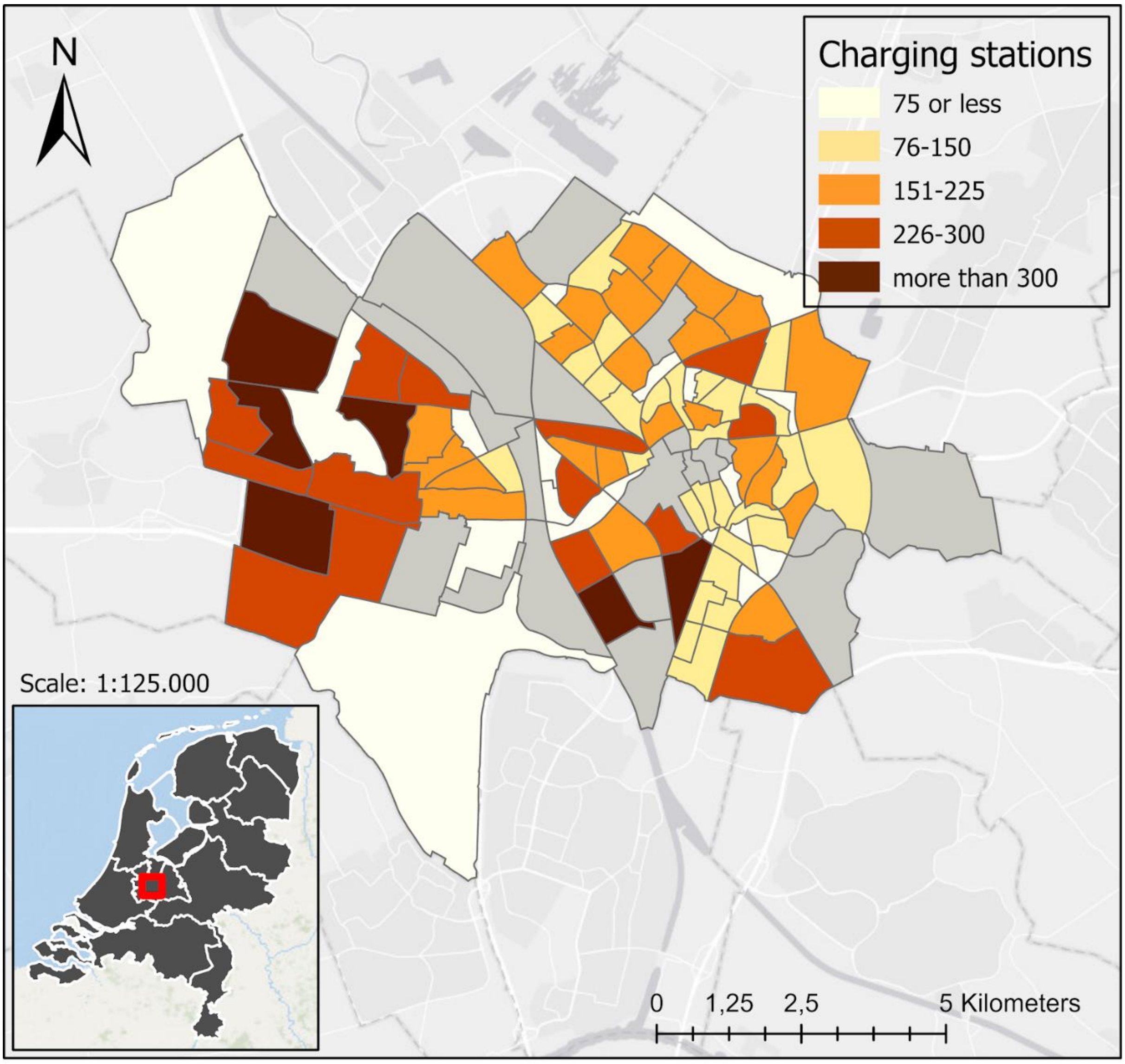
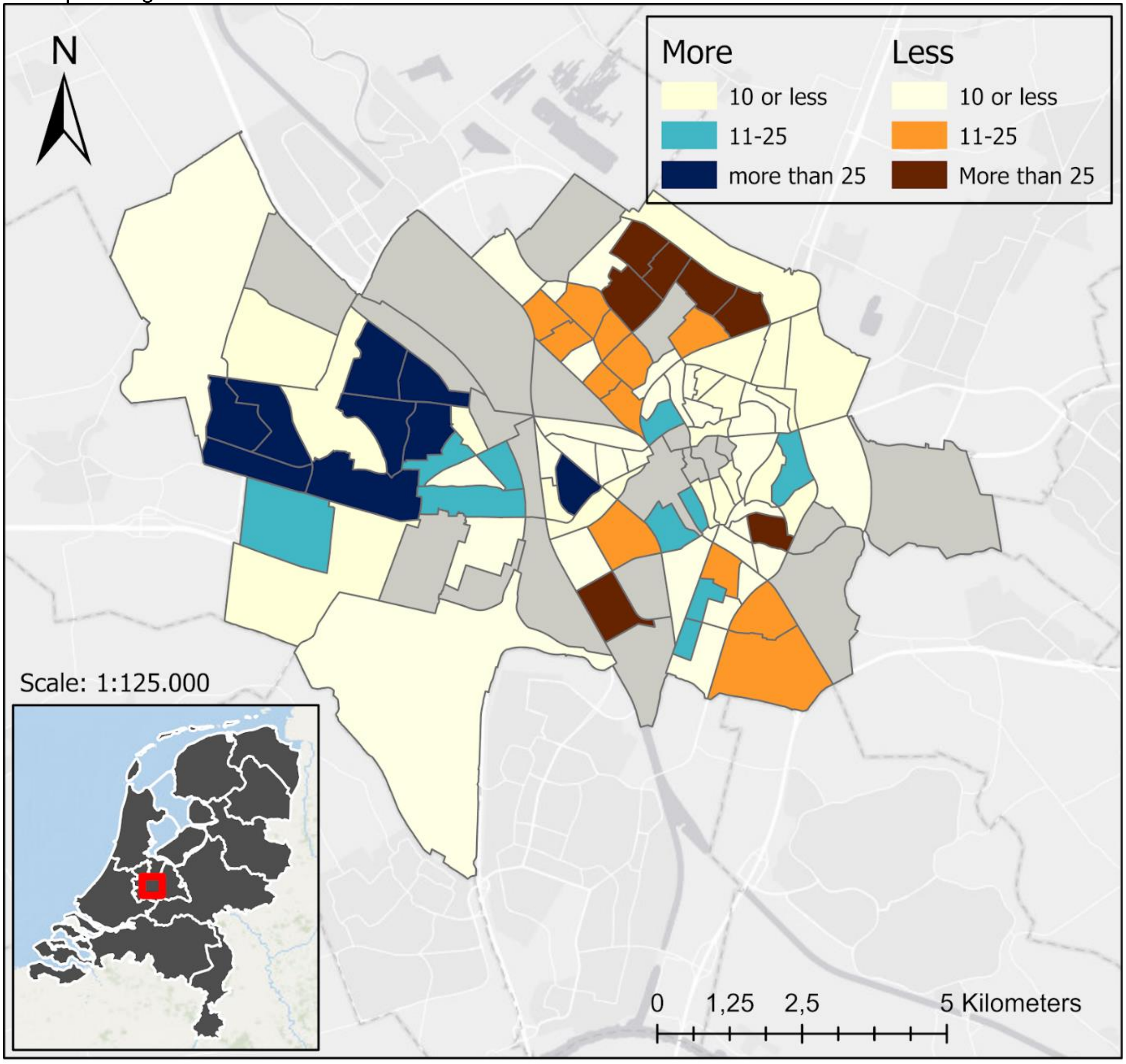


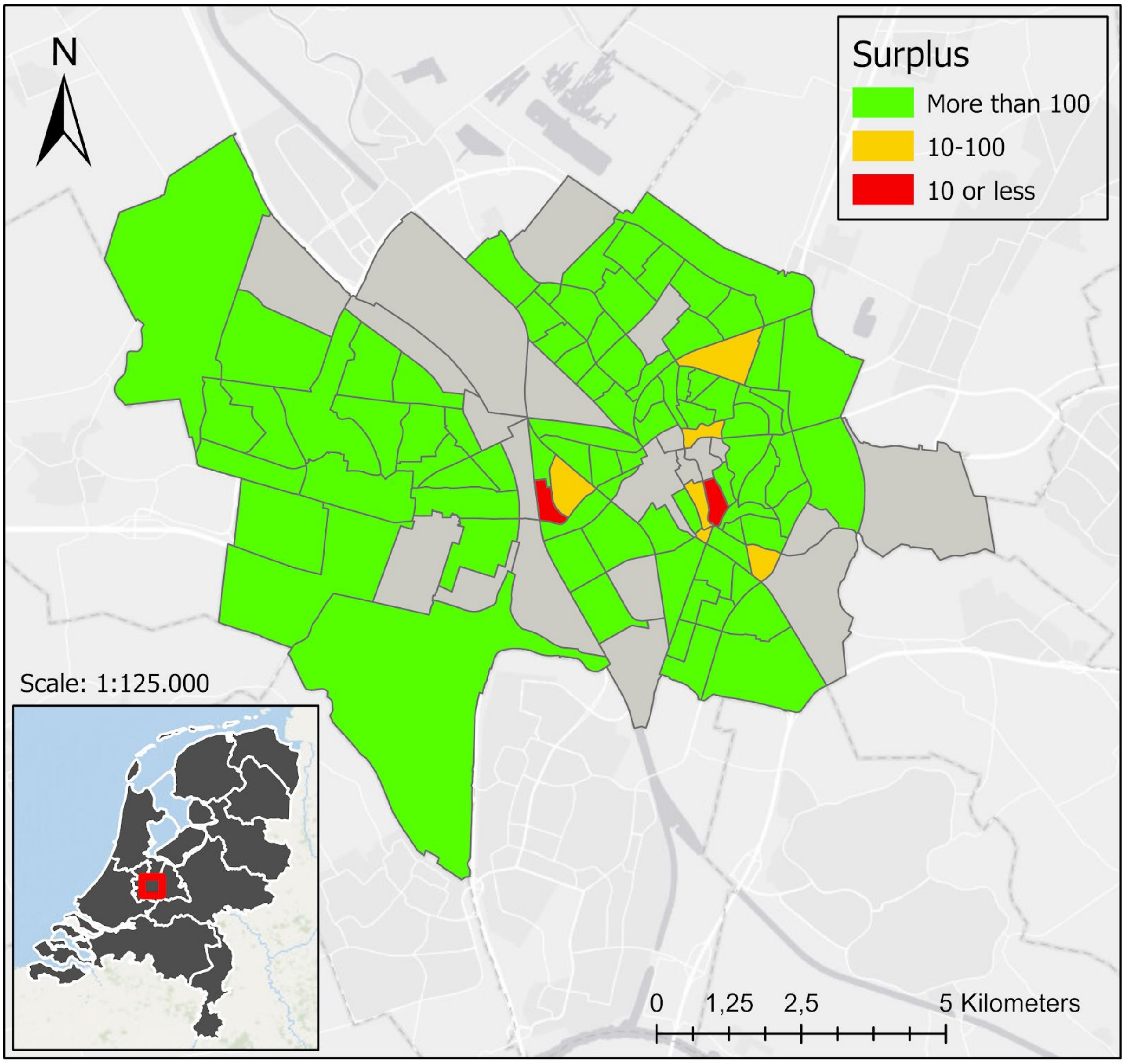
Figure 5.11: Differences between the allocation method based on inhabitants and the outcomes of the MCE per neighbourhood in Utrecht in 2035.



5.3.4 Parking availability

The implications which are made by appointing a number of V2G charging stations to the neighbourhoods has a series of spatial consequences. The most direct of these is the availability of public parking spots. For the scenario in 2035 based on the MCE, the number of charging points was compared with the abundance of public charging spots. Note that roadside parking areas are not listed as parking spots as they are part of the public road. These are not listed in the data set by the BGT (CBS, n.d.), so excluded from the calculation. Figure 5.12 shows the differences between the calculated number of required parking spots for the V2G charging stations and the calculated available number of parking spots. It shows that there are only two neighbourhoods where problems with the parking availability is expected in 2035, and another five neighbourhoods where pressure of placing the V2G charging stations may emerge. Based on a combination of the BGT (CBS, n.d.) and satellite images of Google Maps (2020), both Halve Maan-Zuid and Lange Nieuwstraat en omgeving do not have many allocated parking spots. In Halve Maan-Zuid there is an abundance of roadside parking. The neighbourhood Lange Nieuwstraat en omgeving is located in the city centre where roadside parking is not always allowed. Based on the calculations, 100% of the available parking spaces will need to be reserved for EVs in 2035, and still it may not be enough. The municipality may need to review their parking policy on this subject in this particular neighbourhood.

Figure 5.12: Surplus of parking availability compared to the allocated number of charging points in the MCE.



5.4 Overview

The analysis chapter contains the results of the research. This subchapter reviews the most crucial outcomes and foresees them of interpretation, and discusses the results. Based on the analysis of the used theories and technical details in paragraph 5.1, there are no real threats to the development of V2G in Utrecht. The downsides are the fear of technical issues with the user which and partially a cause of not knowing how many people are interested in using the system. In other words, the participation grade is unknown. On the other hand, the progressiveness of the municipality of Utrecht shows that actively participating in the field of legislation and subsidies is covered for. All in all, there are no real threats to the development of the system. However, increasing consumer knowledge is key in making the system function. There are possibilities to increase consumer awareness, so if the V2G system is implemented, sharing knowledge must be considered as part of the implementation process.

Based on the socio-economic variables of influence on the likeliness to purchase an EV in the (near) future found by Sovacool et al. (2018) a pattern became clear. As the MCE outcomes and differences between the control group and scale up over time between the prospects of 2025 and 2035 these patterns intensify. Figure 5.2 on page 28 and figure 5.11 on page 39 clearly show that the socio-economic variables by Sovacool et al. (2018) seem related to the Vogelaarwijken: Kanaleneiland, Overvecht, Ondiep en Zuilen Oost. These are neighbourhoods labelled as deprived in 2007 by minister Ella Vogelaar, hence Vogelaar-neighbourhoods (Van der Lucht, 2007). As other variables which do not relate to work, income or education are included as well, the outcomes still show a pattern which resembles the socio-economic status of the different neighbourhoods. This means that when the outcomes of the MCE are realized the inhabitants of these four Vogelaar-neighbourhoods are disadvantaged. As V2G is explained as a chance for EV users to decrease overall EV costs and benefit from the storage in their batteries, as explained in chapter 3, inhabitants of the neighbourhoods with the lower scores might end up not benefitting from driving electric. Although the differences in allocation, for better or worse, especially the neighbourhoods with high populations still get a lot of V2G charging stations allocated.

The number of calculated EVs needed to provide a significant storage capacity or to participate in other means of ancillary services, the calculation made in paragraph 5.3.1 shows that a number of 10.000 EVs could already eliminate the peak power consumption or a number of around 20.000 EVs to cover the a full winter night's use. If all new charging stations which are to be placed from 2020 onwards are V2G capable, a timespan of approximately 10 years would be sufficient to provide for around 100% of current day electricity use.

Finally, the implementation of V2G seems feasible in most of the neighbourhoods in terms of parking availability. This is not seen as an obstacle.

A data check has been executed to explore to what extend the outcomes of the research are influenced by the number of inhabitants a neighbourhood has. The null group was used to verify how much of the results of the MCE are caused by the number of inhabitants. The outcomes are shown in the table in Appendix E.2. As the results above show, there is a large influence of the number of inhabitants. On average, 91,5% of the scores is based on the inhabitants. The neighbourhoods with lower dependence percentages are the neighbourhoods with either high or low average scores. In other words, using this method, the influence of the socio economic variables is 8,5% on average per neighbourhood.

6. Conclusion

Chapter 6, the conclusion, summarizes the outcomes of the research. It will overview if the objectives are fulfilled and finally answer main the research question. This answer comes through combining the answers of the four sub-questions. This is also the structure of the conclusion chapter.

SQ1: What are crucial preconditions in order to implement Vehicle to Grid in Utrecht? Implementing the V2G system is subject to many preconditions in order to make it work. One of the main reasons is that it involves large numbers of participants and could be a large scale system. It has the potential to relieve the contemporary and future grid pressure, lower energy costs due to the use of ancillary services and acts as a flexible energy storage. It could stimulate the use of renewable energy sources and ultimately that may lower the energy prices. However, due to the complexity and the scale of V2G as a municipality wide system, there are several preconditions which must be in place. These preconditions can be divided into different categories. First of all, the EV must be able to discharge back to the energy network, and allows for communication. This is the VSL chip and is relatively cheap to install. The two main additions to EVs which do not have these yet are the chip which meters the flow of energy in and especially out of the battery of the EV. The other is that the car must physically be able to discharge by the charging station by placing a socket which is capable of doing this.

Secondly there are several technical preconditions. Firstly, the charging station must be able to discharge the car. Since these stations are not available publicly yet, this precondition is not met and is the subject of this research. Other technical challenges such as battery degradation, energy efficiency of the system and data security are challenges to cope with. However, as the actual risks are not significant and/or solutions are available and feasible, the precondition of technical feasibility is met as well.

Finally there is a precondition that the involved parties participate with the V2G system. The most crucial participant is the EV owner. He/she must allow for their EV battery to be used for temporary storage. This asks for flexibility, may have technical drawbacks such as battery degradation and consumers are not knowledgeable in the matter of V2G. On the other hand, the participants will receive financial compensation and spreading information about V2G helps to mitigate the fear of technical issues for the participants. Because of the novelty of the system, it is not known what a reasonable participation grade is. However, due to the different solutions and financial benefits for the participants, it is assumed that participants are willing to join V2G.

The network operator must be willing to participate as, in the current system, they are responsible for arranging ancillary services. The precondition of them to participate is feasible because they benefit financially because V2G is a cheaper ancillary service and the urgency to invest in new energy infrastructure is relieved.

The role of a public aggregator needs to be in place to arrange the logistics. Communication between actors, flow of money and possibly financing and installing the charging stations are their role. This role must be claimed by either a third party or the municipality or a combination. This precondition is not met, but as the municipality is currently involved of other V2G developments, it is assumed that this is not an insurmountable step in the process. Due to the current participation of the municipality, the precondition of the governing body to allow for V2G development is met as well.

All in all, the preconditions to start with V2G in the municipality of Utrecht are met, except for the bidirectional charging stations and the aggregator. By answering this sub-question the first objective is fulfilled

SQ2: How can the distribution of future EV ownership be calculated for the residential neighbourhoods in Utrecht?

The distribution of future EV ownership is based on the likeliness of inhabitants to own an EV in the (near) future. In this research that likeliness is based on socio-economic characteristics of the neighbourhood. Seven different variables indicate that a person is more likely to be interested in, or own an EV in the (near) future. These are: elderly people, young adults, people who are employed, larger households, men, people with high income and people with a high education. These data on a neighbourhood level were combined into scores for every neighbourhood with more than 20% residential dwelling surface. This resulted in a map and table indicating the score each person in the research area has to own and EV in the (near) future. This is the basis of a calculation on how the distribution of EV ownership can be prospected. This relates to the second objective, define suitability and is fulfilled.

SQ3: What are the prospects for EVs and EV charging in Utrecht in 2025, 2030 and 2035? Two different prospects for EV use in 2025, 2030 and 2035 have been reviewed, containing a total of three different numbers per future scenario. This research used the prospect by the municipality of Utrecht for the high scenario because it was more actual than other sources. The prospects for 2025 was a total of 11.132 public charging points, in 2030 the municipality expects to need 20.835 and finally in 2035 the prospect a total of 27.915. This is the last data which needed to be collected so by answering this sub-question, the third objective is fulfilled.

SQ4: What can future spatial allocation of Vehicle to Grid charging stations in the municipality of Utrecht look like?

Finally the last sub-question translates the data to spatial representations. Based on the input data collected and computed as part of sub-questions one through three, the visualization of the data showed several patterns. The distribution is relatively even in 2025, but the differences expand rapidly towards the prospect in 2035. The number of charging stations is the prospected number of charging points divided by two for each of the prospects. These charging stations are allocated to the residential neighbourhoods based on the number of inhabitants and the likeliness variables. That resulted in a pattern where wealthier and more highly educated neighbourhoods in the city centre and the west of the research area relatively get more V2G charging stations allocated per neighbourhood compared to the generally poorer neighbourhoods which are the former Vogelaar-neighbourhoods. On the other hand, the number of inhabitants is an important factor in this research. Neighbourhoods with high number of inhabitants will get a large number of charging stations ~~appointed to them~~, no matter what the socio-economic characteristics of that neighbourhood are, and vice versa for neighbourhood with small populations. In this sub-question the last two objectives are fulfilled.

How are suitable locations within the municipality of Utrecht allocated to realize public vehicle to grid charging?

The combination of the sub-questions hold the answer to the main research question. The combination of literature research, data collection and (spatial) calculation lead to the answers to the sub-questions. So to conclude: the suitable locations within the municipality of Utrecht to realize public vehicle to grid charging are found and allocated by defining what suitable locations are to distribute the number of V2G charging stations found in different future prospects. Using multi-criteria analysis as a method the allocation of the charging stations was calculated. This resulted in a distribution that followed two clear patterns. On the one hand, the number of inhabitants resulted to be a leading factor in the number of allocated V2G charging stations, whereas disadvantaged neighbourhoods are generally less likely to own an EV and therefore have less chance to profit from the benefits of V2G charging compared to the average or more wealthy and educated neighbourhoods.

7. Discussion

The outcomes and interpretations in the preceding chapters are based on choices made during the research. The discussion will overview some of the outcomes and how different inputs or choices could influence the results of the research. The discussion is either based on the data or involves the scope of the research. Possible follow up research topics which involve some of the discussed topics as further research recommendations are suggested next, thereafter the research process is reflected upon.

7.1 Discussion of data

The data used in this research were all publicly available. These data sets were on a high detail level and held loads of different data concerning the inhabitants of Utrecht on a neighbourhood scale. The built environment was of influence on the parking availability per neighbourhood. The problem statement and the theory chapter referred to relieving grid pressure. The methodology chapter described a data set by Stedin (n.d.) about the energy infrastructure to add more importance to the neighbourhoods where grid pressure was higher. However, the data only contained information about the location of the main electricity cables. There was no information about the capacity, age or quality whatsoever. The missing data in this source caused the results to neglect the existing grid pressure and assumes that the V2G system provides a grid pressure relief for the whole research area.

Another data set which was not available due to time constraints held information about the locations of public charging stations in the municipality of Utrecht. This data set was to be used in many ways but could not. The data may have influenced the outcomes because it would have been used to test the variables by Sovacool et al. (2018). The outcomes of this statistical test could then be used to find out which of the socio-economic variables are more of influence than other, based on the existing charging station stock. These statistical outcomes could be used as a weight in the MCE. In addition, the predicted number of V2G charging stations is calculated from an expected total number of charging stations in Utrecht for the selected future scenario. This also involves replacing the existing stock. If the existing stock was retrieved from the data set, urgency of placing any type of charging station could be taken into account. So if a neighbourhood with currently a low number of charging stations would be appointed the average number of V2G charging stations by the MCE, on the short term it may be more urgent to appoint them more V2G charging stations in 2025 than neighbourhoods where currently a large number of charging stations is already present.

Another subject which influenced the outcomes is the actuality of the used data. As explained in the methodology, not all data sources had the same subjects. The CBS (2017) data set was more complete than the CBS (2018b) data set. That resulted in the use of two different years of collection and may influence the outcomes. Whereas the research by Sovacool et al. is published in 2018 and the used data concern 2017 and 2018, the results of the research are in line with the theories on which they are based. Since the development of data collection of EVs and the abundance of EVs is fast, the execution of the research could be redone with more actual data. However, based on the socio-economic variables in Utrecht, it is expected that the overall pattern of distribution does not change dramatically. However, neighbourhood populations may change and urban processes like neighbourhood development, studentification and gentrification to name a few, can change the socio-economic balance in a neighbourhood. Prospects for the municipality are available on a district scale, for example in Bevolkingsprognose 2018 (Gemeente Utrecht, 2018). These are on a different scale and recomputing these values was out of scope for this research. However, these changes could play a role in the dynamics of neighbourhoods and therefore the outcomes of this research.

7.2 Discussion of usability

Further use and application of the research methods and/or outcomes could be based on this research one on one. If it were to be applied, the users could, however, adjust the input variables to their own needs. Governing bodies, investors, entrepreneurs, businesses or others could have other insights in the importance of the variables. Based on other views, needs and policies, the input variables can be adjusted by adding weights in the MCE. Adding weights to the variables or adjusting the importance of the number of inhabitants by a weight changes the outcomes of the research.

In line with the importance of the inhabitants, the sensitivity analysis showed that a large share of the explanation of the allocation numbers is caused by the number of inhabitants. The chosen methods lead to these figures. The same data but a different approach in recalculating the end results from the scores would lead to other results. The regional differences would become either larger or smaller.

Another aspect which was not taken into account was that the municipality of Utrecht preferred clustering when appointing sites for charging stations in general (Gemeente Utrecht, 2019). The research did account for parking availability, but due to the content of the used data sets, retrieving possibilities for charging squares or other clustering possibilities were not taken into account.

Finally it must be noted that there were two neighbourhoods which had missing values. As mentioned in the results chapter, they are Rijnvliet and Rijnenburg. Their outcomes have been included in the final average scores. However, their missing values became a 0 whereas the other lowest values were 1. The outcomes became lower than they would have been when there were no missing values. In the interpretation of the results, they have not been included in the maximum, minimum or average scores. Another possibility to cope with this was to calculate the average scores of these two neighbourhoods based on the values that were available.

7.3 Recommendations

The outcomes of this research are not finite. As the discussion pointed out there are several points where future research can continue with the methods and outcomes of this particular study. These are divided into three different categories.

Firstly, municipalities or government could use this research as a basis for their EV and charging station policy. The results and discussion show that the outcomes are dependent on the approach of the data. Distributing the future charging stations are now expected to be simple, non-smart charging stations based on Kok (2018). In addition, in the Netherlands there is a discussion about raising the energy prices to pay for large scale grid upgrades, partially due to electric driving (Parool, 2020). If, instead of classic charging, smart charging or V2G were embraced rapidly, these costly investments may not be necessary. Expected grid pressure is not researched in this study. That could be a follow up research topic.

Next to that, governing bodies may have their own policy concerning disadvantaged neighbourhoods. As the results indicated a regional difference, the municipality could use that knowledge and the risk that people may miss out on the benefits as an input for further research.

The aim of the research was to research the possibilities for V2G in Utrecht and find an answer to what the allocation might look like. A means of acquiring more detailed information on the weights and importance of certain socio-economic variables is by investigating the current situation in Utrecht. The importance of the socio-economic characteristics of neighbourhoods could be retrieved on a more detailed scale by testing the hypotheses by Sovacool et al. (2018) or other hypotheses. This could be a topic of further research in the form of testing these hypotheses. Or exploring how the built environment or other factors influence the probability for inhabitants to own an EV in the near future.

A crucial part of this research build on the precondition that V2G is actually a topic of large scale implementation. This is based on all the potential benefits the system has. However, currently no widespread knowledge or momentum is in place for implementing V2G as a municipality or nationwide system. Follow up research could be focussed at exploring how business, governmental and public become more knowledgeable with this topic.

V2G is such a novel charging technique that only estimates about the benefits are calculated. Exact outcomes and possible newly emerging challenges may show up during implementations. Therefore a suggestion for future research is to keep track of all facets of the system. Investigate how technology, consumer behaviour, communication, flow of finances, the role of the government and other impacts are related to each other is the last research suggestion. Keep track of the developments so more detailed prospects and estimations can be made in the future.

7.4 Reflection on the research process

The research process was based on an initial planning. A large part of this planning was subject to acquiring data, as data is a major part of this research. The literature review went smooth and exactly according to plan. The research was really eye opening to the additional possibilities of electric vehicles, apart from them driving without fossil fuels. This was a motivation to create outcomes which were applicable by readers or policymakers. In contact with a research division of the Utrecht University the research process counted on a dataset containing all charging stations in Utrecht with at least their coordinates in the data set. The planning included using these data to extract weights from them as input for the multi-criteria analysis. Since the communication resulted in the expectation to get the data set by the end of December or, worst case, after the winter holidays. Unfortunately this did not work out and the acquiring of the data set was delayed. By the time the analysis started without these weights it was too late to base weights on other sources. However, the method without the charging station data set still resulted in a spatial data analysis with widely applicable outcomes.

References

Apostolaki-Iosifidou, E., Codani, P., & Kempton, W. (2017). Measurement of power loss during electric vehicle charging and discharging. *Energy*, *127*, 730-742.

Bockarjova, M., & Steg, L. (2014). Can Protection Motivation Theory predict pro-environmental behaviour? Explaining the adoption of electric vehicles in the Netherlands. *Global environmental change*, *28*, 276-288.

Breyer, C., Bogdanov, D., Aghahosseini, A., Gulagi, A., Child, M., Oyewo, A. S., ... & Vainikka, P. (2018). Solar photovoltaics demand for the global energy transition in the power sector. *Progress in Photovoltaics: Research and Applications*, *26*(8), 505-523.

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information System*, *5*(3), 321-339.

Centraal Bureau voor de Statistiek (n.d.). Bestand bodemgebruik - BBG. Retrieved on 6 November 2019, from: https://www.cbs.nl/nl-nl/onze-diensten/methoden/classificaties/overig/bestand-bodemgebruik-bbg#id=classificatie-bodemgebruik-0

Centraal Bureau voor de Statistiek (2018a). Trends in Nederland 2018. Retrieved on 21 October 2019, from: https://longreads.cbs.nl/trends18/economie/cijfers/energie/

Centraal Bureau voor de Statistiek (2017). Kerncijfers wijken en buurten 2018. Retrieved on 6 November 2019, from: https://www.cbs.nl/nl-nl/maatwerk/2017/31/kerncijfers-wijken-en-buurten-2017

Centraal Bureau voor de Statistiek (2018b). Kerncijfers wijken en buurten 2018. Retrieved on 6 November 2019, from: https://www.cbs.nl/nl-nl/maatwerk/2018/30/kerncijfers-wijken-en-buurten-2018

Centraal Bureau voor de Statistiek (2019a). Statline: Emissies naar lucht op Nederlands grondgebied; totalen. Retrieved on 21 October 2019, from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37221/table?ts=1571648210944

Centraal Bureau voor de Statistiek (2019b). Statline: Energiebalans; aanbod en verbruik, sector. Retrieved on 21 October 2019, from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83989NED/table?ts=1571650609661

Centraal Bureau voor de Statistiek (2019c). Aantal volledige elektrische auto's verdubbeld. Retrieved on 22 October 2019, from: https://www.cbs.nl/nl-nl/nieuws/2019/19/aantal-volledig-elektrische-auto-s-verdubbeld

Centraal Bureau voor de Statistiek (2019d). Hernieuwbare energie in Nederland 2018. Retrieved on 21 November 2019, from: https://www.cbs.nl/nl-nl/publicatie/2019/40/hernieuwbare-energie-in-nederland-2018

Dallinger, D., Gerda, S., & Wietschel, M. (2013). Integration of intermittent renewable power supply using grid-connected vehicles–A 2030 case study for California and Germany. *Applied Energy*, *104*, 666-682.

De Utrechtse Internet Courant, (2019, 2 September). Overheid trekt miljoenen uit voor innovatieve Utrechtse laadpaal. Retrieved on 24 November 2019 from, https://www.duic.nl/algemeen/overheid-trekt-miljoenen-uit-voor-utrechtse-innovatieve-laadpaal/

Eastman, J. R. (1999). Multi-criteria evaluation and GIS. *Geographical information systems*, *1*(1), 493-502.

El-Zonkoly, A. (2014). Intelligent energy management of optimally located renewable energy systems 4.incorporating PHEV. *Energy conversion and management*, *84*, 427-435.

ElaadNL (2019). Waar rijden én laden EVs in de toekomst? De ontwikkeling van elektrische voertuigen en laadpunten in Nederland t/m 2035. Retrieved on 4 December from: https://www.elaad.nl/uploads/files/ElaadNL_Outlook_EVs_Laadpunten.pdf

Electric Vehicle Database, 2019. Retrieved on 19 November 2019, from: ttps://ev-database.uk/cheatsheet/useable-battery-capacity-plugin-hybrid

Emadi, A., Lee, Y. J., & Rajashekara, K. (2008). Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles. *IEEE Transactions on industrial electronics*, *55*(6), 2237-2245.

Energy Storage Association (2019). Frequency Regulation. Retrieved on 23 November 2019, from: https://energystorage.org/frequency-regulation/

ESRI (n.d.). How weighted overlay works. Retrieved from: https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-weighted-overlay-works.htm

European Union (2014). *De Europese Unie in het kort: Klimaatbescherming.* Retrieved on 21 October 2019, from: https://europa.eu/european-union/file/761/download_nl?token=lIFrJVCL

European Environment Agency (2018). Overview of electricity production and use in Europe. Retrieved on 22 October 2019, from: https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4

Geels, F. W. (2006). Multi-level perspective on system innovation: relevance for industrial transformation. In *Understanding industrial transformation* (pp. 163-186). Springer, Dordrecht.

Gemeente Utrecht (n.d.). Wist U data. Retrieved on 6 November 2019, from: https://wistudata.nl/

Gemeente Utrecht (n.d. a). 030laadpaal. Retrieved on 25 November 2019, from: https://030laadpaal.nl/

Gemeente Utrecht (2018). Afdeling onderzoek. *Bevolkingsprognose 2018*. Retrieved on 24 February 2020, from: https://www.utrecht.nl/fileadmin/uploads/documenten/bestuur-en-organisatie/publicaties/onderzoek-en-cijfers/bevolkingsprognose/2018-12-Bevolkingsprognose-2018.pdf

Gemeente Utrecht (2019). Afdeling Ruimtelijke Kwaliteit en Duurzaamheid. *Plaatslingsleidraaf en inrichtingskader publieke laadinfrastructuur.* Retrieved on 06 January 2020, from: https://www.utrecht.nl/fileadmin/uploads/documenten/wonen-en-leven/verkeer/elektrisch-vervoer/2019-05-plaatsingsleidraad-en-inrichtingskader-publieke-laadinfrastructuur.pdf

Gerritsma, M. K., Al Skaif, T. A., Fidder, H. A., & van Sark, W. G. (2019). Flexibility of Electric Vehicle Demand: Analysis of Measured Charging Data and Simulation for the Future. *World Electric Vehicle Journal*, *10*(1), 14.

Google Maps (2020). Satellite imagery of Utrecht. Retrieved on 22 February 2020 from: https://www.google.com/maps/@52.0884202,5.0981322,960m/data=!3m1!1e3

Hirst, E., & Kirby, B. (1996). *Electric-power ancillary services* (pp. 1-48). Oak Ridge: Oak Ridge National Laboratory.

Ibrahim, H., Ilinca, A., & Perron, J. (2008). Energy storage systems—Characteristics and comparisons. *Renewable and sustainable energy reviews*, *12*(5), 1221-1250.

International Energy Agency (2018a). Renewables 2018. Retrieved on 21 October 2019, from https://www.iea.org/renewables2018/

International Energy Agency (2018b). Global EV Outlook 2018. Retrieved on 21 October 2019, from: https://webstore.iea.org/global-ev-outlook-2018

International Energy Agency (2019a). Global Energy Outlook 2019. Retrieved on 21 October 2019, from: https://www.eia.gov/outlooks/ieo/

International Energy Agency (2019b), Global EV Outlook 2019. Retrieved on 22 October 2019, from: https://www.iea.org/publications/reports/globalevoutlook2019/

Kempton, W., & Tomić, J. (2005). Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of power sources*, *144*(1), 268-279.

Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy policy*, *36*(11), 4093-4103.

Kok, M., (2018). Gemeente Utrecht. Utrecht laadt op voor 2030. Retrieved on 6 February 2020 from: https://www.nklnederland.nl/kennisloket/wp-content/uploads/2019/06/Utrecht-Strategisch-plan-laadinfrastructuur.pdf

Lake, M. (2001). How it works; A Tale of 2 Engines: How Hybrid Cars Tame Emissions. *New York Times.* Retrieved on 19 November 2019, from http://www.nytimes.com/2001/11/08/technology/how-it-works-a-tale-of-2-engines-how-hybrid-carstameemissions.html

Mozafar, M. R., Amini, M. H., & Moradi, M. H. (2018). Innovative appraisement of smart grid operation considering large-scale integration of electric vehicles enabling V2G and G2V systems. *Electric Power Systems Research*, *154*, 245-256.

Nederlandse Norm (2014). NEN 24443:2013 nl. Retrieved on 5 February 2020 from, https://www.nen.nl/NEN-Shop/Bouwnieuwsberichten/Comfortabel-parkeren-door-NEN-2443.htm

Netherlands Enterprise Agency (2019). Statistics Electric Vehicles in the Netherlands. Retrieved on 22 October 2019, from: https://www.rvo.nl/sites/default/files/2019/03/2019_02_Statistics%20Electric%20Vehicles%20and%20Charging%20in%20The%20Netherlands%20up%20to%20and%20including%20February%202019.pdf

Noel, L., Carrone, A. P., Jensen, A. F., de Rubens, G. Z., Kester, J., & Sovacool, B. K. (2018). Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. *Energy Economics*, *78*, 525-534.

Noel, L., de Rubens, G. Z., Kester, J., & Sovacool, B. K. (2019). *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility*. Springer.

Noori, M., Zhao, Y., Onat, N. C., Gardner, S., & Tatari, O. (2016). Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings. *Applied energy*, *168*, 146-158.

Nederlandse Omroep Stichting. (2020, 17-02). Laadkabels over de stoep voor je auto toestaan of niet. retrieved on 17 February, 2020 from: https://nos.nl/artikel/2323419-laadkabels-over-de-stoep-voor-je-auto-toestaan-of-niet.html

Open Geospatial Consortium (OGC). (2012). OGC Market Report Open Standards and INSPIRE. Retrieved on 28 November 2019 from, https://portal.opengeospatial.org/files/?artifact_id=48233

Voermans, T. (2020, 21 February). Energienota hoger door warmtepomp en laadpaal. *Parool.* Retrieved on 23 February 2020, from https://www.parool.nl/nederland/energienota-hoger-door-warmtepomp-en-laadpaal~b32dfb44/?referer=https%3A%2F%2Fnews.google.com%2F

Publieke Dienstverlening op de Kaart. (2019). Dataset: Basisregistratie Adressen en Gebouwen (BAG). Retrieved on 6 November 2019 from: https://www.pdok.nl/introductie/-/article/basisregistratie-adressen-en-gebouwen-ba-1

Reed, S. (2017). Power prices go negative in Germany, a positive for energy users. The New York Times/Energy & Environment, pp. 25. Retrieved on 18 September 2019 from: https://www.nytimes.com/2017/12/25/business/energy-environment/germany-electricity-negative-prices.html

Remkes, J. W., Dijkgraaf, E., Freriks, A., Gerbrandy, G. J., Maij, W. H., Nijhof, A. G., ... & Vet, L. (2019). *Niet alles kan: Eerste advies van het Adviescollege Stikstofproblematiek: aanbevelingen voor korte termijn 25 september 2019*. Adviescollege Stikstofproblematiek.

Rijksoverheid (n.d.). 3.2 Mobiliteit. Retrieved on 22 October 2019, from https://www.rijksoverheid.nl/regering/regeerakkoord-vertrouwen-in-de-toekomst/3.-nederland-wordt-duurzaam/3.2-mobiliteit

Smart Solar Charging, (n.d.) Project Partners. Retrieved on 22 October 2019, from: https://smartsolarcharging.eu/en/project-partners/

Stedin (n.d.). Verbruikgegevens. Retrieved on 4 December from: https://www.stedin.net/zakelijk/open-data/verbruiksgegevens

Sortomme, E., & El-Sharkawi, M. A. (2011). Optimal combined bidding of vehicle-to-grid ancillary services. *IEEE Transactions on Smart Grid*, *3*(1), 70-79.

Sovacool, B. K., & Hirsh, R. F. (2009). Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. *Energy Policy*, *37*(3), 1095-1103.

Sovacool, B. K., Kester, J., Noel, L., & de Rubens, G. Z. (2018). The demographics of decarbonizing transport: the influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. *Global environmental change*, *52*, 86-100.

Sovacool, B. K., Noel, L., Axsen, J., & Kempton, W. (2018). The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review. *Environmental Research Letters*, *13*(1), 013001.

Staat van Utrecht. (n.d.). Energieverbruik. Retrieved on 1 February 2020 from: https://www.staatvanutrecht.nl/thema/energiegebruik

Stichting BOVAG-RAI Mobiliteit, 2019. Mobiliteit in Cijfers 2018-2019. Retrieved on 19 November 2019, from https://bovagrai.info/auto/2018/media/MIC-Auto-2018-download.pdf

Tamis, M., Van den Hoed, R., & Thorsdottir, R. H. (2017, March). Smart Charging in the Netherlands. In *In Proceedings of the European Battery, Hybrid & Electric Fuel Cell Electric Vehicle Congress*.

Tan, K. M., Ramachandaramurthy, V. K., & Yong, J. Y. (2016). Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. *Renewable and Sustainable Energy Reviews*, *53*, 720-732.

TenneT (2019). About Tennet. Retrieved on 25 November 2019, from: https://www.tennet.eu/company/profile/about-tennet/

United Nations (2015). *Adoption of the Paris agreement.* Retrieved on 21 October 2019, from: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Van der Kam, M. J., Meelen, A. A. H., van Sark, W. G. J. H. M., & Alkemade, F. (2018). Diffusion of solar photovoltaic systems and electric vehicles among Dutch consumers: Implications for the energy transition. *Energy research & social science*, *46*, 68-85.

Van der Lucht, F. (2007). Veertig gezonde krachtwijken. *TSG*, *85*(7), 357-359.

Van Sark., W. G. J. H. M. & Van der Ree, B. G. C., (16 October 2019). V2G and the Energy Transition [PowerPoint]. Personal communication.

Verzijlbergh, R. A. (2013). *The Power of Electric Vehicles-Exploring the value of flexible electricity demand in a multi-actor context* (Thesis). Technische Universiteit Delft, Delft

Wang, D., Coignard, J., Zeng, T., Zhang, C., & Saxena, S. (2016). Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services. *Journal of Power Sources*, *332*, 193-203.

Weckx, S., & Driesen, J. (2015). Load balancing with EV chargers and PV inverters in unbalanced distribution grids. *IEEE transactions on Sustainable Energy*, *6*(2), 635-643.

Wenting, F. (2002). Programmaverantwoordelijkheid. *TenneT report, Amsterdam*. Retrieved on 25 November 2019, from: https://web.archive.org/web/20110814070634/http://www.tennet.org/images/toelichting_pv_algemeen_tcm41-11965.pdf

Yong, J. Y., Ramachandaramurthy, V. K., Tan, K. M., & Mithulananthan, N. (2015). A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. *Renewable and Sustainable Energy Reviews*, *49*, 365-385.