The electric vehicle charging infrastructure of the future

Using stakeholder interviews and electric vehicle driver surveys to compare options for electric vehicle charging points in the Netherlands

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Abstract

Electric vehicles (EVs) are part of the solution towards a sustainable energy system. To reach the international and Dutch national climate goals, implementation of EVs is necessary. While EVs are emerging, specifics on what charging will look like are still unknown.

Electric vehicles are connected to the electricity network through chargers that can be on different locations and have different charging rates. The types of chargers are for instance slow 3.7 kW home chargers or ultra-fast 300 kW highway chargers. Visions of stakeholders concerning the future of EV charging and additionally, the preferences of EV drivers themselves are topics of this thesis.

18 stakeholders are interviewed on their visions for the future of EV charging. While national regulators have vision at all, all other stakeholders foresee some combination of fast and slower charging in the future. The results show that there is no clear consensus between stakeholders concerning the type of chargers that will be deployed in the future.

One group of multiple types of stakeholders envision that charging at home or work with rates up to maximum 22 kW will be the most important type of charging. Another group sees that there is an important role for fast charging. Innovations in car sharing, autonomous driving and smart charging will influence charging. However, stakeholders do not agree on how these innovations will influence the types of chargers.

Through a discrete choice experiment, the preferences of EV drivers are researched. Analysis of 330 datasets using a Hierarchical Bayesian method, leads to utility values that describe how satisfied EV drivers are with certain charging point types. Results show that EV drivers prefer charging at home or at work. The preferred charging rate depends on the situation of the EV driver. When their battery is running low, EV drivers value the charging rate twice as much compared to when there is no need to charge. When there is no need to charge, EV drivers consider the price of charging significantly more.

A comparison between stakeholders' views and EV drivers' preferences shows there is some consensus between stakeholders and EV drivers, namely on the importance of home and work medium rate chargers. While EV drivers prefer to charge fast or ultra-fast anywhere, especially when their battery is running low, not all stakeholders view fast charging as crucial for the future of EV.

The results imply that clear direction is missing and stakeholders, including EV drivers, are misaligned in their views. The future of EV charging is dependent on the influence of stakeholders, a changing landscape and innovations in both the energy and mobility domain. The complexity of the topic calls for more interdisciplinary research and drawing up of scenarios.

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Abbreviations

ABCD	Agent-based buying charging driving
ABM	Agent-based modelling
CAS	Complex adaptive system
CPO	Charge point operator
CPM	Charge point manufacturer
DCE	Discrete choice experiment
DSO	Distribution system operator
ES	Energy supplier
EV	Electric vehicle
GHG	Greenhouse gas
HB	Hierarchical Bayes
MSP	Mobility service provider
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid electric vehicle
SOC	State of charge

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1. Introduction

This chapter introduces the research project. First, a description of the background underlines the societal and environmental relevancy of the research project and sets the context for the research. Secondly, the previous research on the subject is outlined. This shows where this research can add to academic literature. Lastly, the research question is set.

1.1. Electric vehicle implementation

Electric vehicles (EVs) are fuelled by electricity instead of conventional fossil fuels. Worldwide, the need for mobility increases and the motor vehicle use increases as well. Passenger transport demand in Europe is steadily increasing, according to the European Environment Agency (2015). In the EU, 72% of all passenger transport, measured in pkm (passenger·kilometres), was travelled by car. Cars have a large impact on environment: car passenger transport is responsible for 11% of all GHG (greenhouse gas) emissions in the EU (International Energy Agency, 2018). EVs have the potential to substantially decrease GHG emissions of passenger transport (International Energy Agency, 2016).

Climate policies therefore include goals for electric vehicle market share (International Energy Agency, 2016). At the UN Climate change conference in 2015, the Paris Declaration on Electro-Mobility was presented, calling for a deployment of electric vehicles compatible with a 20% share of all road transport vehicles in 2030, including more than 100 million cars (up from 1 million in 2015). In the Netherlands as well, the national government stimulates electric vehicle implementation (Rijksoverheid, 2016). They furthermore highlight that the charging of the electric vehicles is crucial for the implementation and recognize that current and former policies are not effective for stimulating EV implementation (Rijksoverheid, 2016).

The deployment of electric vehicle charging infrastructure, the support system for electric vehicles, is a topic of interest for many stakeholders. This includes electricity grid operators, energy suppliers, policy makers and municipalities. It has been a topic of research from different perspectives and fields of research, as it is a technological development but also represents a social innovation and paradigm shift. Consumers as well as the mobility industry need to shift from the original fossil fuel infrastructure to an infrastructure that enables electric vehicles. To achieve this paradigm shift, the electric vehicle charging infrastructure needs to be economically profitable for the industry, but it must also fit the needs of consumers.

An increasing market share of electric vehicles and consequently increasing electricity consumptions will have large effects on the electricity grids (Bradley, 2013). However, the real impact of the deployment of electric vehicles is not yet known as there is not a consenting vision on the parameters of EV charging. Many uncertainties about the future of EV charging infrastructure occur; concerning the rate (speed) of charging, the locations where EV users will charge and how this impacts our electricity grid. There are many different *types* of charging stations and it is unclear which of these types of charging stations will be deployed mostly in the future.

1.2. Previous research

To remove some of the uncertainties and to gain more insight in the future of electric vehicle charging infrastructure, models are created by researchers all over the world. The most relevant models are introduced in this chapter. Afterwards, the research that has been done on the topic of stakeholders and their views is set forth.

1.2.1. Models for EV charging predictions

Key element to the market penetration and the necessary paradigm shift to sustainable electric transport is its support system. To fully enable the implementation of EVs, the charging infrastructure needs to align with the driving patterns of the users, the size of the batteries that are being developed, the power and rate of charging that the EVs allow, the preferences of the users, the support of municipalities, optimal geographical locations for the charging points, local, national and international policy measures, the capability of the grid to deal with the loads in an efficient way and so on.

All these factors influence the deployment of the charging infrastructure. This matter is complex and includes so many stakeholders that it is impossible to approach this issue with simple, basic mathematical models. Researchers from all over the world are recognize the need to develop extensive models to comprehend the developments in the future charging infrastructure. Below, some models that researchers have developed are discussed.

Most models that are developed in this field are optimization models, that optimize for instance the placement of one type of charging infrastructure based one or a few factors. For instance, Yi & Bauer (2016) constructed a model that optimizes the placement of slow public charging points in Chicago, taking into account the reachability for EV drivers and amount of energy used to get to a charging point.

Environmental factors and service radius are considered by Lui, Wen, & Ledwich (2013) to determine the optimal charging station locations. A similar study was done as a case study in Seattle by Dong, Liu, & Lin (2014), where public charging locations were optimized based on the maximization of the number of kilometres driven electrically considering activity patterns of drivers. Also, models have been developed that optimized the charging infrastructure placement based on traffic flow (Wang, Xu, Wen, & Wong, 2013) or the number of people that can complete their trips (You & Hsieh, 2014).

Wirges, Linder, & Kessler (2012) developed an extensive time-spatial model for the development of charging infrastructure. However, none of the studies mentioned took fast charging and corridor[1] charging stations into account as an option. The same accounts for Hess et al. (2012), who also developed an optimization model for charging points.

This might be because they did not take new developments into account, but only reason from the situation at the time. But the field of EVs is developing vastly, with breakthroughs in battery prices and charging rates (Russon, 2016; Yuzawa, Yang, Bhandari, Sugiyama, & Nakamura, 2016). Clearly, since 2012, large improvements have been made in these fields and therefore these should be considered.

The subject of EV charging is also very relevant for grid operators. The grid operators recognize the need to look at the impact of fast charging on the electricity grid. Therefore, in research by Leemput

[1] A corridor charging station is usually a fast-charging station one uses to top-up their battery and continue their journey similar to a gas top-up station, as opposed to destination chargers where one parks for a longer period of time while charging.

et al. (2015), the impact of different types of charging (fast or slow charging) on the electricity grid was investigated. This study focused on the impact on the low and mid voltage grid in Flanders, Belgium. A similar study was done by Ge, Feng, & Liu (2011) using the so-called grid partition method.

Many of the models focus on the locations of future charging points. The models named above are mainly system dynamic, equilibrium and multi-integer linear programming optimization models. These types of models can take several factors into account, but none of the models that were already developed used the preferences of actual EV drivers as a factor. None of the previously discussed models aimed to model the complex EV system and its stakeholders either.

Complex systems with a large amount of interactions can be modelled using the method of Agent-based modelling (ABM)[2]. Some agent-based models in this field have already been developed. For instance, Sweda & Klabjan (2011) developed an agent-based decision support system for the strategic placement of EV charging infrastructure considering the driving patterns, applied to the Chicago metropolitan area in the USA. However, their model only considers the placement of already planned public infrastructure (which it uses as an input) and does not focus on the deployment of new charging points.

Olivella-Rosell, Villafafila-Robles, Sumper, & Bergas-Jané (2015) have also developed an agent-based model for the charging of electric vehicles, applied to Barcelona, Spain. As several other studies, this model analyses the impact of the charging on the grid. Olivella-Rosell et al. (2015) use agent-based modelling to incorporate different factors into the prospected charging demand in an area: battery capacity and energy consumption of each trip, economic and some social attributes and mobility needs. This model also only takes conventional slow charging into account and does not incorporate other developments such as faster charging rates and corridor charging.

The models that have already been developed are useful. However, they become outdated as new developments and innovations occur. For instance, many models do not take fast charging into account. The models simulate rational behaviour patterns but the real, more complex behaviour of EV drivers is usually neglected. Also, most of the research looks at the perspective from one stakeholder's point of view rather than combining multiple perspectives. This calls for further research on the behaviour and preferences of EV drivers and other stakeholders.

Morrissey, Weldon, & O'Mahony (2016) have already done a more interdisciplinary study, where the some of the charging behaviour of the drivers is considered and a comparison between slow (standard) and fast charging is made. Their study was an analysis on the current use of some different types of charging points, measuring the energy consumption and charging time of hundreds of charging points in Ireland. It focused on the implications of the current use of charging stations and did not include a prediction on the future deployment of charging stations. The conclusion of their study was that home charging is clearly EV drivers' preferred place to charge their vehicles with this location recording the highest charge durations and the highest usage frequency (Morrissey et al., 2016).

[2] Agent-based modelling is a bottom-up approach to simulation, where each individual entity/stakeholders' behaviour is modelled and this together forms the system. Argumentation for why agent-based simulation models are a relevant method for analysing complex systems can be found in paragraph 2.1 of the theoretical framework.

The models and studies described in the previous paragraphs mostly look at the charging options that were available at that time and how this influences the electricity grid. They are usually based on current charging technologies. Furthermore, no model predicting the charging infrastructure for EVs has been applied to the Netherlands specifically. The aim of this study is to also take important Dutch stakeholders into account as stakeholders are different for every country.

1.2.2. Research on stakeholders

There has not yet been much research on the stakeholders that influence the EV charging infrastructure deployment. A stakeholder in the case of this research is considered a party that has an interest in the EV charging infrastructure. The electric vehicle charging system can be looked upon as a network of actors. The stakeholders have different perspectives and objectives.

Stakeholders in the Dutch public charging domain have been analysed by van Galen (2015). As van Galen (2015) concludes, there is a significant misalignment between these different stakeholders in the case of public electric vehicle charging. Commercially driven stakeholders have different views than governments, is what van van Galen (2015) concludes. Furthermore, there is no clear, aligned vision between the stakeholders for the future of electric vehicle charging.

Madina, Zamora, & Zabala (2016) also argue that an integrated view over the different stakeholders is still needed. They stress this importance as it can be useful for policy makers and regulatory bodies to come up with cost-effective strategies for GHG emission reduction. The interactions between stakeholders and the surrounding environment influence the deployment of charging infrastructure significantly and should therefore be researched more elaborately (Madina et al., 2016).

One way to gain some insight in how electric vehicle charging will emerge, is to create an overview of all relevant stakeholders and their visions. EV drivers themselves are important stakeholders as well in this case. The views of different stakeholders can then be compared.

1.3. Research question

The aim of this research project is to provide insights in the future deployment and use of electric vehicle charging points. It aims to contribute to an agent-based simulation model called the ABCD model. The model will simulate the EV sales, the charging of the EV's and the driving patterns of EV drivers. ABCD thus stands for 'Agent-based Buying Charging Driving'. This model was initiated by Eindhoven University of Technology and will provide insights for researchers and policy makers in the Netherlands. The 'Charging' part of the model will be enhanced, and some of the model parameters will be set by using the results from this research project.

As a start, the stakeholders of electric vehicle charging in the Netherlands should be researched. The business field of EV charging consists of many parties, that all contribute to or influence the future of electric vehicle charging infrastructure. An overview of the views of the stakeholders concerning different types of charging stations is needed. Furthermore, the stakeholders can be considered so-called agents and the overview of the stakeholders' views can be used as a basis for the extended ABCD model. The ABCD model implementation is however out of the scope of this thesis.

One important group that influences the charging of electric vehicles are the EV drivers. Each EV driver makes their own decisions on what type of charging points they use, when they use it and where they charge. Market parties will invest in charging points that have a positive business case and are used often. Therefore, the behaviour of EV drivers concerning the charging of their electric vehicles is crucial to how the charging infrastructure will develop. The choices of the EV drivers are dependent on the situation they are in, so multiple scenarios can be considered. Aim of the Dutch government is also to create a charging infrastructure that services the EV drivers optimally and thereby stimulating EV sales to reduce GHG emissions (Rijksoverheid, 2016). The choices of the EV drivers and their reasoning should therefore be researched.

The research project is ultimately divided into two parts of primary research. The first part concerns the different stakeholders in the domain of electric vehicle charging. The second part looks closely at the EV drivers. In the third part, a comparison is made between the two first part to find out whether the views of stakeholders align with the EV drivers' preferences. The research questions are:

Stakeholders' views

1a. What stakeholders influence the deployment of different types of charging points?

1b. What are these stakeholders' views on the future of the different types of charging points?

EV drivers' preferences

2a. What are the perceived utility values for different characteristics of charging points in two common scenarios for EV drivers?

2b. How important are the different characteristics of charging points that EV drivers consider for their choice of a charging point in two common scenarios?

Comparing stakeholders' views to EV drivers' preferences

3. How do the views of stakeholders on the different types of charging points for EVs compare to the preferences of current EV drivers?

1.4. Reading guide

In chapter 2, the basic framework and important theories are discussed. The reader is provided with a conceptual basis of socio-technical systems, which includes the EV charging system. Diving deeper in the specifics, chapter 3 provides important background knowledge on EV charging in the Netherlands.

Thereafter, the methods of research (chapter 4), the results (chapter 5) and discussions and conclusions (chapter 6) are presented. Chapters 4, 5 and 6 are outlined according to the same sequence as the research questions. Each first paragraph is on the stakeholders' views. The topic of the second paragraph is consistently the EV drivers' preferences. In each third paragraph, the comparison of stakeholders is discussed. Finally, concluding remarks are stated in chapter 7.

2. Theoretical framework

This chapter draws the basic framework for the research, and it describes the theory behind the most important research concepts. Firstly, socio-technical systems and the multi-level perspective are featured. Secondly, utility theory and choice models are described.

2.1. Socio-technical systems and complexity

A socio-technical system analysis looks at technology in its complete context. The theory behind socio-technical systems is based on the idea that you should be analysed by bringing 'social' and 'technical' aspects together and treat these as interdependent parts of a complex system. It looks at new innovative technologies in an interdisciplinary matter as it recognizes the interaction between people and technology. In their book, van Dam, Nikolic, & Lukszo (2013) describe the electricity infrastructure as a typical example of a socio-technical system.

The transport system is described by van Dam et al. (2013) as a separate socio-technical system. Electric vehicles are charged by the electricity infrastructure and transport people, so they are embedded in both socio-technical system and must therefore be looked upon from both perspectives. This creates a challenge of complexity. It is not just the complexity of a socio-technical system, but also a technology that is embedded in two socio-technical systems.

Geels & Schot (2007) describe both systems as well in their articles on socio-technical transitions, which highlights the relevance of this approach to the EV landscape. As founders of the theory of the Multi-level Perspective (MLP), they look at how sustainable transitions can occur. As a sustainable transition in the transport and electricity system is needed in the coming decades, their theory provides valuable insights for the implementation of electric vehicles.

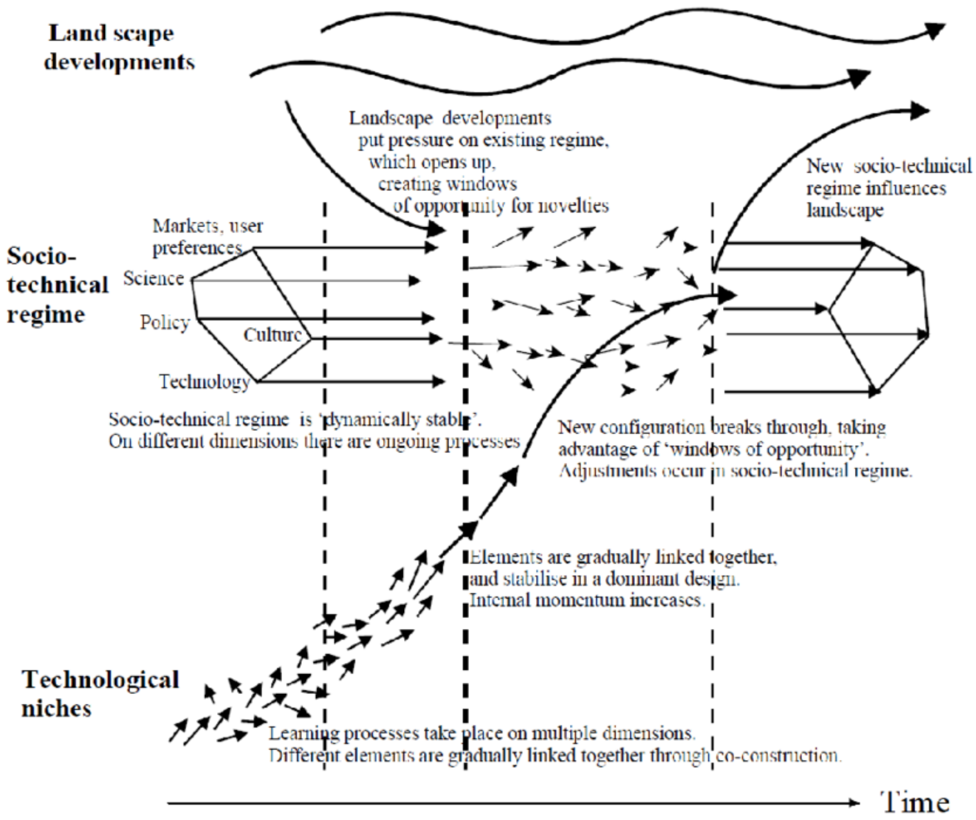

Figure 1: Multi-level Perspective: landscape, regime and niches (from Geels & Schot, 2007)

The Multi-Level Perspective (MLP) offers a framework to study socio-technical transitions and how innovations change the system. It describes transition in terms of a socio-technical regime, which is the dominant mode of operation of the system within its socio-technical landscape. Many niches operate below the regime. These niches have the potential to change the regime, which describes a transition in the socio-technical system. Over time landscape effects, interactions among stakeholders, and the changing environment can collectively cause long-term changes in the landscape and the system as a whole. This is illustrated in Figure 1. The processes described as arrows can be viewed as small changes, triggered by behaviour and interactions.

The electric vehicle system can be looked upon as a complex adaptive system (CAS). Complex adaptive systems are a subset of nonlinear dynamical systems. The study of CAS has become a focus in interdisciplinary research (Lansing, 2003). Since the stakeholders in the field of electric vehicle charging originate from different socio-technical systems and have misaligned strategies, these stakeholders cause uncertainties for the future (van Galen, 2015). Lansing (2003) argues that for complex systems, one must not assume rational choices of stakeholders, but assume the evolution of strategies over time, and both include local interactions and their global effects. This concept fits the current business ecosystem of electric vehicle charging and aligns with the Multi-Level Perspective from Geels & Schot (2007).

As each stakeholder's strategy influences the deployment of electric vehicles in different ways, each stakeholder must be considered individually. To gain insights in the future of electric vehicle charging, each stakeholders' behaviour can be modelled using agent-based modelling. Agent-based models have been commonly used to simulate complex adaptive systems (Lansing, 2003); (van Dam et al., 2013). Agent-based models are also well fit for interdisciplinary problems that cross research fields, similar to the socio-technical approach (Axelrod, 2006).

2.2. Utility theory and choice models

Utility can be defined as the satisfaction that a consumer (EV driver) gets from an alternative (a type of charging point) (Fishburn, 2006). This is used as an indication of how often that alternative will be chosen. Utility theory is often used in consumer economics and it can be used to predict actual choice behaviour. Furthermore, it can provide insights into how a person makes a decision (Fishburn, 2006).

In the case of this research, the utility value of a charging point will indicate how much a certain type of charging point will be used by the pool of EV drivers in different use cases, expressed in the probability that they will choose a certain type. If you compare two products (charging points) by utilities, the product with the highest utility is has a higher probability of being chosen by EV drivers over a lower utility. One charging station has multiple parameters that characterize the charging station, such as the price for charging at that point, the charging speed and the location of the charger. The combined utilities for the parameters, will compose the final utility value for a charging point.

Morrissey et al. (2016) conclude that the EV drivers and their behaviour are not homogenous. Their choices depend also on the use case, meaning a specific situation. One should refer to multiple use cases rather than taking the aggregate results when considering the charging point choices (Morrissey et al., 2016). Using the final utilities of charging stations in a certain use case, a so-called choice model can be derived that models the choices of charging points of EV drivers.

A choice model is often based on revealed preferences, which are actual actions of respondents. Currently, not enough data is available on how EV drivers charge their cars at the existing charging points. Furthermore, this data may not be representative for how the charging infrastructure will be used in the future as the number and variety of charging points now are limited. The technology of both the EVs as well as the charging stations is developing fast. A model that describes the decisions of EV drivers in the future is needed to get realistic representation of the behaviour of EV drivers. Using stated preferences that are expressed during a discrete choice experiment is a valid alternative for obtaining utility values and creating choice models, when using revealed preferences is not possible (Adamowicz, Boxall, Williams, & Louviere, 1998).

3. Electric vehicles and charging

It is important to understand the basics of EV charging and its developments in this research. Therefore, the technical characteristics of charging points are discussed in 3.1. An introduction to the stakeholders in the ecosystem of electric vehicle charging is given in 3.2.

3.1. Charging point characteristics

Within the field of electric vehicles and their charging infrastructure, several concepts are important to be defined. An electric vehicle can either be a plug-in hybrid electric vehicle, that besides an electric motor also has a traditional internal combustion engine. A full-electric vehicle only has an electric motor, that is powered by a battery. As these cars require a larger battery, they will have the largest impact on the electricity grid and are therefore the focus of this research. The battery of these cars is charged by electricity using a charging point. The battery can have many characteristics, most important are the battery size (kWh) and the charging rate capabilities (in kW). Three characteristics of charging points relevant for this research are discussed below.

The first characteristic is the charging rate. The electricity grid provides electricity in alternating current (AC), but a battery is charged in direct current (DC). Therefore, an AC to DC inverter is incorporated in most EVs. However, when the charging point incorporates an inverter, the vehicle can be charged using DC, which can be a much faster process because the battery is directly charged in DC without the limits of an AC to DC inverter (Yilmaz & Krein, 2013). In the Netherlands, single phase AC can produce a power of 3.7 or 7.4 kW (230 V x 16 or 32 A respectively). Three phase AC can produce 11.0 to 43.5 kW.

DC charging is now under development. Current DC chargers in the Netherlands produce a power of 50 kW or 120 kW, each only used for a specific EV model. Other EV models that are announced and will be on the market in the coming years have DC charging capabilities of up to 150 and 300 kW (Shahan, 2016). These are not yet commercially deployed in the Netherlands but will be in the near future and are therefore also considered. The current use of the term ‘fast charging’ is charging with a rate of 43.5 kW AC or DC (>50 kW) (Yilmaz & Krein, 2013).

Secondly, there are different locations where a driver can charge the car. Locations can be points of interest, like the driver’s workplace or home, where people spend lots of their time while their car is parked. Corridor charging points are also deployed now. These charging points function as a traditional gas station: one stops at a station during a trip to top-up its battery.

The third important characteristic is how the charging point is operated. When at a driver’s own driveway, there is no other party involved and the charging is considered private. This could also be the case when the driver’s employer provides free charging at the workplace. At a public charging point, a charge point operator (CPO) handles the billing of the electricity. Semi-public constructions are also possible, which can be the case at for instance a parking garage or shopping centre where the ground is owned privately but the charging point is not operated privately.

The three characteristics are shown in Table 1. One charging point has three characteristics in this case and one set of characteristics combined is a type of charging point. Several types of charging points will be deployed more often the others for obvious reasons. For instance, on-the-go slow charging is very inconvenient and will not be used. However, in this research no type will be excluded as the model is a simulation model in which all possible options are considered.

Table 1: Possible types of charging points

Charging rate		Home			Work			Other destination			Corridor		
		Public	Private	Semi-public	Public	Private	Semi-public	Public	Private	Semi-public	Public	Private	Semi-public
AC 1-phase	3.7 kW												
	7.4 kW												
AC 3-phase	11.0 kW												
	22.1 kW												
	43.5 kW												
DC	50 kW												
	120 kW												
	150 kW												
	350 kW												

3.2. Introduction to the stakeholders

Many different parties are involved in the process of electric vehicle charging. Therefore, some insightful information on the relevant stakeholders is given (A. Wargers, personal communication, May 2017; A. Hoekstra, personal communication, May 2017).

The electric vehicle itself is owned by a lease company, an employer or the drivers themselves. It is manufactured by an OEM (original equipment manufacturer), or car manufacturer in simple terms. The drivers connect to charging points to top up the car its battery. In some cases, on private ground or workplaces, they are directly connected to the net connection of the building or site. If there is a charging point that does not use software and communication with the car, it is called simple or direct charging. On most (both public and private) charging points however, charging points are smarter. It uses software to communicate with the car which is operated by a charging point operator.

The drivers must then identify themselves using a card (or other type of chip holder) or phone at the charging point. These cards are given out by mobility service providers (MSPs), who bill the EV drivers for the use of the charging points and who are responsible for making sure their cards work at different charging points. This is needed because every charging point has a CPO (charge point operator). They make sure the charging point is installed, maintained and connected to the net. The back-offices of the CPO and MSP must be able interchange data to allow an EV driver with a certain MSP card X to charge at a charging point operated by CPO Y. In many cases, stakeholders have a double role. This can be a CPO that also functions as an MSP or an OEM that also provides MSP services.

Municipalities give out permits to CPOs to place charging points in the public space. The CPO requests their net connections for new charging points at distribution system operators (DSOs). DSOs are responsible for the balance of the low-voltage electricity grids in the Netherlands. An energy supplier (ES) buys (or produces) energy that is transported on the grid. They indirectly sell the energy, through the CPOs and MSPs, to the EV drivers.

4. Method

This chapter describes the methods used throughout the research project and provides argumentation as for why these specific methods have been chosen. Firstly, the research method on the stakeholders and their views is discussed. Secondly, the methods on researching the EV drivers' preferences for charging points using a survey is set forth. The last step is comparing stakeholders' views to EV drivers' preferences.

4.1. Gathering stakeholders' views

In their book, van Dam et al. (2013) describe ten steps to construct an agent-based model of a socio-technical system. In the second step, System Identification and Decomposition, they say the modellers need to "get social" in order to obtain the necessary information for understanding the system. This can for instance be done by interviews with relevant entities. They propose interviews and brainstorm sessions with domain experts, stakeholders, and relevant actors. North et al. (2010) also argue that structured interviews to extract information on agent behaviours is a useful technique as basis for agent-based models.

The stakeholders in the EV charging domain in the Netherlands vary in type of organisation, in their role and in their vision (A. Wargers, personal communication, March 2017). This adds complexity to the data collection and makes quantitative data collection more difficult. To gain in-depth insight in the visions of the stakeholders for the future of EV charging, qualitative data can be collected through interviews. Chapter 4.1.1 describes the stakeholder identification process and chapter 4.1.2. describes the interview method and interview questions.

4.1.1. Stakeholder identification

Firstly, the relevant actors (or stakeholders) must be identified. A stakeholder analysis was conducted by Assum, Kolbenstvedt, & Figenbaum (2014) for the stakeholders of the electric vehicle charging domain in Norway. They distinguish stakeholders as authorities, NGOs, industry and BEV owners. A more detailed stakeholder list is needed however for this research, applied to the Netherlands specifically. In the stakeholder analysis of van Galen (2015), stakeholders in the domain of public charging are already identified. The stakeholders from these previous studies will be included, but additional relevant stakeholders will also be added to the interview list. To gain insight in who to interview, a full list is created in collaboration with A. Wargers (personal communication, March 2017) from the ElaadNL knowledge and innovation platform for electric vehicle charging.

4.1.2. Stakeholder interviews

After the stakeholders are identified, the views of these stakeholders can be researched through interviews. The data is gathered through semi-structured interviews. The goal is to construct a list of stakeholders, their properties and their views on what type of charging points will be most relevant in the future. To enable a clearer view on what a certain type of stakeholder's views are, multiple stakeholders of the same type are interviewed. At least two organisations of each of the stakeholder types are interviewed. Only open questions are asked and there is room to elaborate on certain topics of discussion. The interviews are conducted in three parts, namely 'organisation and partners', 'types of charging points' and 'future developments'.

Organisation and partners. This first part has the goal to set the context of the organisation and to clarify the playing field of different stakeholders for the interviewer. The organisations' core business and its interrelations, what other types of stakeholders they are connected to, are questioned through the following questions:

1. What is your current core business as an organisation or department of a larger organisation?
2. What other organisations does your organisation collaborate with?
3. How do you see the roles of these organisations?

To facilitate the interview process, a tool is used. This is a large A3 paper sheet with all the stakeholder types found in the stakeholder identification step (described in paragraph 4.1.1) on it. A copy of this sheet can be found in appendix A: Interview tool stakeholders. The interviewees are given markers and they can draw the relations on the sheet. This part of the interview results in a list of stakeholders with their role and a categorisation of stakeholders based on the attributes in Table 2. These attributes are assigned in order to group the stakeholders and compare groups of stakeholders to each other.

Table 2: Interview attributes

Attributes	Options
Type of organisation	Public, Private, Semi-public
Relation to technology	Technology producing, working with technology, not directly related to technology
Domain	Vehicles, energy, charging, regulatory

Types of charging points. This part focuses on the types of charging points the organisation is focusing on now and expecting to focus on in the future. The following questions are asked:

1. What type(s) of charging points is your organisation currently involved in?
2. What type of charging points do you expect to focus on in in the future?
3. If you expect a shift in focus concerning the types of charging points, why is that?
4. What type of charging do you think will be used most often and why?

In the second part, a tool is used as well. This tool is based on the types of charging points from Table 1 in paragraph 3.1. A copy of the tool can be found in appendix B: Interview tool charging point types. The interviewees cross out the cells in the table with the charging points they are focusing on to prevent misunderstandings.

The type of charging points that they are focusing on currently show what their interests are in the deployment of certain types of charging points. The views on the future of the stakeholders give insight in what they deem as relevant types of charging points for the future. If stakeholders' views differ, the results will show whether one group of organisations with similar attributes from Table 2 (for instance private technology producing companies) have different views from organisations with other attributes.

This part of the interview will result in a table with the types of charging points, filled in with the number of times a type of charging point is mentioned as a focus by one of the stakeholders. This is used to compare the views of the stakeholders and the preferences of EV drivers on what type of charging points will be relevant in the future.

Future developments. The third part of the interview addresses the visions for the future of electric vehicle charging. In this section, the interviewees are asked about the developments that influence the deployment of electric vehicle charging points. This is addressed in the following questions:

1. How do you see the deployment of charging points in the future until 2035?
2. What are the barriers for the deployment of these types of charging points?
3. What developments do you think influence the deployment of charging points and how?

Also in this last part, a tool is used. This tool consists of a timeline, from now until 2035. The interviewees put the developments and other important issues discussed on the timeline to clarify their views for the future. An example of the tool can be found in appendix C: Interview tool timeline.

The interviews are recorded using a voice recorder and then summarized. The interviews are conducted in Dutch and the summaries are translated to English. These translated summaries are checked for accuracy with each of the interviewees by emailing the summary.

4.2. Finding EV drivers' preferences

Besides the other stakeholders, the EV drivers are arguably the most important stakeholders as they purchase the services of charging their vehicles and make the final decision for a charging point. The preferences of the EV drivers can be derived from stated preferences of a sample of EV drivers. These stated preferences are researched in a discrete choice experiment (DCE).

4.2.1. Discrete choice experiment design

As mentioned in paragraph 2.2, utility can be defined as the satisfaction that an EV driver gets from a type of charging point. An EV driver will maximize their perceived utility when deciding for a certain charger. Combining all utility values for chargers of all EV drivers will result in an estimate of the overall demand for certain types of charging points. The values for these utilities can be estimated by analysing data of a discrete choice experiment (DCE). In such an experiment, a survey is put out to the consumers (EV drivers). They receive a survey that contains a series of choice tasks. They choose between certain alternatives, of which each is a type of charging point. In each choice task, the EV driver is presented with multiple options to choose from.

Respondents base their choices on the levels of the attributes that are associated with each alternative. These attribute levels should vary over the choice tasks and different questionnaires for each respondent, in such a manner that the overall DCE contains an experimental design in which the correlations between the attributes are minimized (Hensher, Rose, & Greene, 2005).

Hence EV drivers chose a charging point based on the characteristics that are presented. To compare utilities, alternatives of charging points must be determined. In cooperation with drs. A. Hoekstra from TU Eindhoven (personal communication, May 2017), the characteristics of charging points that EV drivers consider when choosing a charging point are determined. A type of characteristic is called an attribute and the attributes have multiple levels. Each option for a charging point contains one level of every attribute. The attributes used in the DCE are presented below and summarized in Table 4.

4.2.1.1. Attributes for the discrete choice experiments

The attributes for the charging points in the DCEs were selected after consultation with two experts (A. Wargers, personal communication, May 2017; A. Hoekstra, personal communication, May 2017). The attributes are: charging rate, price, availability, location and familiarity. The attributes are discussed below.

Charging rate. One very important characteristic of charging points that EV drivers consider is the charging rate. As shown in Table 1, charging points can have a charging rate within a range of 3.7 to 350 kW. An average electric vehicle uses around 0.2 kWh/km (Miles, 2018). For the purpose of clarification and simplification, the factor of charging time for 100 km range is used in the survey. This charging time is also related to the state of charge of the battery, temperature and many other factors in reality, but these are neglected. To simplify, for driving 100 km in an EV, 20 kWh is used. With a rate of 350 kW, charging your car battery enough to drive 100 km would take (20 kWh/350 kW) *60 min/h ≈ 3.41 minutes. For 3.7 kW, this is approximately 5.4 hours. For simplification, this has been roughly rounded off to 3 minutes and 5 hours respectively. 50 kW (≈ 20 min) and 11 kW (≈ 1.5 hours) are also used charging rates.

Price. The cost for charging is also one aspect of a charging point that EV drivers consider. The costs are billed per kWh to the driver. Again, 100 km range is taken as a point of comparison. A price of 2.50 euro for 100 km translates to an electricity price of 12.5 ct/kWh, 10 euro corresponds to an electricity price of 50 ct/kWh. The levels of 2.50 euro, 5 euro, 7.50 euro and 10 euro are chosen. The 5 euro level (=0.25 ct/kWh) corresponds mostly to the kWh price consumers pay at their house, which is around 23 cents including taxes (Consumentenbond, 2018).

Availability. Something else that EV drivers may consider is the chance that the charging point is taken by another EV driver. In busy areas, charging points might not be available and there could be only a 40% chance that the charging point is actually available. Apps that show whether a charging point is taken or not are not considered for simplification. 100% availability translates to a private parking spot with a charger, such as at one's private driveway or a reserved parking spot at the workplace. This is related to how a charging point is operated (privately, semi-public or public) as a private charging point always has 100% availability and a public one has a lower chance of availability, but it is not the same concept. The concept of availability rather than operation is chosen as an attribute since availability is unrelated to location. A driver can charge at home using either a public charging point on the street or a private charging point on their driveway. The attributes in a DCE should be as unrelated to the respondents as possible to prevent interdependencies in the data. Chance of availability is chosen in a linear set with 20% steps.

Location. One important attribute all EV drivers consider is the location of a charging point. There are destination chargers at home, at one's workplace or at shopping centres. Shopping centres are considered places where people regularly come for errands. One other option is corridor charging. This is charging in the way one would use a gas station nowadays: stopping near a road to top up the battery of the car. These are already deployed in the Netherlands. For a charging station like this, one might go off-route and take a 5- or 15-minute detour just like a driver might do for a gas station. These options are therefore also considered.

Familiarity. Another aspect that EV drivers value is whether they are familiar with the charging point. EV drivers might prefer the charging points that they know and they have used before. People might have strong habits and value that they know exactly where to find and how to operate the charging point.

The attributes and their corresponding levels used in the DCEs are put forth in Table 3.

Table 3: Discrete choice experiment attributes and levels

Attribute	Levels	Explanation
Charging speed (in minutes for 100 km range) [3]	3 min / 20 min / 1.5 hour / 5 hours	Rate in which can be charged, based on 350 kW, 50 kW, 11 kW and 3.7 kW respectively.
Costs (in price for 20 kWh/100 km) [3]	2.5 eur / 5 eur / 7.5 eur / 10 eur	Costs for driving approximately 100 km.
Availability (in chance that a point is available)	40 % / 60 % / 80 % / 100 %	Chance that a charging point (the parking spot) is available. A 100% availability would be equal to a private charging point or a semi-public charging point where a sport has been reserved for the driver.
Location	Home / work / shop / corridor on route / corridor 5 min detour / corridor 15 min detour	Location of the charging point.
Familiarity	Yes / No	Whether the driver is already familiar with the charging point or not.

To give an example of two combinations:

- A charging point that costs 10 euro and takes 20 minutes to charge 100 km, on an on-route corridor charger with 80% availability chance and you are not yet familiar with, representing a fast charger that is deployed currently in the Netherlands.
- A charger at home, that takes 5 hours and costs 5 euros (0.25 eur per kWh) to charge 100 km, is 100% available and familiar to you. This resembles a charger like many EV drivers have at home currently.

These are two very relatable and realistic examples. In an DCE experiment however, the levels of the attributes are randomly set. All combinations of levels are possible alternatives in the DCE. This leads to unrealistic alternatives that are presented in the experiment. However, an analysis of an DCE is based on comparison of how many times levels of alternatives are chosen. To enable this comparison in the analysis, all possible alternatives should be presented and not just the realistic ones. The

[3] Based on the assumption that an electric vehicle drives around 0.2 km/kWh of electricity and the charging rate remains relatively constant throughout the charging session.

experiment aims to for instance to gain insight in how much EV drivers are willing to pay more for a faster charging rate.

This research experiment therefore includes no prohibitions. Furthermore, some charging points are not realistic for a scenario now, but the preferences of the EV drivers illustrate their needs and demands for the future. As their preferences highly impact the deployment of charging infrastructure, insights in what they value are useful on the longer term.

4.2.1.2. Scenarios for the discrete choice experiments

The preferences that EV drivers have are not only dependent on their general personal preferences but are also dependent on the situation they are currently in, the so-called use case. In a DCE experiment, a situation is explained, and the respondent is asked to imagine that he or she is in that situation. EV drivers' choices differ for the situation they are in: what type of car they are driving, what their planning for the coming days is, what their usual driving pattern is. These factors cannot be incorporated in the DCE since they are different for each respondent and there are too many variables to take into account.

Franke et al. (2012) researched psychological barriers in EV implementation and outline some concepts of stress-buffering traits. One of these is the range safety buffer, the concept that EV drivers experience stress when the range is decreasing, even when they have enough range to cover all their needs. People behave differently when they have a lesser range and tend to keep a range buffer to prevent stress. The range is therefore such an important factor of a scenario, that two separate DCEs are conducted in one survey in order to gain insight in how the range influences the choices of EV drivers.

EV drivers need some parameters and explanations before they can be a choice between alternatives in the DCE. The two DCEs have separate introductions. The scenarios are briefly explained below. The translated introductions that the respondents are given are shown in appendix D: Introductions and choice task examples.

Optional Charging scenario. In this scenario, the EV driver has a no direct need to charge. The respondent is asked to imagine the or she is driving a 300 km fully electric range vehicle. In the coming three days, he or she is planning to drive 250 km. The driver has two opportunities to charge **today**, e.g. two alternatives of charging points. The respondent is given a choice to choose either one of the charging points, but also the option to choose none of the options. In that case, they will not charge today, but charge on a different charging point on a later day.

Urgent Charging scenario. In this scenario, the EV driver has a direct need to charge. They have a 50 km range left in this scenario. Later on this day, they drive from their work location to their home via a shopping centre. It is intentionally not specified how long the trip from work to home is.[4] They are presented with three alternatives for charging points of which they will need to choose one. This implies that they will charge either at work, on their way, at the shopping centre or at home (whatever combination of 3 they are presented with). They can also indicate what option they would prefer the least.

Two scenarios call for two different DCE approaches. Whether or not a driver has the need to charge makes them approach the choice task differently. When there is no need to charge, the driver will

[4] On average a Dutch person travels 24 km between a home address and the workplace per day (CBS, 2018). It is assumed that one will experience the need to charge before the end of the day.

only choose a charging point that satisfies their demands, as they know they will have other options on other days. They will then exhibit utility-satisfying behaviour. The analysis of this data will then give insight in the question: what charging points are considered good enough to satisfy the EV drivers?

EV drivers that need to choose one and don't have the option to skip all charging points, are forced to choose their best and worst option. Choosing the best option is called utility-maximizing as they will choose the alternative with the highest perceived utility. The analysis of this DCE will answer the question: what attributes are considered most important for the choices of EV drivers and how do the attributes relate to each other?

Besides the situation being different in the two scenarios, there is also a different perception when a "none" option is included. Simple utility theory would suggest that in both scenarios, the same choices would be made, and utilities would be equal for the levels of attributes. However, both the context of the question as well as the "none" option that is included, cause different choices tasks of the respondents. The utilities of the two scenarios can thus not be compared without the context (Ben-Akiva et al., 2002).

Each respondent is asked to perform 8 choice tasks of the Optional Charging scenario and 8 of the Urgent Charging scenario. One example of one of each of a choice task is shown in appendix D: Introductions and choice task examples. During the choice tasks, respondents can refer to explanations of the attributes and the levels of the attributes by opening a pup-up with short explanations. They then make a trade-off between the alternatives presented.

An experiment design is created using Sawtooth Lighthouse software. This experimental design ensures that attribute levels have little to no correlation with each other, which makes it possible to assess the relative influence of each attribute on the choice for an alternative without any confounding factors. The design of the experiment will make sure that every respondent is given different alternatives.

The DCE is conducted as an online survey amongst EV drivers. They are firstly asked a couple of questions regarding their experience with driving in electric vehicles. Only respondents who regularly use an electric vehicle are directed to the DCE since they are perceived to have a better understanding of charging points and they have experience which makes it easier to imagine using one of the alternative charging points. This does not mean that they own an electric vehicle themselves, as they can also use the EV of a family member or a car sharing service. Respondents are also asked what EV model they most regularly drive, so plug-in hybrid (PHEV) driving respondents can be separated from full electric driving respondents in the analysis.

4.2.2. Analysing the survey data

After the DCE is conducted, the data of the experiments is analysed with a Hierarchical Bayesian (HB) analysis to estimate the utilities. HB methods are the newest and currently most used estimation methods in quantitative marketing research (Sawtooth Software, 2009). Below, the method of analysing the survey data is described. Firstly, the process of estimating each individual's utility values is set forth. Secondly, it is described how that leads to an estimation for the utility values of the population of EV drivers. Afterwards, it is shortly described how these utility values can be interpreted. Lastly, the process of calculating the relative importances for each attribute in the DCE is explained.[5]

Utility for each individual survey respondent. In an HB analysis, the first step is defining a vector of utility for each respondent. For each respondent to the survey, this vector is estimated using iteration. For each iteration, a new value for the individual's utility is created and then tested whether it represents an improvement. If the new iteration has a better probability of representing the individual's utility, it is accepted as the next estimate and so on until no better iteration is found. The probabilities (or "likelihood") of the utilities for each individual being correct are calculated using a logit model, which is incorporated in the Sawtooth Software package and described in the technical paper (Sawtooth Software, 2009).

Estimating the utility of the population. The individual's utilities are combined for the estimated utility of the population of EV drivers for each of the levels from the attributes. Below, the steps the software takes in the HB analysis are explained, adopted from the technical paper provided by Sawtooth Software (Sawtooth Software, 2009). The Sawtooth Software uses an equation to estimate the probability of the i_{th} person's choosing the k_{th} alternative. In short, the software makes the following steps:

1. Calculate the so-called part-worths: part-worths are estimates of the overall utility associated with each level of an attribute.
2. Multiply the part-worths for the attribute levels by a vector of descriptors of each alternative (a charging point option) to get the EV driver's individual utility for a certain alternative.
3. Exponentiate that alternative's utility.
4. Perform the same operations for other alternatives in that choice task.
5. Percentage the result for the alternatives by the sum of similar values for all alternatives.

The parameters to be estimated are the vectors of part-worths for each individual, the vector of means of the distribution of worths, and the matrix of the variances and covariances of that distribution. These parameters are all estimated by an iterative process in the Sawtooth software.

Final utility values. The final product of these estimations will be an estimate of utility values for the EV driver population of all charging point types. The chance of an EV driver choosing an alternative is derived from the total amount of satisfaction (utility) that a person expects to receive from this charging point, considering all attributes of this alternative. These values will answer research question 2a.

These utility values calculated by the Sawtooth Software are presented numerically where the sum of the utility of all levels of an alternative will equal 0. A level that has a negative utility is not favourable, while positive utility is favourable. These utilities however will not only tell us whether it is favourable or not, but also how favourable it is. For instance, if the utility of the location of charging at work is '+5' and the utility of the location home is '+30', it means that both are deemed favourable since they are both positive, but charging at the home location gives the EV driver relatively more satisfaction than the location of work does.

[5] Besides the final utilities, the results of the DCE can also be used for creating a market simulator (or a so-called choice model) in the Sawtooth Software. Choice models are not used for answering the research questions in this research. However, using the DCE data from this research several choice models were created to supplement the ABCD model. A short report of this can be found in appendix I.

Relative importances. The Sawtooth software calculates the relative importances for the attributes as well. Importance measures are based on differences between maximum and minimum utilities within each attribute (Sawtooth Software, 2017). These differences are preferred to using ratios of how much an attribute level has been chosen, as in that case attributes on which respondents disagree will appear to have less importance in the aggregate, even though respondents feel very strongly about their differences in opinions (Sawtooth Software, 2017). The relative importance illustrates how much difference each attribute could make in the total utility of a product and provides an answer to research question 2b.

4.3. Comparing stakeholders' views to EV drivers' preferences

In order to compare the quantitative data from the discrete choice experiment and the qualitative data from the interviews, a convergent design for mixed methods research is used. This basically entails collecting and analysing both quantitative and qualitative data and bringing these results together so they can be compared. In the comparison, it is analysed whether there is convergence, divergence or contradictions between the two sources of data (Creswell & Plano Clark, 2017).

After the stakeholder and EV driver research is done separately, topics are identified which are present in both datasets. Both the research parts include quantifiable data on the possible locations as well as the charging rates for the charging points. The location and charging rate can thus be used in the comparison. The comparison is made by extracting the comparable data and bringing it together in so-called joint display tables. Both the quantitative data and the qualitative data are transformed in two simple tables with types of charging points in order to compare the two datasets.

For each stakeholder that is interviewed, the results from filling in the interview tool charging point types (see appendix B) determines whether they include a certain type of charging point as relevant for the future of EV charging in their vision. When a stakeholder finds a charging point type relevant for the future of EV charging, they selected the corresponding box by crossing it out in the tool shown in appendix B. For the comparison, the table from appendix B is simplified so it only has 4 locations by deleting the detour corridor locations. Also, the way a charger is operated (private, public, semi-public) is left out for this simplification. Furthermore, the charging rate is simplified by only including 4 charging rates:

- Slow: 3.7 – 7.4 kW
- Medium: 11 – 22 kW
- Fast: 43 – 50 kW
- Ultra-fast: 150 – 300 kW

This results in Table 4 with 16 boxes for types of charging points:

Table 4: Simplified charging point types

	Home	Work	Shop	Corridor
Slow				
Medium				
Fast				
Ultra-fast				

For every time a stakeholder mentioned one of the 16 options as a focus, a count is added in the table. This results in a filled-in table that shows how many times a stakeholder has mentioned that type of charger as a focus.

Similarly, the discrete choice experiments results are also extracted and put in a similar table to Table 4. This is done for both scenarios, Urgent Charging and Optional Charging. The part-worth utility values of the location and the charging rate options are summed. These part-worth utility summations give an indication of the satisfaction that EV drivers get from a certain type of charging point on an ordinal scale (Orme, 2010a). Also in this case, the detour corridor locations are left out.

The tables have a similar set-up, which makes it possible to compare the results of discrete choice experiments and the stakeholders' views. To make an easier comparison, a colour scale is used. Both sets of tables are given a colour scale using the excel colour-scale function in Excel with red as a negative and green as the most positive stance against the type of charging point. Every charging point type (every box in Table 4) is given a colour according to the colour scale in Table 5.

Table 5: Scale colours for the joint display table

In the case of the discrete choice experiments, the highest resulting utility value is given a green colour and the lowest is given red colour. For the stakeholders' data, the charging point types that are mentioned most often are given a green colour and the types that are not mentioned a red colour. The results, showing possibly convergence, divergence or contradictions between stakeholders and the EV drivers, are then discussed.

5. Results

In this chapter of the thesis, the final results of the research are set forth. The results of the stakeholder analysis and interviews are presented. Secondly, the results of the discrete choice experiment are presented. Lastly, the comparison between the two is shown.

5.1. Results of stakeholders' views

Firstly, a list of the type of stakeholders is presented. Secondly, the stakeholders that were interviewed are categorized by the type of organisation, the relation to technology and their domain.

5.1.1. Stakeholder identification

A full list of the stakeholders that resulted from the stakeholder analysis can be found in Table 6 (A. Wargers, personal communication, May 2017; A. Hoekstra, personal communication, May 2017).

Table 6: Stakeholder abbreviations and core businesses

Abbreviation	Type of organisation	Main activity
CPO	Charge point operator	Installation, operation and maintenance of charging points.
CPO fast	Charge point operator for fast charging points	Installation, operation and maintenance of fast charging points.
CPM	Charge point manufacturer	Manufacturing and development of new charging points.
MSP	Mobility service provider	Link between the CPO and the customer: handling the billing and making sure their customers can charge at the charging points.
OEM	Original equipment manufacturers (for cars)	Manufacturing and development of new electric vehicles.
DSO	Distribution system operators	Installation, maintenance and operation of the low- and mid-voltage electricity grids.
ES	Energy suppliers	Supplying (and sometimes producing) energy for the charging points.
Car lease	Leasing agency	Leasing electric cars to EV drivers.
Advocacy	Advocacy/lobby organisation	Defending interests of organisations in the sector and EV drivers to policy makers.
Municipality	Municipality/county	Handling affairs dealing with public space, creating and carrying out permit policies.
National policy	Parliament/Ministry	Making policies, laws and/or regulations on a national level.
Consultancy	Consultancy/advisory company	Advising organisations, gaining knowledge through research and advising public and private organisations.

In the spring of 2017, 18 interviews were conducted. These were conducted in person at the work location of the interviewees. The interviews were recorded and the interview tools from appendix A, B, and C were filled in and preserved. The interviewees as well as their organisations are anonymized, only the type of organisation is mentioned. Some organisations have double roles. In Table 7, all organisations are numbered, and it is shown which attributes they are given. The interviews on average took 49.6 minutes. Of every interview, there is a summary in appendix E.

Table 7: Overview of conducted interviews and organisations' attributes

	Type of organisation	Public / Private	Relation to technology	Domain	Summary in appendix
1	Advisory	Private	Not directly related	Charging	**E1**
2	Car lease & CPO fast 1	Private	Working with	Charging/Vehicles	**E2**
3	Municipality1	Public	Not directly related	Regulatory	**E3**
4	Municipality2	Public	Not directly related	Regulatory	**E4**
5	OEM1	Private	Producing	Vehicles	**E5**
6	OEM2	Private	Producing	Vehicles	**E6**
7	National policy1	Public	Not directly related	Regulatory	**E7**
8	National policy2	Public	Not directly related	Regulatory	**E8**
9	CPM1	Private	Producing	Charging	**E9**
10	CPM2	Private	Producing	Charging	**E10**
11	MSP1 & CPO1	Private	Working with	Charging	**E11**
12	MSP2 & CPO2	Private	Working with	Charging	**E12**
13	CPO3	Private	Working with	Charging	**E13**
14	DSO1	Semi-public	Working with	Energy	**E14**
15	DSO2	Semi-public	Working with	Energy	**E15**
16	ES	Private	Working with	Energy	**E16**
17	Advocacy	Private	Not directly related	Vehicles	**E17**
18	CPO fast 2 & MSP3	Private	Working with	Charging	**E18**

Of most types of organisations, two were interviewed. Only one energy supplier was interviewed, due to availability of interviewees. Also, one advisory and one advocacy were interviewed. As these two stakeholders are not considered crucial, no time was invested in interviewing more than one of these.

The interview results show whether one group of organisations with similar attributes from Table 2 (for instance private, technology producing companies) have different ideas than organisations with other attributes. The results are divided into the most important subjects on electric vehicle charging: the charging rate, location of charging and other important concepts. The other important subjects include autonomous driving, energy system/smart charging and car sharing[6]. Possible patterns in these attitudes and visions on important subjects are discussed in paragraphs 5.1.2 to 5.1.4. The number of the appendix that the statements are derived from are put in brackets.

[6] The concepts autonomous driving (using vehicles with a so called self-driving function), smart charging (using intelligent charging schemes that unburden the energy system) and car sharing (shifting ownership of a car by one person to multiple) are topics that came up in many interviews as factors that influence EV charging in the future and are thus included.

5.1.2. Charging rate

All stakeholders believe that there will be some combination of fast and slower charging in the future. There is no clear alignment on what the ratio between the two will be however. While the national policy makers share no visions regarding charging rates, municipalities are misaligned amongst each other. They are both focusing on slow chargers at the moment, but their vision on fast charging differs.

One municipality (E4) sees fast chargers as an opportunity to use as little public space as possible in the future, as only a few fast chargers are needed to supply many vehicles in a neighbourhood, since the EV drivers won't have to be parked at the charger for a long time. The other municipality (E3) finds that the EV drivers themselves prefer slow charging as no requests for fast chargers are made. Chargers with 7.4 kW are sufficient for general use according to this municipality (E3). Thus, there is no consent between regulatory organisations on the topic of charging rate.

> *"We are more concerned with EV implementation and don't have vision on charging points specifically"* – National policy 1 (E7)

The argument of using little public space as well as servicing many EV drivers with one charging point, is expectably also given by private stakeholders, namely fast charging charge point operators or CPOs (E2 & E18) and a charge point manufacturer, CPM (E10) that produces fast charging points. Car manufacturer OEM (E6) supports this by saying that they are willing to work on creating a fast charging network as well so that their customers can drive anywhere, anytime.

The other OEM (E5) however, argues that batteries in the vehicles will become larger but the mobility needs do not call for fast chargers, as fast chargers would only be needed when the battery is almost empty and that rarely happens with 500km-range EVs. The other CPM (E9) also focuses on mobility needs and doesn't see the need for fast chargers:

> *"Often, charging is approached in a way that puts a focus on filling up the entire battery […]. It is compared with ICE cars, where you only fill up when the tank is empty. […]. But actually, you should charge according to your mobility needs. These mobility needs are usually driving from and to work, not huge distances. […]. For this reason, the slower charging methods will fulfil most people's needs."* – CPM 1 (E9)

Of the organisations that are producing technology, one OEM and one CPM's ideas align, while the other OEM and CPM's ideas also align, dividing the technology producing stakeholders into two "camps". One "camp" focuses on developing fast chargers so that Overall, they all agree that there are no technological barriers to develop sufficient charging infrastructure for EVs.

The MSP/CPO (E11) acknowledges the DSO net connection costs as a determining factor for the charging rate in the future, as the installation costs of 3-phase net connections are too high for most home locations. One DSO (E14) sees these costs as inevitable and as a fair price that will not change too much in the future. The other DSO (E15) also finds that home chargers are dependent on smart charging for a sufficient charging rate (as otherwise there is need for new net connections). The ES (E17) also recognises this. It can be concluded that stakeholders in the energy domain focus on lower charging rates combined with smart charging for home and work locations.

> "*In the smaller net connections, the successful implementation of EV charging is dependent on smart charging.*" – DSO 2 (E15)

5.1.3. Location

Work locations are preferred by a charge point operator CPO (E13), as they believe charging should happen at the least inconvenient place where one spends time. The charging rates should, according to that CPO (E13), be adapted to the locations and how much time EV drivers usually spend there. At shopping locations, you should be able to charge faster than at home for instance. The advocacy for EV drivers (E17) shares this view and states that work locations should have 22 kW chargers. One fast-charging CPO (E18) also recognizes the convenience of work charging for a large group of EV drivers. The same CPO (E13) sees charging at shopping centres as a very promising option to have a market share, as it fits EV drivers' schedule. A CPM (E10) and the advisory (E1) agree on this. Arguably, the views of the Car lease & CPO (E2) also fit with the above-mentioned visions, as it focuses on the places one comes daily for everyday use of charging stations.

> *"In the future, there will be a combination of corridor fast chargers and slow home or work chargers. At home or at work, when one has a private parking place where they can charge, this is a good solution for everyday use."* – Car lease & CPO fast (E2)

In the energy domain, home chargers are seen as very relevant in the future. ES (16) sees home and work charging as main locations. The DSO (E15) believes that everyone who can should be able to charge at home. A CPO (E13) also sees a large market share for charging at home, as well as MSP/CPO (E11). The MSP/CPO (E12) even says that having an EV makes less sense if you cannot charge at home.

> "*For everyone who can, charging at home should be facilitated.*" – DSO 2 (E15)

Municipalities (E3 and E4) and other organisations such as national policy makers (E7) and the advisory (E1) share concerns on public chargers on the streets near home locations. These stakeholders recognize public chargers near homes as logical locations that EV drivers might prefer but at the same time are concerned that these chargers take up public space (municipalities, E3 and E4) and negatively impact visual amenity. Home chargers that are privately owned (on EV drivers' own driveways) are thus be preferred by municipalities as these won't affect the street scene.

> *"This creates a dilemma that you can place multiple public slow chargers in a neighbourhood, but you could also place one or a few corridor fast charging points near that neighbourhood. For some neighbourhoods, this second option might be more desirable as the multiple slow chargers can change the appearance of the neighbourhood."* – Municipality (E4)

Corridor chargers are evidently part of the vision of fast charging CPOs, as corridor fast chargers are part of their business proposition. But besides this group, also an OEM (E6) recognizes the need for chargers on locations that are not one's home or work. This services EV drivers in such a way that they can be sure to have the freedom to go anywhere, anytime. The CPMs (E9 and E10) agree on this.

Thus, on one hand, a group of stakeholders (from different types and domains) find that charging should be adapted to locations where people spend time anyway such as work, home or shopping centre. Many of these stakeholders believe that there is a very little market share for corridor chargers. Their view is that the majority of charging will happen on destination chargers near work or home and corridor chargers are only needed for exceptions. On the other hand, there is another group of stakeholders, also from different domains and types, that argue that fast corridor chargers are more relevant because they can service more EV drivers while also increasing the (perceived) comfort of being able to charge anywhere.

5.1.4. Other important concepts

***Car sharing*.** In interviews with CPO fast (E18), CPM (E10), OEM (E5), car lease/CPO fast (E2) and advisory (E1), car sharing came up as an important part of their future vision. They believe it affects the charging infrastructure and it will influence the demand for fast charging, as it will increase the mobility of one EV since it will be shared amongst multiple users. This is an important concept, as it would have an effect on the mobility needs of a vehicle that were discussed in section 5.1.2. A shared car will drive more kilometres than the mobility needs for one EV driver and therefore have a larger demand for charging.

The CPO (E13) and MSP/CPO (E12) are exceptions on the topic and do not see car sharing becoming mainstream in the future. One MSP/CPO (E11) sees car sharing as an emerging development, but does not see it affecting the charging infrastructure. Also, a CPM (E9) sees that car sharing will become an important concept, but this will still not increase a demand for fast charging. The batteries of cars are large enough to last at least a day, even with a shared car, and during the night they can be charged on AC chargers.

> *"Car sharing, form a psychological point of view, will not become popular for the mainstream. People value ownership too much to start sharing their cars."* - MSP2 & CPO2 (E12)

Many other organisations recognize car sharing as a concept that will emerge within the coming years, but most of them did not adapt their strategy to this. There is only one pattern that can be distilled on the topic of car sharing: the organisations that do not see car sharing either becoming popular or having an effect on the charging infrastructure are all private organisations in the charging domain.

***Autonomous driving*.** The concept of autonomous driving is mentioned by OEM (E5), car lease/CPO fast (E2), advisory (E1), national policy (E8), CPM (E10), all MSPs/CPOs (E11, E12, E13 and E18), advocacy (E17) and DSOs (E14 and E15). There are many differences in stakeholders' in how autonomous driving will affect the charging infrastructure.

The MSP/CPO (E11) and advisory (E1) see it as a good combination with (fast) induction charging. DSO (E14), advocacy (E17) and national policy (E8) believe it will increase the demand for fast charging. On the other hand, a CPM (E10) recognizes that the autonomous car might drive itself to a slower charging station anywhere at a time the vehicle isn't needed, meaning that it wouldn't necessarily need to charge fast.

There is no consensus amongst any type of stakeholder as for when autonomous driving will become a mature technology. Some believe it will penetrate the market in 2020, while others see more practical barriers and do not see it happening this soon.

***Smart charging*.** All public and semi-public organisations mention charging in a smart way is needed to unburden the electricity system in the Netherlands. As public organisations however do not have the crucial knowledge on how it works and should be implemented, they don't have a strategy for this. The views of the private and semi-public organisations are discussed. Smart charging is mostly relevant to AC charging up to 22 kW.

"Smart charging at home and the workplace, whenever there is more sustainable energy available, will be implemented in the near future. This year already, and it will become more important. It is both cost-efficient and sustainable to smart charge. Smart charging can be sold as a product […]" – OEM (E6)

In general, almost all parties see that EVs have the opportunity to store energy and smart charging can be used in the future more renewable energy system and therefore can be part of the market for flexible electricity. This means that with (a pool of) EV batteries, you can trade on the flexibility energy market. However, while they agree that this is valuable in the future, they do not agree on who will capture that value. This can be the MSPs, the CPOs or an ES in a double role. The car lease company (E2) sees that if they own of the batteries of the EVs, the capacity is theirs and not that of an MSP or CPO.

The DSO (E14) sees that EV drivers can capture the value by getting discounts if they allow their car to be charged in a "smart" way. Some organisations, such as CPM (E9), MSP/CPO (E11) and DSO (E16) mention that see smart charging as a pre-condition for charging at home or work to function. There are no clear patterns found in the stakeholders' views concerning smart charging amongst the different relations to technology or domains of stakeholders.

5.2. Results of EV drivers' preferences

This chapter described the result of the Discrete Choice Experiments. First, some insight in the respondents of the survey is given. Then an analysis of the DCE results is done using a Hierarchical Bayes analysis method, determining utility values. The relative importances of the attributes are also set forth.

5.2.1. Survey respondents

The survey with the DCEs was conducted online between 14-04-2017 and 31-07-2017. It was put out to groups of EV drivers using the platforms of the VER (Dutch electric transport association), several Facebook pages for electric vehicle owners, the blog of TU Eindhoven professor Maarten Steinbuch, Twitter and LinkedIn. The survey was started 497 times. This includes respondents who do not regularly drive electric vehicles and respondents who did not finish the entire survey. The respondents that regularly drive an EV or PHEV are asked what model car they drive. These are distributed as shown in Figure 2. A total of 38% of all respondents are Tesla (Model S or X) drivers.

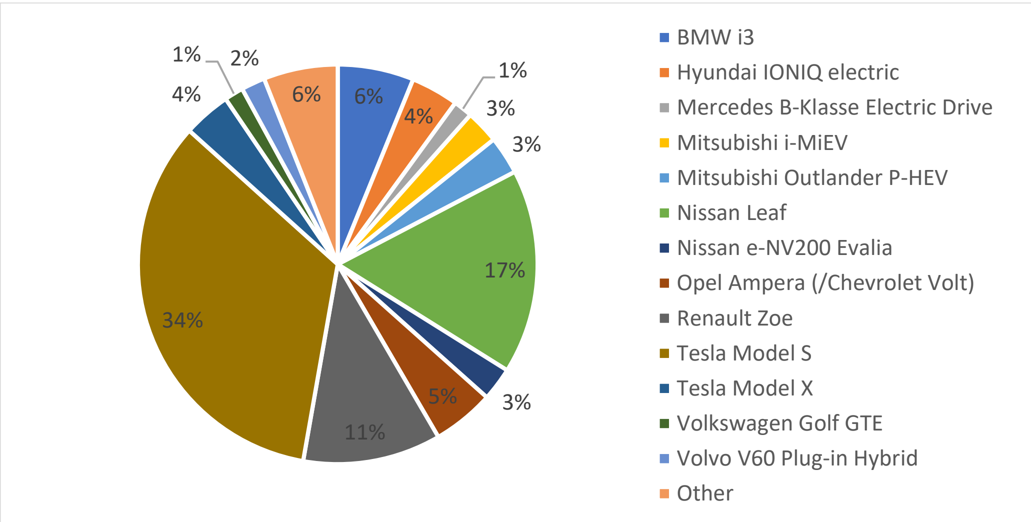

Figure 2: Most used EV model of respondents

Some other average characteristics of the respondents are shown in Table 8 below, to give an idea of the demographics of the respondents. These characteristics show that high-income men have filled in the survey mostly opposed to other demographic groups.

Table 8: Characteristics of respondents

	Average
Number of months they have regularly driven an EV	28.4 months
Times they charge their EV per week	5.7 times
Age	45.7 years

Men	91%
Women	9%

Gross income	%
Below 3000 euro	16.3%
Between 3000-4500 euro	24.0%
More than 4500	44.0%
Unspecified	15.7%

To complete the choice task while thinking through and trading off carefully, respondents would require some time to fully read the questions and understand them. The Sawtooth Software registers the time a respondent has been on a page with questions. There are 33 questions in the survey in total which includes 16 choice tasks. Respondents who did not take more than 8 minutes throughout the survey are considered unreliable, as they probably clicked through some parts without reading and choosing carefully and therefore filtered out. This filter leaves 375 respondents. The number of people who regularly drive an EV, took at least 8 minutes in the survey and completed all choice tasks is 330.

The data of choice tasks the was collected in numeral variables of either the option 1, 2 or 3 (where 3 is the 'none' option in Optional Charging scenario. The respondents' number is linked to the experimental design, of which each respondent was given a unique one, to link the choices to corresponding levels of attributes.

5.2.2. Discrete choice experiment analysis

The analysis is carried out using the Sawtooth Software Lighthouse software package. The visual representations of the iterations in the runs of the part-worth estimations can be found in appendix F: Hierarchical Bayes analysis runs. Furthermore, a table with the values for the utilities can be found in appendix G: Utilities and confidence intervals. The sum of the utilities for every attribute (location, charging rate, price, availability and familiarity) always equals zero.

Charging rate. In Figure 3, the utility values for the different charging rates are shown in a bar-graph including both the Optional Charging and the Urgent Charging scenarios.

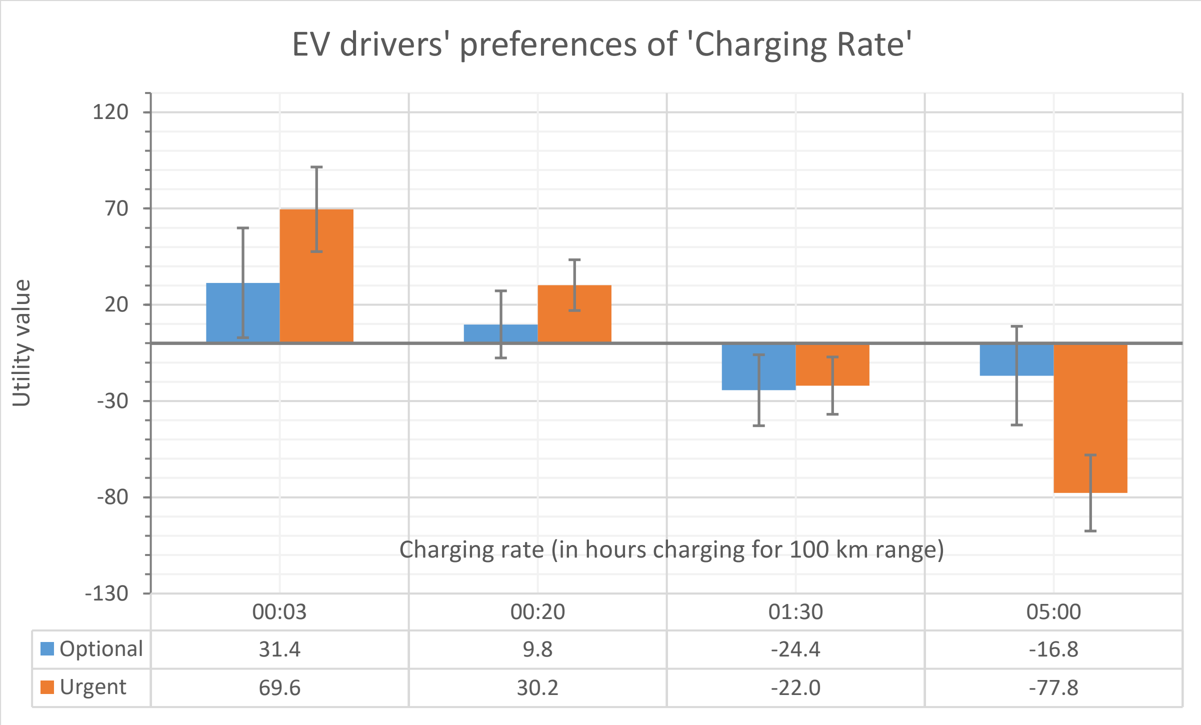

Figure 3: EV drivers' preferences of charging rate

The graph shows that the 3 min charging rate has the highest utility value in both scenarios, meaning that EV drivers prefer charging ultra-fast (3 min) over slowly (5 hours). The graph also shows that in the Urgent Charging scenario, a relatively higher utility value (69.6) is allocated for charging ultra-fast then in the Optional Charging scenario (31.4 utility value). This indicates that with a lower state of charge (SOC) there is an even stronger preference for charging quickly.

Notably, the utility value for the 5-hour charging rate option is higher (-16.82) than for the 90min (1h30min) rate (-24.39). This is not an expected result, but the standard deviations of these utilities show that the results are not significant enough to draw conclusions on this with this level of significance.

In the Urgent Charging scenario, a clear trend can be distinguished. The faster charging rates have higher utilities. For the Optional Charging scenario, the error bars show that the standard deviations are larger. In this Optional Charging scenario, the EV drivers' preferences are more distributed than in the Urgent Charging scenario.

Price. For the prices, shown in Figure 4, there is a significant trend where lower prices are strongly preferred to the higher prices in the Optional Charging scenario. In the Urgent Charging scenario however, the difference between average utilities is smaller and the error bars are significantly larger, which indicates that in this case the EV drivers were more divided in their preferences.

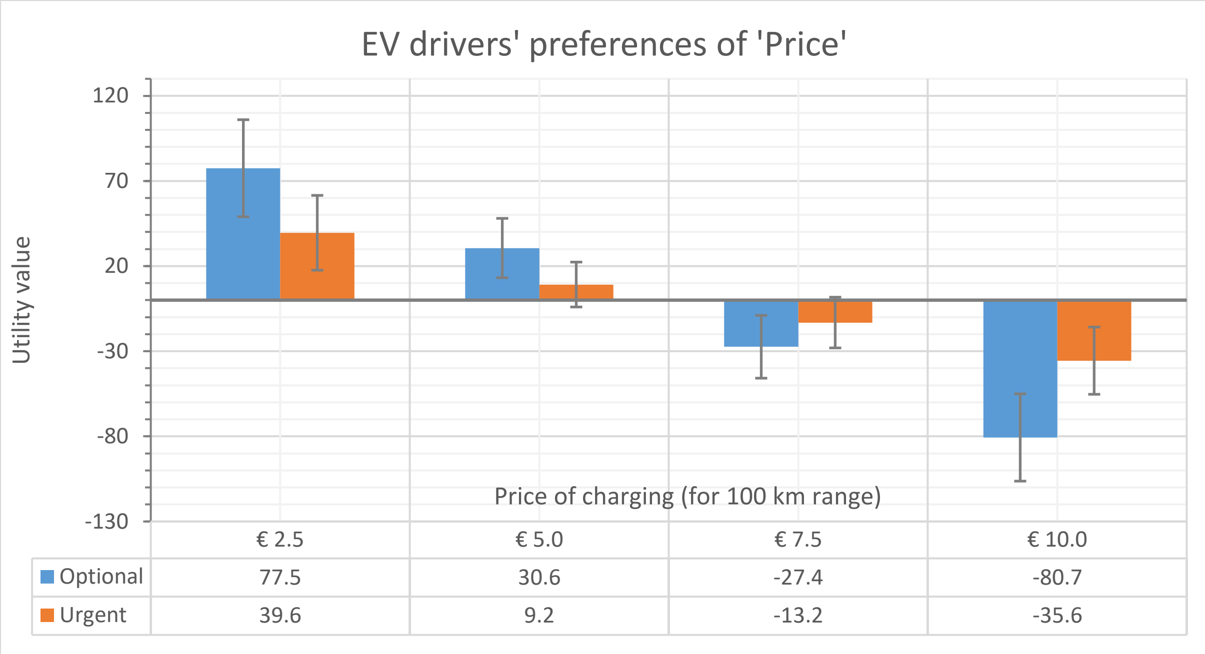

Figure 4: EV drivers' preferences of price

In general, the same trends for the utilities of the attribute levels can be found in the Optional Charging scenario. The difference in average utility for the prices, from (39.56—35.56=) 75.12 for Urgent Charging to (77.47—80.67=) 158.14 for Optional Charging shows that EV drivers get more satisfaction from finding the right price in a scenario where there is no urgency to charge compared to when there is urgency.

Location. Figure 5 displays the utility values for the location of charging points. The locations are put in order of where one spends most of their time in a general situation. People would generally spend most of their 24 hours in a day at home, followed by at work, followed by other places such as a shop and then on-route, ending with detours.

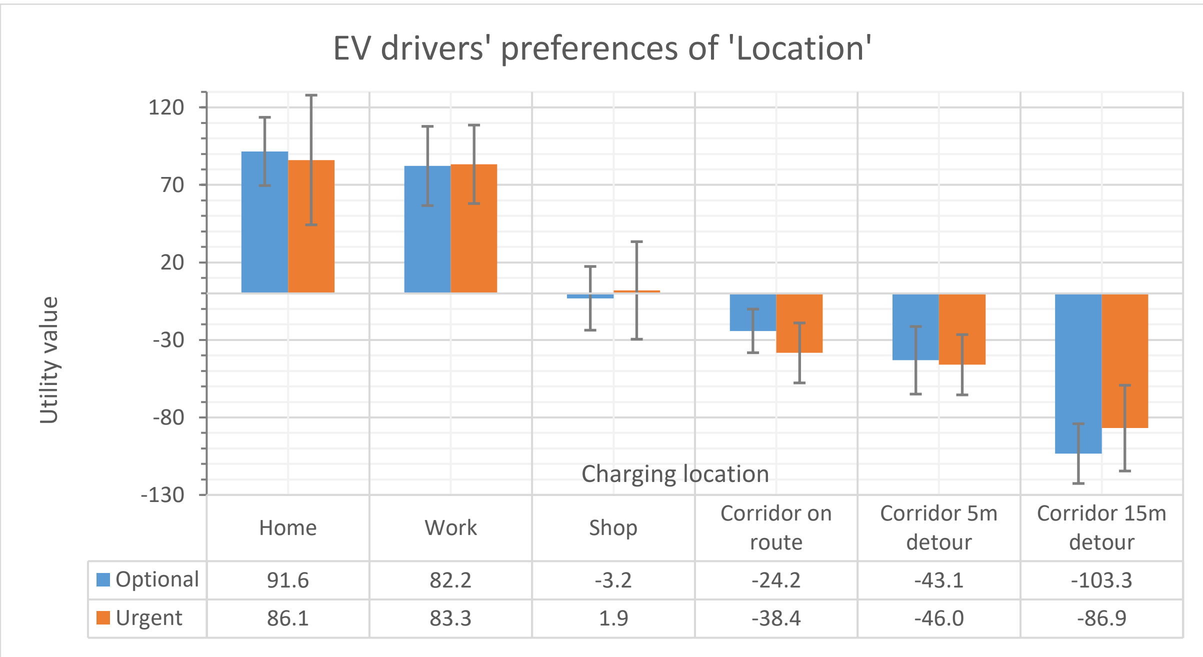

Figure 5: EV drivers' preferences of location

The graph above shows that the home location has the highest utility value for both scenarios, closely followed by the work location. The shop doesn't have a significant positive or negative utility value, suggesting that EV drivers get no satisfaction nor dissatisfaction from charging at a shop. The corridor charger locations have negative utility values descending with the amount of minutes for the detour.

Availability. The graph in Figure 6 shows the utility values for the chance that a charger is available. Although the values are lower in general then for the other characteristics of the charging points such as charging rate, location and price, it shows a higher utility for chargers where there is a 100% chance that the charger is available for the EV driver such as a private or reserved parking spot.

The high utility value (30.6) for the 100% in the Urgent Charging scenario shows that EV drivers get satisfaction from knowing that a charging point is available when the state of charge of their vehicle's battery is low.

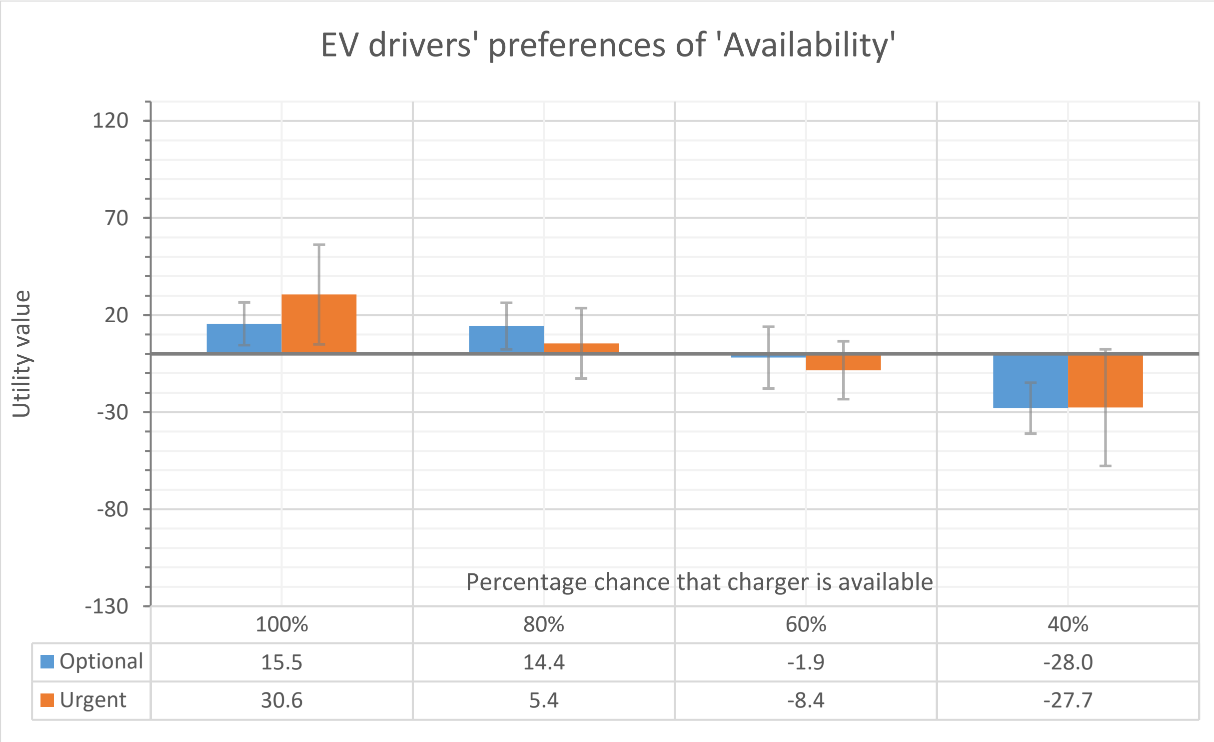

Figure 6: EV drivers' preferences of availability

Familiarity. Figure 7 shows the utility values for the attribute familiarity. These results show that there is no significant satisfaction or dissatisfactions an EV drivers gets when choosing a charging point they already know or do not yet know.

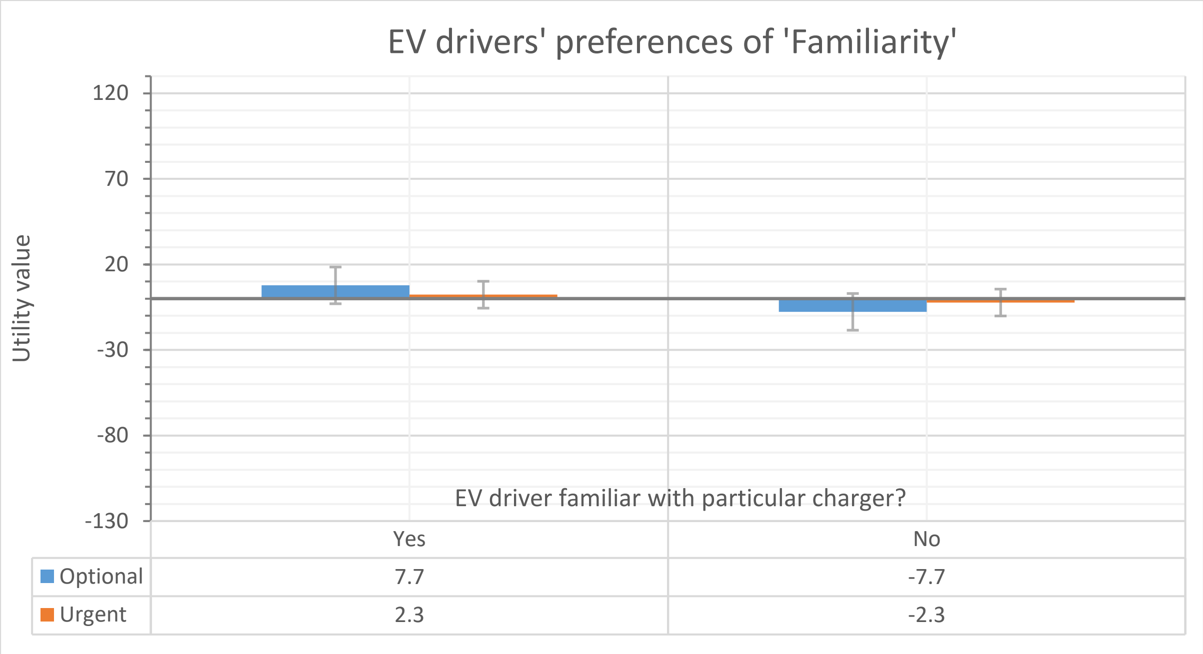

Figure 7: EV drivers' preferences of familiarity

The on average larger standard deviations for the utilities in the analysis for Urgent Charging imply that preferences of EV drivers vary less when there is a higher need to charge. When they have a battery charge for three days, they show more distinctive behaviour. When the need to charge is higher, their preferences are more consistent amongst each other.

5.2.3. Relative importances

The relative importances are shown in Figure 8 and Figure 9 below in circle diagrams.

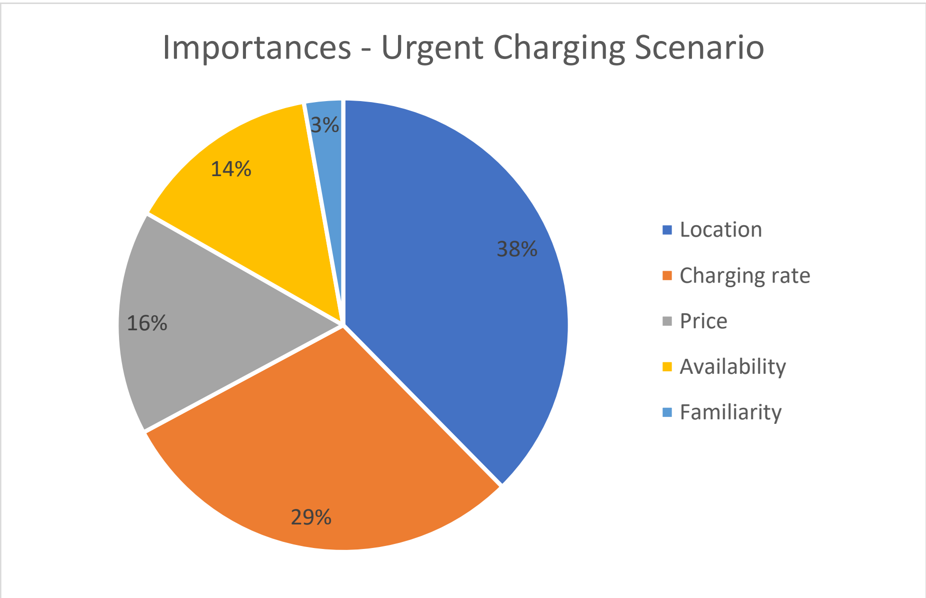

Figure 8: Relative importances Urgent Charging scenario

This relative importance shows that the location attribute is deemed most important for the respondents when choosing between alternatives, and familiarity is deemed less important.

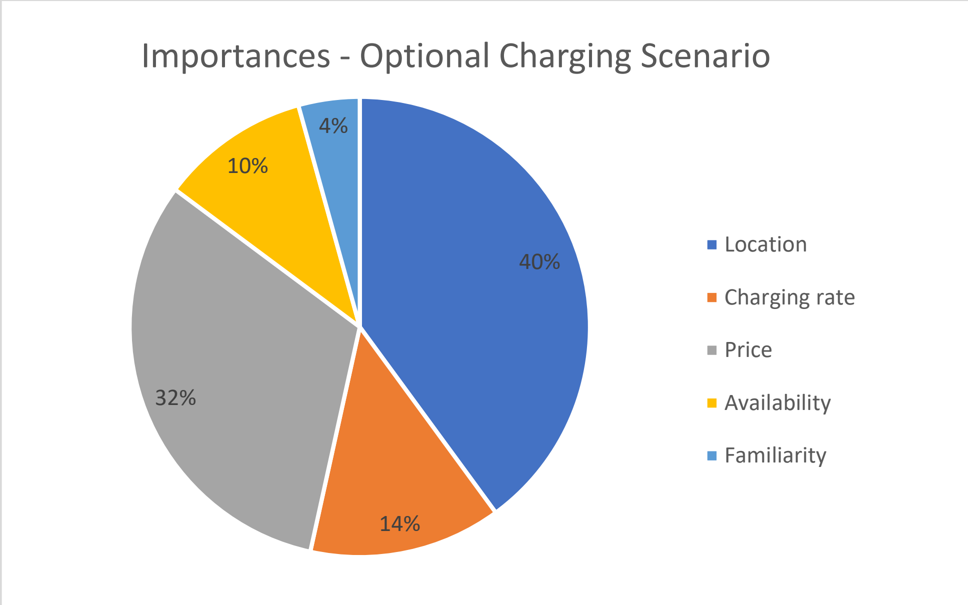

Figure 9: Relative importances Optional Charging scenario

In the Optional Charging scenario, the price is deemed more important when making a choice. This implies that EV drivers will put more effort in finding a charging point with a lower price when there is less of an urgency to charge. The relative importances do not specify which levels are most desirable within the location attribute. The desirability for users may vary greatly. For instance, one likes charging at home better than at work, while another EV driver may have the opposite preference. The utilities of these levels will than differ, but they could find the location equally important in making a choice.

Table 9: Confidence interval data relative importances

Optional Charging scenario	Importance	Std Deviation	Lower 95% CI	Upper 95% CI
Location	39.87	6.86	39.13	40.61
Charging rate	13.54	8.18	12.66	14.42
Price	31.66	8.46	30.75	32.58
Availability	10.45	3.43	10.08	10.82
Familiarity	4.47	2.82	4.17	4.77
Urgent Charging scenario	Importance	Std Deviation	Lower 95% CI	Upper 95% CI
Location	37.74	8.98	36.77	38.71
Charging rate	29.59	7.57	28.78	30.41
Price	16.08	8.25	15.19	16.97
Availability	14.02	8.72	13.08	14.96
Familiarity	2.56	2.04	2.34	2.78

Table 9 shows the data including the 95% confidence intervals of these relatives importances. it shows that in the Urgent Charging scenario, the standard deviations on location and availability are significantly higher than in the Optional Charging scenario. This would imply that there is a greater variance amongst EV drivers in the Urgent Charging scenario concerning the importances of location and availability.

5.3. Comparison of stakeholders' views and EV drivers' preferences

Table 10 displays the results of the added utility values for both scenarios as well as the stakeholders' focus points. In this joint display table, the colour scaling is used to visually compare the outcomes of the two parts of the research. As mentioned in paragraph 4.3, only location and charging rate are compared.

Parts 1 and 2 are results of the summed utility values for each of the 16 options in this 4 by 4 matrix of charging point types. Part 3 counts the number of times a stakeholder mentioned a certain type of charger as a focus point in their vision.

Table 10: Joint display table comparing EV drivers' preferences and stakeholders' views

Part 1: EV Drivers preferences in Optional Charging scenario
Based on the combined utility values

Rate	Location			
	Home	Work	Shop	Corridor
Slow	75	65	-20	-41
Medium	67	58	-28	-49
Fast	101	92	7	-14
Ultra-fast	123	114	28	7

Part 2: EV Drivers utility values in Urgent Charging scenario
Based on the combined utility values

Rate	Location			
	Home	Work	Shop	Corridor
Slow	8	6	-76	-116
Medium	64	61	-20	-60
Fast	116	113	32	-8
Ultra-fast	156	153	72	31

Part 3: Stakeholders focus points[7]
Number of times a stakeholder mentioned it as a focus in their vision

Rate	Location			
	Home	Work	Shop	Corridor
Slow	8	5	3	0
Medium	15	15	9	0
Fast	0	3	2	3
Ultra-fast	0	0	1	9

The used colour scale displays some convergence, divergence and contradictions between the three parts. It is clear that corridor slow and medium charging is not an option for any of the stakeholders, including the EV drivers. Furthermore, there is convergence between the scores for the home and work medium rate chargers as these have a relatively positive score for all parties.

Slow home and work chargers are also positively seen by all groups, but there is some divergence. In the Optional Charging scenario, EV drivers have an equally positive preference for slow as for medium home and work chargers, where medium home and work chargers are significantly preferred over slow ones in the Urgent Charging scenario as well as by stakeholders.

[7] The results divided into type of organisation, domain and relation to technology, are displayed in appendix H.

Notably, the utility values of EV drivers for fast and ultra-fast charging are high, which causes a very positive score for fast and ultra-fast charging points at home and work as well. This strongly contradicts the visions of stakeholders, of which none mentioned these charging point types as part of their vision. These chargers are in general technically not possible at home or work locations because these locations do not have the net connection to realize these charging rates. Both the stakeholders, as well as the EV drivers, have a significantly more positive view on ultra-fast chargers of 150 - 300 kW as opposed to fast chargers of 43 - 50 kW.

Concerning chargers at shop locations, the EV drivers' state a stronger preference for charging at a shop in an Urgent Charging scenario than they did in the Optional Charging scenario. Many stakeholders focus on medium chargers near shops, whereas EV drivers prefer fast and ultra-fast chargers overall.

6. Discussions and conclusions

This chapter will discuss the results found. It will firstly discuss the results of the stakeholders' views and provide conclusions for this part of the research. Secondly, the discussion and conclusion on the results of the EV drivers' preferences research is put forth. Lastly, the comparison of the stakeholders' views to the EV drivers' preferences is discussed and some final conclusions on this comparison are drawn.

6.1. Discussion and conclusion on stakeholders' views

18 interviews were held with 12 different types of organisations (see Table 6), where some stakeholders had double roles. In semi-structured interviews, open-ended questions were asked on how stakeholders view the future of EV charging. The portrayed future was different for every single stakeholder, so no general and consensual view of all stakeholders can be distilled. Overall, there were few distinct patterns found in the view of stakeholders with a certain type of organisation (public/private), domain or relation to technology. Some key takeaways are discussed below.

An interesting observation is that public organisations lack vision. National policy makers have no vision on the types of charging stations and municipalities are mostly concerned with chargers taking up public space. In a previous study on stakeholders including OEMs and regulators by Santos & Davies (2019), it was argued that visible charging stations in the public space improve the visibility of chargers and positively impact the implementation of EVs. This opposes the view of the municipalities and an advisory in this study, as they prefer charging stations that do not take up public space and negatively impact visual amenity. Whether visible charging stations will help to reach the national and international climate goals should thus be researched.

The technology producing stakeholders, namely OEMs (car manufacturers) and CPMs (charge point manufacturers) can be divided into two "camps". One camp focuses on home and work charging, as they argue that this is what people would prefer and where EV drivers spend time anyway. The other camp sees an important role for fast charging in the future charging infrastructure.

During the interviews, the stakeholders filled in a tool (see appendix B) on charging point types. Table 10 shows that 9 out of 18 stakeholders see fast corridor charging as relevant. The results of filling in the interview tool on charging point types show similar results to the conclusions drawn from the text from the interview summaries. In both results, the two "camps" are visible, which demonstrates the internal validity of this research.

Home/work medium and slow chargers are a focus for 15 out of 18 stakeholders. The ratio of home and work chargers are influences by EV battery size, autonomous driving, net connection limitations, car sharing and so on. However, stakeholders have varying ideas of how these concepts influence the charging infrastructure of the future. Within all domains and types of relations to technology, large variations on the effects of these concepts exist. Even within DSOs, who operate the electricity network, ideas on future electricity system and how EVs can be incorporated differ.

Several charge point operators (CPOs) and manufacturers (CPMs) indicate that the most important stakeholder group who influences the charging infrastructure will be the OEMs. Many stakeholders, especially in the energy sector, mention DSO net connections as an important factor for EV charging and smart charging as a precondition for the implementation of EVs. Although the interviewees of national policy organisations didn't mention smart charging, the views of the stakeholders in the energy sector on the importance of smart charging resonate with the vision document of the Dutch national government (Rijksoverheid, 2016). The vision document of the Dutch national government differs from the views of the national policy interviewees, which shows a lack of unity within the government.

A note for further research is that a so-called stakeholder Power-Interest Matrix could provide quantification of the interests of different stakeholders and the impact they have on certain types of charging points (Ginige, Amaratunga, & Haigh, 2018). Closed questions would have to be asked to be able to quantify the interests and assumptions would have to be made on the influence of certain stakeholder. This method is often used as a practical tool in project management, but not in scientific literature.

As van Galen (2015) already concluded, stakeholders in the charging domain are misaligned when it comes to deployment of public charging station. The results from this research have shown that misalignment between stakeholder views is significant when it comes to all types of charging stations. Furthermore, it is important to note that the questions on who the stakeholders partner with were very frequently answered with “we partner with all stakeholders from the sheet”. The relationships between the stakeholders are not clear as new organisations arise, and established organisations take on new roles.

Most stakeholders have a vision on what the future charging infrastructure will look like. However, the argumentations and reasoning behind their views differ, causing stakeholders to have different visions for the future. The inconsistency on the views for the future socio-technical system are caused by complexity of the subject. The effect of different innovations on the system is unclear. The interactions between the possibilities offered by emerging technologies and the behaviour of people should be a topic for further research.

6.2. Discussion and conclusion on EV drivers’ preferences

The EV drivers have a strong preference for faster chargers in a scenario where their battery is almost empty. When it is not empty, the charging rate is considered about half as important (29% compared to 14% relative importance) and prices are considered more important (32% compared to 16%). To conclude, EV drivers’ preferences strongly vary depending on their situation. This implies that there will be a demand for different types of charging points.

Of the respondents, 45 started the survey and stated they regularly drive an EV but did not complete all choice tasks. This might imply that the questions were not clear enough for this group or the survey was too lengthy. Some respondents might have clicked through some of the choice tasks without consideration, which would increase the uncertainty. The Optional Charging scenario was the first part of the survey, while the Urgent Charging scenario turned out to have the lowest standard deviation. Respondents clicking through without consideration is expected more in the final part of the survey. It is therefore assumed that clicking through the survey did not impact the results of this research.

Some respondents commented that they found the questions too hypothetical. For instance, one of the respondents indicated “I never chose the work charger, since I can’t charge at work”. This would affect the results in such a way that they are biased towards charging point types that respondents can relate to more. Furthermore, one respondent also commented “I want to charge smart on renewable energy, so I don’t like fast chargers”. In this case, they would not choose according to what they would find most comfortable, but what they believe is the best EV charging system. A DCE analysis never results in fully objective utilities (Orme, 2010a). The comments made by the EV drivers in the survey illustrate that the information the respondent has from experiences changes the perception of the attributes.

For further research, using a Latent Class Model (LCM) to analyse EV drivers' preferences is proposed. An LCM uses the same DCE data as in the Hierarchical Bayes (HB) analysis but includes a different statistical analysis. Traditional models used in regression analysis contain parameters that describe only relationships between the observed variables. LCMs differ from these by including one or more discrete unobserved variables that remain undefined. One can interpret the categories of these latent variables, the latent classes, as clusters or segments of people (Magidson & Vermunt, 2003).

Passenger mobility is not a homogenous subject, as people travel for different reasons and use different mobility options (CBS, 2018). As passenger mobility choices depend on many factors and personal preferences, EV drivers can potentially be divided into groups that have similar preferences. These can be sorted in latent classes. The respondents can be distributed amongst groups using a statistical LCM method. The underlying theory of LCM is that individual behaviour of respondents depends on observable attributes and also on latent heterogeneity that varies with factors that are unobserved by the researcher (Hensher et al., 2005).

The standard deviations in the DCE dataset indicate that there is an important factor, or different factors, that were not embedded in the attributes of the DCE. These can be part of the before mentioned perception, but this should be further researched. There is a larger variance in what levels of attributes EV drivers prefer in the Optional Charging scenario compared to the Urgent Charging scenario.

There is not a significantly larger variance in the relative importances of the attributes. This would imply that the respondents agree on what attributes are important in the Optional Charging scenario equally as much as they agree on what attributes are important in the Urgent Charging scenario.

However, concerning the levels of the attributes, in the Optional Charging scenario they disagree on what levels they prefer more than in the Urgent Charging scenario. Thus, when charging is not necessary, the EV drivers still find the same attributes such as location important, but what specific locations they prefer vary more amongst EV drivers than in the Urgent Charging scenario.

Morrissey et al. (2016) already found that the EV drivers' behaviour is not homogenous. The results of this research show support this, especially in the case of Optional Charging scenario. In the Urgent Charging scenario, it is relatively more homogenous and EV drivers prefer to charge as fast as possible.

6.3. Discussion and conclusion on comparison of stakeholders' views and EV drivers' preferences

Home chargers are, especially in an optional charging scenario where charging is not needed, preferred by EV drivers. In cities, where not everyone has a driveway, this will create a need for publicly operated chargers in the public space near EV drivers' houses. This need will be less when people would be able to charge at work as the work location also has a positive utility value. Medium-rate 11 to 22 kW home and work chargers are considered by both the stakeholders (15 out of 18) as well as the EV drivers (relatively positive utility values) as an important part of the EV charging infrastructure of the future. The stakeholders' views align with EV drivers' preferences in the case of medium rate home and work chargers.

EV drivers have a strong preference for ultra-fast charging, especially in a scenario where the EV's battery is almost empty and there is an urgent need to charge. Some stakeholders, including an OEM, CPO and CPM see ultra-fast chargers as a focus point. Both the stakeholders, as well as the EV drivers, have a significantly more positive view on ultra-fast chargers of 150 - 300 kW as opposed to fast chargers of 43 - 50 kW.

EV drivers would also prefer (ultra-)fast chargers at work or home locations. Net connections near houses and work generally do not allow these types of chargers. An alternative for this could be ultra-fast chargers not just near highways, but around hubs where people work and neighborhoods where people live as well.

Utility values of levels within attributes are relative and are always in comparison to the other levels within that attribute. It should be noted that for the comparison, the utility values of corridor chargers on a 5- or 15-minute detour were not taken into account. The stakeholder tool did not include detour corridor chargers and the comparison was therefore simplified. Furthermore, the utility values of the different attribute levels (the part-worths) were simply added, which did not account for complex effects like two-way interactions and cross-effects.

The comparison between stakeholders' views and EV drivers' preferences is a very simplified analysis of a complex socio-technical system. EV drivers' preferences may change resulting from new innovations, public opinions and a shifting paradigm. Depending on the shift of the paradigm, the future charging infrastructure will adapt. The socio-technical system of passenger mobility is closely related to the energy system. The effects of innovations such as car sharing, smart charging and autonomous driving should be further researched. Possible scenarios on this should be drafted, which can be used by stakeholders to adapt their strategy.

7. Concluding remarks

It is clear that charging points are not just the support system for EVs, and also not just appliances connected to an end of the electricity network. They are the link between the passenger mobility system and the electricity system. How these two should be linked, e.g. what type of charging points should be deployed, is still up for debate. The link of these two socio-technical systems calls for interdisciplinary research. Technology is developing rapidly, and human behaviour also influences the implementation of different types of charging points. Further research should look into scenarios how upcoming innovations will influence the electric vehicle charging infrastructure of the future.

In general, one could say there is a gap between mathematical models and conceptual innovation theories. While one is quantitative, the other is only qualitative description of the system. Both perspectives are relevant for EV charging, as mathematical models can for instance calculate electricity demands and interpretations of the socio-technical system will help us understand how innovations will emerge within our society.

This research aims to bridge this gap, using both interview data on stakeholders and predictions of EV drivers' behaviour. It uses interdisciplinary data to grasp the future of EV charging. When modelling a complete socio-technical system, one must include social, environmental and economic factors. It is impossible to include the full system in one simulation model. However, this research sets an important conceptual basis for stakeholders and provides substantiated parameters for the behaviour of EV drivers that make the ABCD model more realistic.

"All models are wrong – some are useful." - Box (2014)

8. References

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9. Appendices

A. Interview tool stakeholders

Figure 10 was used in the first part (on organisation and partners) of the stakeholder interviews.

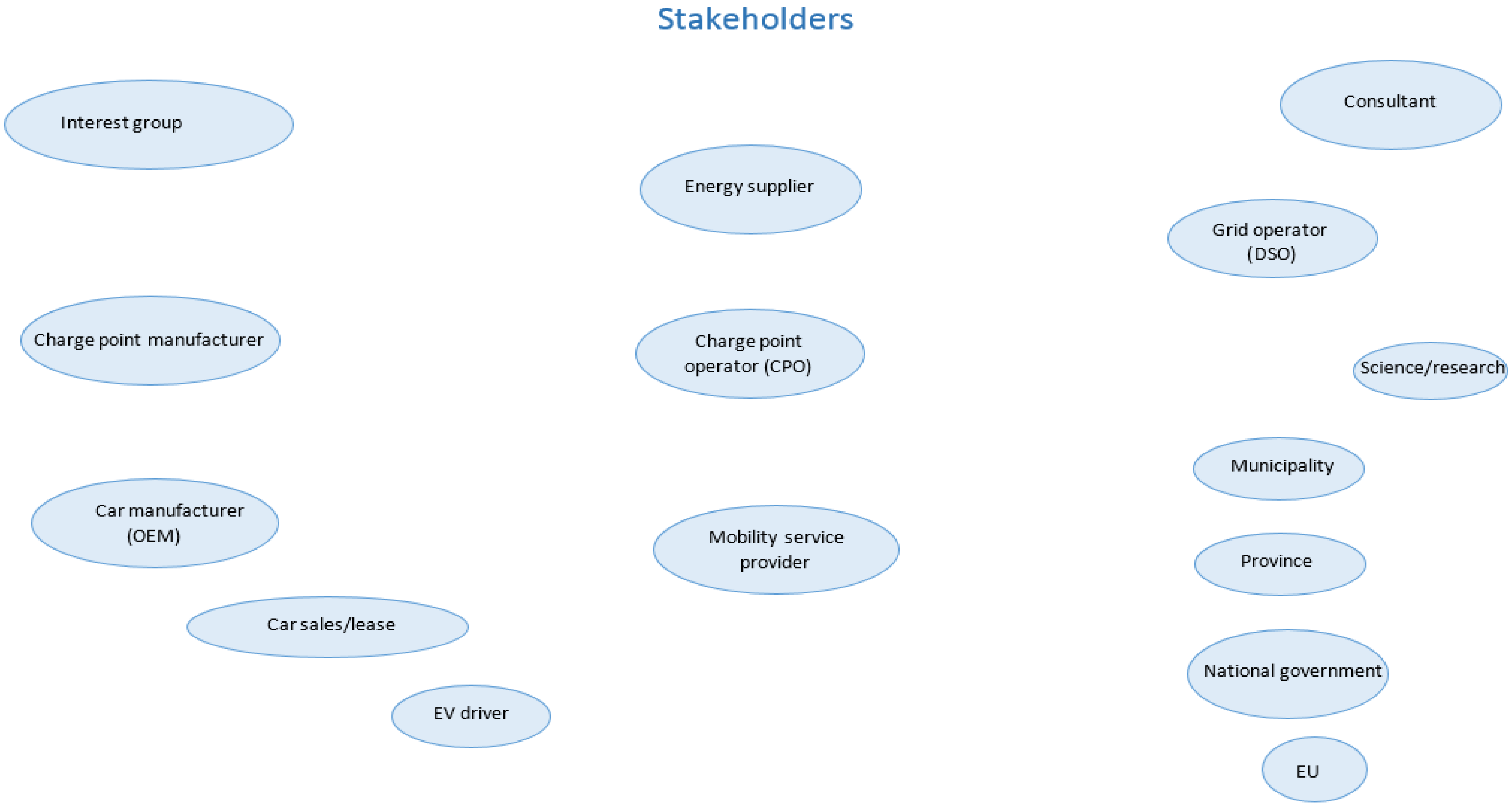

Figure 10: Interview tool 1 - Stakeholders

B. Interview tool charging point types

Figure 11 was used in the second part (on types of charging points) of the stakeholder interviews.

Matrix charge point types

		Home			**Workplace**			**Other destination**			**Corridor**		
	Charging rate	Public	Private	Semi-public	Public	Private	Semi-public	Public	Private	Semi-public	Public	Private	Semi-public
AC 1-phase	3.7 kW												
	7.4 kW												
	....												
AC 3-phase	11.0 kW												
	22.1 kW												
	43.5 kW												
	....												
DC	50 kW												
	120 kW												
	150 kW												
	300 kW												
	.....												

Figure 11: Interview tool 2 - Charging point types

C. Interview tool timeline

Figure 12 was used in the second part (on future developments) of the stakeholder interviews.

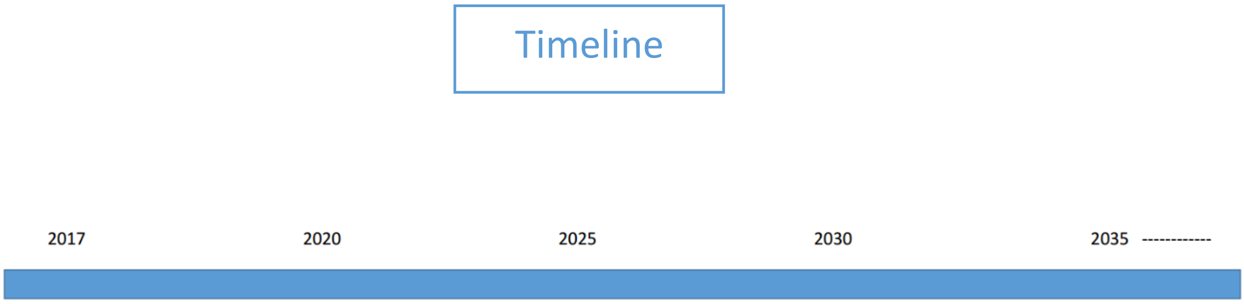

Figure 12: Interview tool 3 - Timeline

D. Introductions and choice task examples

Figure 13 to Figure 16 show screenshots of the DCE experiments in the survey for EV drivers.

Please read this information carefully

In the following questions, you will be asked to choose between a set of charging points. The goal of these questions is to find out what characteristics of charging points are crucial for you to make a decision on what charge point you use.

Imagine that you are driving a **fully electric** car that has a range of 300 km. In the coming days, you are planning to drive 250 km. Your battery is still pretty full, so their is no absolute need to charge **today**.

> You will be asked about the same statement 8 times. The options you are given for charging points will randomly change. Some options are unrealistic, as they are not (yet) available in real life. In that you you are asked to **imagine** what you would choose if that charge point would exist.

A number of characteristics are shown for every option for a charge point. There is a link on the bottom of every page that describes these characteristics.

0% 100%

Figure 13: Introduction to Optional Charging DCE experiment survey

Survey EV charging preferences (1)

Your fully electric car is charged enough to complete all your trips in the coming three days.

Which option to charge your car today would you choose? You can also choose none, then you will not charge today.

(task 5 of 8)

	Charge point 1	Charge point 2	
Location	Shopping centre	Workplace	**None** of these options is acceptable
Charging time	5 hours	20 min	
Price	10 €	5 €	
Chance charge point is available	40%	40%	
Familiar with this point	No	Yes	
Select:	○	○	○

Explanations of the attributes can be found here

Figure 14: Choice task Optional Charging DCE experiment survey

In the following questions, you are again asked to choose a charge point. This time, there is a different situation.

Imagine again that you are driving a fully electric car with a range of 300 km. You have 50 km of range left on the battery. You **need** to charge today.

You are planning to, later on today, drive from **work**, via a **shopping centre** where you will do some grocery shopping, to your **home** address.

0% 100%

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Figure 15: Introduction to Urgent Charging DCE experiment survey

Survey EV charging preferences (2)

The battery of your fully electric car is almost empty. It is neccesary to charge it soon. Which charge point do you think is your best option en which the worst?

(task 3 of 8)

	Charge point 1	Charge point 2	Charge point 3
Location	Along the road, 5 min detour	Along the road, 15 min detour	Workplace
Charging time	20 min	5 hours	3 min
Price	7,50 €	2,50 €	5 €
Chance charge point is available	80%	100%	40%
Familiar with this point	No	Yes	Yes
Best option:	☐	☐	☐
Worst option:	☐	☐	☐

Explanations of the attributes can be found here

Figure 16: Choice task Urgent Charging DCE experiment survey

E. Interview summaries

E1: Interview Advisory 1

Organisation and partners

Core business

The organisation is a consultancy firm that mainly focuses on advising governmental agencies, such as municipalities and provinces. They operate as a link between market parties and governmental organisations. They experience a barrier in communication and interests between those two different types of organisations. Their goal is to help the governmental organisations facilitate the market parties, with the ultimate goal of facilitating a market system that is independent of the government. This should become independent because of a positive business case where the CPOs can make money. This is the main interest of the CPOs, while the main interest of the municipality is a transition towards a sustainable mobility system and enabling the transition for EV drivers.

The consultancy firm is involved in CPO projects, but the core business is the advisory. They can have a CPO role in the municipalities they advise, which helps them learn about CPO´s practices. The objectives of a charge point operator can differ from the objectives of a municipality. A municipality might want to facilitate as many charging as possible, but a CPO only wants to operate charging points where enough charging transactions are (perceived to be) performed.

Partners

The main partners of the consultancy are their customers, the governmental organisations, and the CPO’s. They are hired as project managers for actual charge point projects, and in these projects, they also function as CPO themselves and work together with DSO’s. In this double role, they notice that interests of CPO’s and municipalities differ: municipalities place charge points on request by their inhabitants, while CPO’s want the most cost-efficient placement strategy for charge points.

The core business of the municipalities is to create a level playing field. They have to play a central role. Many municipalities face the same challenges, and this is where the province comes in. They bundle the problems and centralise the knowledge. They take a leading role in this.

Types of charging points

Now

The consultancy is now mainly focusing on 22 AC public charging, in both the home, work and other destination charge points. Basically, all charge points in public space. Public space and visual amenity are important topics for municipalities. They originate from focusing on public home chargers (first 11 kW, now 22), but now also advice municipalities on large visitation locations, such as attractions, concert halls etc.

Future

In the near future (5 years), the focus of the company will more and more be large visitation locations. In the long-term future (2035), the business will be so much different that the company will have to focus on other innovations in the mobility.

Fast charging will only be applicable in very specific situations. People use these because they travel long distance now, because their normal charging point is out of order or taken, or because it is free (for Tesla owners). They will not be the basis for charging in the future, but are essential to the implementation of EVs. This is because EV drivers want to be able to charge anytime and this gives them the feeling of security. The threshold for buying an EV becomes lower. This is why governments should subsidise fast chargers specifically, not the normal home and work chargers. Even when the batteries are larger and it is no longer needed to fast charge for longer distances, fast charging will still provide the drivers with a secure and dependable network.

Induction charging is also feasible, but only for autonomous cars. The location of the charging stations for autonomous cars doesn´t have to be outside the cities, as many people foresee. When the cars are also shared, this creates extra time in which the car is not available. There are enough large parking spaces for this available in the cities.

Future developments

Vision for the future

The charging infrastructure can be supported by government at the start, but market parties should apprehend this eventually. Scale is not the solution, because if a charging station has a negative business case and the municipalities deploy more charging points, there are just multiple negative business cases.

In the future, the system should be designed not just from a fiscal perspective (net connections are expensive on public grounds, slow charging is cheaper at home), but from the energy system perspective. The national government should play a central role in this transition.

Smart charging at night, when wind power is available and there is few demand, will become important in the future.

Autonomous cars come to the market in 2020. Car sharing is already happening now. These two developments combined, enable autonomous taxis. The hardware of the newest cars by Tesla are already equipped for autonomous driving. The software is now also developing, but the software also needs to learn save driving patterns. This involves a lot of data, but this should be solved within a couple of years.

Car sharing is a beneficial development for all parties and stakeholders involved. This excludes the car manufacturers. The lease and sales companies should change their business model from towards a sharing model. One important barrier in the car sharing model, is that it requires substantial investments. However, the benefits car sharing has for the drivers and municipalities (communal space), will make sure that there is enough incentive to overcome.

Barriers

The municipalities are now tendering the placement of lots of charge point. CPOs are now placing lots of charge points, to create a large market share. This however is not always efficient, as not every location has enough potential for a positive business case.

Currently, municipalities place charging points when they are requested by inhabitants. This is current policy. Companies place charging points for their employees. Visitors however, are not often considered because they don´t request charging point on locations where you come once or twice. This are for instance museums, theme parks, shopping malls. Now, if there are charge points, they are always taken. So, there is a large potential there.

E2: Interview Car Lease + CPO fast 1

Organisation and partners

Core business

The company is a car lease company for electric vehicles. They are leasing mostly Tesla vehicles, but also other full electric vehicles. Furthermore, they own the infrastructure for fast charging stations next to the highway. This is a new part of their business. They are actually two separate businesses, with partly overlapping customers of course.

Partners

For their fast charging points, they work together with an MSP, CPO and a CPM. Of course, there is also an energy provider involved.

Types of charging points

Future

Super-fast chargers are being developed now. Tesla is already working on the technology for 350 A chargers. Around 8 minutes is the crucial time that it should take at maximum.

There is a large potential for fast chargers, but this is not the perception of all the stakeholders. In the future, there will be a combination of corridor fast chargers and slow home or work chargers. At home or at work, when one has a private parking place where they can charge, this is a good solution for everyday use. This will be 22 kW AC chargers for charging at work. At home, the costs for the net connection are too high, so 11 kW AC chargers will be installed mostly. This is not a problem, as people spend a lot of time at home. However, not everyone has their own parking place, only 30 percent of people can be serviced in this manner. The 70 percent that cannot be serviced at home, will use fast charging stations near the highway.

Future developments

Vision for the future

The lease company owns the cars and thus the batteries in the cars. There is a large potential for a revenue model with the flexibility for the energy system. They own the batteries, and this can be used as a buffer. When their customers provide the company with the permission to use (part of) the battery, they get a discount on their monthly lease payment.

The vision is that there is a large amount of kWhs available in the cars of the future and that the batteries of these cars can be used in the electricity system as buffers and energy suppliers whenever needed. Furthermore, around 2030, 50 percent of all new cars sold will be electric. In 2020, car manufacturers that sell electric vehicles, mainly Tesla, are most interesting for investors.

In 2020, autonomous cars will be realized. Also, in 2020, car sharing will truly become interesting. After 2025, Tesla will not be the only car manufacturer that provides good electric cars. In 2018-2019, they will also provide leasing contracts for just the batteries.

Barriers

Consultant and advisory companies are very involved in the process with the municipalities. They steer towards slow charging points, because one slow charging point can service a few cars a day, or a single car. When we use fast corridor chargers, one charging point can service more than 1000 cars every day. There are way fewer charging points needed in that case. But this is not beneficial for the consulting companies as they advise municipalities on every tender.

Lobbyists can disrupt the innovation process. The large companies have a lot of power and are not in favour of radical innovations. The media is highly influenced by large companies. Large oil companies for instance, provide papers with stories and articles. Fake news is also a possible barrier.

The low TCO of EVs will ensure a transition to electric cars. This however brings the challenge of changing the mind-set of the drivers. This has to change from a traditional favour for possession to the idea that you use products and services instead of actually buying the car.

E3: Interview Municipality 1

Organisation and partners

Core business

The core business of the department that handles the charging of EVs is finding a balance between the market and the government. This means that they specifically issue invitations to tender to which market parties (CPO's) can respond. In this tender the placement, maintenance and operation of the charging points is discussed. They also influence the province and work together with them in a type of consortium. Together with other governmental organisations, they set the rules for the tenders. In the tenders, they want to create a 'level playing field' and make sure the drivers get a fair and cheap price that stimulates electric driving. The tendering can be an iterative process, where the municipality asks the technology providers whether their ideas are still up to date.

Partners

In tenders in the past, the OEM's also were involved when there was not that much knowledge yet and they needed to be advised. DSO's are also involved in the tenders. They also work with consultancy agencies in certain projects in cases where external knowledge is needed. Now the industry is developing, there is less contact with the OEM's and the CPM's and more with CPO's on the tenders.

Types of charging points

Now

Evidently, public charging points are the main focus as they are the decision-makers on public space as municipality. This is not just parking at home, but also at work and other destinations. The 'other destinations' are not their focus, but there is lot of progress needed. For instance, in parking garages, the payments are done very inefficiently: one pays for charging and parking separately. They are not involved in private chargers.

As for speed, they used to install 22 kW chargers, but changed to 7.4 kW as this is much cheaper in net connections (3x25 A connections). Their investments were not met by other parties in the beginning, so they focused on the needs and not the fastest chargers. Very few DC chargers are installed now.

Future

They expect both fast and "normal" charging to be demanded in the future. However, from their own experiences, they see that EV drivers in the city ask for the "normal" chargers. They see that they prefer to leave their homes and work with a fully charged battery. This makes the EV drivers feel comfortable. There are no requests for fast chargers.

Also, charging at home in the big cities will very often be public charging, as very few people have their own parking places in the inner city. In the future, it is expected that charging during the nighttime is very important. Private charging is relatively easy solved. But it will still be difficult in the public domain: for instance, the question of how many charging points will facilitate how many electric cars.

At other destinations, it will increasingly become relevant to charge at semi-fast rates, 22 kW. Dynamic pricing is already relevant and will be even more in the future.

Future developments

Vision for the future

From a financial point of view, the slower charging rates are most interesting and will be used intensively in the future. It also provides comfort. Corridor charging (having to charge on your way to work) is not necessarily comfortable. It will be an addition to the "normal" charging. Also, in the inner cities, the fast chargers can be an addition to the regular facilities. On the other destinations and for professional drivers (taxi's and delivery) the fast chargers will be used. On other destinations, the business cases for the fast chargers can however be difficult. The corridor charging is needed to stimulate electric driving, but it won't become the main use.

Barriers

Some municipalities are not as experienced with EV charging as the big cities are. Some of these think corridor charging might be a final solution, because it is less hassle for them to realise a couple of corridor chargers instead of a slower public charging infrastructure.

E4: Interview Municipality 2

Organisation and partners

Core business

The municipality is a regional governmental institute, with many departments. The goal the interviewee is working on is bettering the air quality in the municipality. Furthermore, the municipality also stimulates locally produced energy with a transitional agenda. Air quality has recently been added to this agenda as this is a logical combination. It is not the municipality's objective to create long term plans, but to enable projects. These projects are usually on stimulating EV adoption and charging infrastructure. This used to be in both the privately-operated charging points as well as public, but is now only in the public domain. One other main activity is putting out invitations for tenders for charging infrastructure within the municipality. This is not just about putting out the invitations, but this is an iterative process in which they form the tenders and are in close contact with the CPOs who respond to them.

Partners

Where the tenders were first only for the municipality, now they are working together with other municipalities to put out a tender on a province scale. In these tenders, CPOs bid on the tenders. Before the tender is put out, it is firstly discussed with different market parties to make sure the demands are clear and aligned with their views.

They are also in contact with the national government on other projects, concerning hydrogen energy. As a municipality, they also cooperate and consolidate with the DSO of their area. They are in direct contact to discuss strategic issues.

They also use the services of advisory and consultancy companies. During the first years when charging stations were deployed, they were in close contact with the EV drivers. Now, they outsource this to the front office of the CPO. They still have a say in where in the public space the charge points are placed, but most of the contact is outsourced. The smooth communication with the EV drivers is also part of the tender for the CPOs.

Types of charging points

Now

They are involved in public charging points on the streets mostly. They are also involved in corridor fast charging points with a fast charging CPO.

With fast chargers, there are less chargers needed to service more cars. For slow charging at home, one needs a charger at every house or multiple in every street. This is not desirable because the chargers on the street take up public space and they change the street scene. Therefore, it could be a solution to place fast chargers in the city or around hubs as well. In that case, you might only need a couple of chargers for a neighbourhood as all neighbours only need to use the charger a couple of minutes instead of being parked at the charger all night.

Workplace charging is something they are looking into as this can enable small-scale networks with solar energy, depending on the location. They are testing smart charging in projects.

Future

The corridor charging points are getting faster. This creates a dilemma that you can place multiple public slow chargers in a neighbourhood, but you could also place one or a few corridor fast charging points near that neighbourhood. For some neighbourhoods, this second option might be more desirable as the multiple slow chargers can change the appearance of the neighbourhood.

Future developments

Vision for the future

Their vision for the future is that it is cost-effective to combine resources allocated to sustainable energy and sustainable mobility. They aim for a more direct connection between renewable energy resources and electric vehicles, in the form of small-scale local energy system where solar energy is directly used to charge electric vehicles. This decreases the costs for energy net connections. They collaborate with a DSO to realize projects related to this.

MSPs are creating a non-transparent layer for consumers. It is preferred that the consumer pays directly to the CPO without an MSP in between.

The European Union will also play a role in the future deployment as EU-countries are collaborating more and more.

Barriers

There is a knowledge gap. They have insight in the current charging situation, but not in the future of charging. They do not know what people in what neighbourhoods will buy EVs and also not how the technology will develop over time. These uncertainties are a barrier for creating a long-term strategy. Many municipalities will experience these uncertainties that makes it difficult to plan 5 years ahead.

An unambiguous payment system is needed for better communications and to make the MSP redundant. A direct payment, with for instance directly paying at the charging point using a bank card, is preferred. This is comfortable for the EV drivers and simplifies the system.

One barrier for the EV charging infrastructure development is that the regulations of net connections require a standard view that you have to pay for a net connection to the DSO. The national government should enable a deviation of costs for a net connection for a building and a charging point. The national government should stimulate the EV infrastructure by enabling lower prices for the net connections of charging points, possibly in pilot projects. This is determined by the national government and not the DSO.

The missing plans of the national government concerning stimulation regulations for EVs (such as "Bijtelling" cause uncertainties for many parties. The "wobbling" policies cause the inability to do properly make a long-term budget as to one knows what they are due for.

E5: Interview OEM 1

Organisation and partners

Core business

The company is focusing on electric transport, not just small vehicles. It started out as a battery business and is now producing all kinds of products: electric vehicles, hybrid vehicles, conventional cars, electric busses, batteries, solar panels and so on. 40 percent of the global sales are hybrid and electric vehicles. In the Netherlands, most of the sales are electric busses. Their domestic market is where electric cars are sold more often. Europe is not a prime outlet for their electric cars, as the market is suboptimal. There is a desire to sell more cars on the European market, but their market advantage due to the advanced battery technology is rapidly decreasing and marketing costs are large for a new market.

Partners

The OEM works together with lease agencies for financing. In certain projects concerning V2G, they cooperate with DSO's and energy suppliers. Municipalities and provinces are also contacts. They try to influence the national policy through lobbying. They are not in close contact with charge point manufacturers and they have their own production line of charge point

Types of charging points

Now

They produce their own charging points, which are three phase AC (up to 40 kW). The cars can charge on any other type of charge point, however, the models sold in Europe are AC. They can charge on both single and three phase AC chargers for now. The location of the chargers is not something they are concerned with: they will place the chargers wherever the customer wants chargers. This is currently mainly large bus depots.

Future

The busses will charge on 120 DC in the near future. This is already available; however, the customers prefer AC charging now due to the high installation costs of DC chargers. For now, there is no smart charging implemented for the busses. There is no controlled charging yet.

There will be two types of cars in the future, one with up to 250 km range and one with up to 500 km range. This is due to the consumers themselves and what they are willing to pay. The higher range cars do not have a demand for fast charging, except for when occasional large distances such as a holiday.

They need the possibility to fast charge but will not be using it often in practice. Home charging will be sufficient for them. The number of fast charging points doesn't have to be that large. The rest of the charging demand, which is the largest part, can be fulfilled with 22 kW charging.

Future developments

Vision for the future

Their vision is that cars will be an essential part of the energy system. Cars are not just means of transport, but also energy carriers. You can put energy in and take energy out of the car and it contributes towards a sustainable energy system. V2G technology integration in standard in their products. Their core business in the future will also include electric freight transport. They will also produce more batteries for energy storage.

The demands for batteries in cars might change. Therefore, in possibly five years, the batteries from cars might get a second life as energy storage devices. This is a more sustainable option for old batteries than just recycling. In the future, batteries for fleets of busses can be placed as buffers.

Electric cars will reach the general public within a couple of years, so that car buyers will consider purchasing an EV and a critical mass can be reached. Most OEMs have fully electric models either in production or as a prototype. The number of models to choose from will rapidly increase in the next few years. Popular OEMs that will bring new models to the market will boost the entire market. This helps the process of the large public getting accustomed to electric cars: this process of accustoming is very important. Within 5-10 years, they expect 10% of new sales to be electric cars.

Prices for batteries will decrease and this will affect the buying behaviour. OEMs will offer the same model of car, with two different battery packs and sell it at different prices, considering the customer's demand. Not all customers will want the largest battery possible. This is very relevant, as the difference between larger and smaller battery packs will always be a couple of thousand (more or less 4000 euro) and there will thus be a demand for the smaller battery packs.

In the years 2025-2030. The public transport sector should be zero emission, so electric busses will become more relevant. They already see also other alternatives to busses in their domestic market, such as a monorail. Sharing cars is also a very logical transport option in cities. Owning an expensive car will no longer be a symbol of status, also most relevant in cities and urban areas as there are very few parking places. This is way more pragmatic.

Even though cities will be leading in some of the movements (such as sharing a car), it can also be useful in less densely populated areas. Some bus lines are disappearing because there are not enough people to transport in the small villages. In these cases, sharing a car with the inhabitants of a village can be a valuable addition to public transport. Though in the more rural areas, people will still want to own a car. However, this is not the majority of population.

In their domestic market, there are also autonomous driving projects. Some pilot projects are also in the Netherlands. This movement will go in steps, as there are different phases to autonomous driving. The full autonomy, where a driving licence is no longer required, will not be used in practice for another 20-25 years.

Barriers

Currently 1.5 to 2 percent of newly sold cars is electric (last year this was 1.8%). This is largely due to national policy, where some policies are ending in 2017, so this might me a barrier. National policies have a proportionally constant relation to the number of cars sold.

One other barrier is that the electric busses are compared to conventional diesel busses and the time schedule is crucial. In Amsterdam, some bus lines will drive 800 km a day. Electric busses are not ready for such driving patterns.

The more cars are sold, the higher the impact on the energy system. This is also something to keep in mind. A shift towards TCO-thinking of customers is already visible. Private lease is gaining popularity, solving the issue of higher initial investment costs for the drivers. Electric cars, car sharing, and private lease are trends that reinforce each other.

Public transport companies in the Netherlands already use the TCO-thinking. In the southern part of Europe however, the public transport companies get a limited budget from (local) governments with which they should buy new busses. This is a barrier for the electric busses, as they have a higher purchase price but lower TCO.

E6: Interview OEM 2

Organisation and partners

Core business

The company is a car manufacturer, but the department in the Netherlands focusses on sales and innovation. This departments puts the products that the OEM produces on the market. Innovation in the context of mobility is the core business of the department. This does not just include conventional car sales, but they view mobility in an innovative perspective, including public transport combinations and EVs.

Partners

They partner with interest groups to advise local and national governments. They also partner with CPOs. They have their own mobility service providing label, which provides access to charging points of CPOs. They first cooperated with MSPs and now have their own MSP label. They also have contracts with energy providers, for instance in home charging stations, their customers can get a deal with an energy provider. Lease companies are of course important for their sales. In some projects, consultants are involved. DSOs are also involved in pilot projects. CPMs are contracted to provide the OEMs customers with the charging stations. The CPMs can manage the implementation of the charging points and this benefits the sales of the OEM.

Types of charging points

Now

All of the charging point types are relevant for the OEM and projects are set up in all different types. The focus is now on AC home charging (private), but more and more on public chargers as well. The PHEV are still charging on single phase.

Future

On a European level, more fast charging points are developed. Four super-fast chargers will be installed in the Netherlands in cooperation with a CPO. The future of charging will still be a combination of corridor and destination charging. The destination charging has the advantage of not having to spend any extra time. The vision for the charging of the future is that it should be possible anywhere and anytime. The basis is charging at home and at the workplace. For incidental charging or whenever the customer feels that it is necessary, they believe other parties (in cooperation with them when needed) can provide corridor fast charging station. In Germany, these efforts have already been made successfully.

Induction charging is something they are also involved in and have pilot projects in, on a small scale for now.

Future developments

Vision for the future

Smart charging at home and the workplace, whenever there is more sustainable energy available, will be implemented in the near future. This year already, and it will become more important. It is both cost-efficient and sustainable to smart charge. Smart charging can be sold as a product and can be connected to both the home appliances as well as weather and energy forecasts. Energy storage is still a missing link and should also be implemented to enable the customers to charge on solely sustainable energy. Recycling of the old, partly degraded batteries is an opportunity. Providing flexibility on the energy market is very interesting as well.

More electric vehicles will be sold in the future. Eventually, all the cars that they will sell will be electric. It is hard to say when exactly this is realized. Within 15 years, it should be possible to have a fully electric version of every car model that they sell. This is a vision for the entire company, the top management includes this in their visions and strategies.

Research in the charging behaviour of EV drivers could provide more insights into what investments are necessary. A combination of charging stations and streetlights can reduce costs for the charging stations, as well as improve the spatial looks that municipality's policy makers can be concerned about. This is especially an opportunity in new to be developed urban areas.

Barriers

Even though the company's vision is to sell only electric cars eventually, one barrier could be the market and the consumers. How fast this is going depends on the public and their demands, but also international markets. The capacity for production will not be a barrier. Charging infrastructure can be a factor that slows down the implementation of electric vehicles. The scale on which the cars are sold and produced are important for the business case. Until the scale is large enough, there should be support from governments. This is in their interest as well and therefore the interest groups and other OEMs can work together to urge the governments to support the implementation of EVs.

E7: Interview National Policy 1

Organisation and partners

Core business

The core business is critically assessing national policies. The departments main activity is to assess national policies that the government has implemented or is planning to implement. Their role is furthermore to develop a vision for the future. An ideological view of GHG-free transport options is distilled into practical terms. This includes dealing with the current industry and economy. For this, they are in contact with many parties to hear their side of the story. Research from universities is also valued for this purpose. They have written a vision for electric transport recently. The main features are discussed within this party, but the details are worked out by the ministry.

Partners

Many parties are in contact with this party as many parties have interests in national policies. The national policies interest DSOs and energy providers, so these parties come around regularly. OEMs also do this in some extend. One other type of organisation that they are in contact with are research universities for exchanging knowledge and insights without (commercial) interests.

Types of charging points

Now

As they are only concerned with the main features of national policy, they have no explicit visions for the types of charging points. They are more concerned with organising regulations in a way that facilitates the deployment of EV charging stations, but not a specific type.

Future

Goal is that commercial parties can compete with each other and the charging points are easily accessible for consumers. The preference is in broad terms for solutions that do not negatively affect public space too much. Furthermore, they are now more concerned with EV implementation and not yet a vision on charging point implementation.

Future developments

Vision for the future

The goal of the national government is that in 2025 all new car sales are electric ones. The current administration has not created effective policies on the subject, so they do not expect that this goal is realized. In 2040, all fossil fuel cars should be phased out. This requires an exponential increase in EV sales for private persons.

A guarantee given out on the lifetime of batteries is something they are looking into to stimulate EV implementation.

Barriers

Decisiveness is missing concerning the subject of EV implementation as no effective policies are carried out. This is even less for policies concerning the charging of EVs. Innovativeness is something the national government is evidently not a front runner in. It is crucial that a covering infrastructure is needed for the implementation in EVs and that it is set up in a smart way. Information on charging tariffs is missing in charge locations.

E8: Interview National Policy 2

Organisation and partners

Core business

The core business is creating and assessing national policies. Goals are not set for EV charging, but for EV implementation in general. A goal is to have 100% of new sales electric cars in 2035. A realistic goal is to have 10% of new car sales fully electric in 2025. These goals are related to climate and air quality policies. EV is considered as one option for zero emission passenger transport, but not the only one. This organisation is involved in these issues as fiscal policies are their responsibility. There are no policies effective on the deployment of EVs.

Their role in facilitating the transitions, while maintaining cost-efficiency. A balance should to be found here to enable both.

Partners

They are in contact with all parties in the game. Municipalities and provinces have the responsibility to place charge points. As long as there is nothing drastically wrong and the municipalities can handle the requests for charge points, they are not involved. In general, the policy on charge points is that it is up to the market parties to deploy the charging points. As long as there is a demand and supply and the business case is positive, the market will emerge.

Types of charging points

Now

They are not involved in the specifics of charging.

Future

Public charging (in the public space) is less desirable, as this pollutes the public space and is more expensive than charging at home. Flexibility in the energy system is something that will largely affect the charging point deployment.

Future developments

Vision for the future

The batteries are assets to many, in the context of smart charging and flexibility. Some parties are already trying out to use these assets. There are no regulations concerning ownership of these batteries. This flexibility is already something both multinationals and start-ups are taking action on.

Around 2020, autonomous cars will have matured. The technical part is not the issue, this will emerge fast. When mobility is provided as a service, fast chargers will become more relevant.

Barriers

It is very desirable that protocols for charging are organised in a way that everyone, with every MSP card, can charge at all charge points. This however not easy to realize, as this is a multi-national issue and many parties have interests in this.

E9: Interview CPM 1

Organisation and partners

Core business

Providing charge points for small (cars and vans) EVs is their core business. They develop new charging points. They have the entire production process in their own hands. Selling these charge points also is an activity of the organisation.

Partners

Their most important partners are OEMs, MSPs (their biggest customers), energy suppliers and CPOs. They also collaborate with DSOs, advocacies, consultants, provinces and municipalities. In the start of the Mode 3 charging implementations, OEMs tested their vehicles at this CPM. This goes on today, as the protocols of the chargers and the EV must align to enable charging. This is a collaboration on a technological level, not on a sales level.

They sell charge points to mainly MSPs and CPOs. They participate in many tenders with these organisations for the municipalities. It is in their interests to also associate themselves with advocacies.

Types of charging points

Now

They are currently producing 3.7 to 22.1 kW chargers. Only AC chargers are produced. These are located on all types of location. This includes home, work and other destinations. They are operated privately, semi-public and public. This depends on who their customer is, as they don't place the charge points themselves. It sometimes happens that people use these relatively slower charging points also for corridor charging, even though this is not usual.

Future

Often, charging is approached in a way that puts a focus on filling up the entire battery, e.g. filling up with SOCs. It is compared with ICE cars, where you only fill up when the tank is empty. The range anxiety comes in to play, because you can drive a lot less with an EV than an ICE car. This approach should not be applied to EVs. But actually, you should charge according to your mobility needs. These mobility needs are usually driving from and to work, not huge distances. For this, EVs are already compatible and the charging infrastructure covers for the mobility needs.

For this reason, the slower charging methods will fulfil most people's needs. Only when you are going on vacation, you might need a fast charger. Smart charging concepts, where you charge on the right times of the day are always based "slow" chargers.

Car sharing would increase the mobility needs. But this still does not make fast chargers cost-effective. If a car is shared and used throughout the day by different people, it drives more, but those mobility needs will not surpass a range of 400 km that EVs can have. The fast charging options are more expensive while this is not necessary, since the cars can be charged during the night still.

Faster charging (up to 22, but not more) is only cost-effective when you would need more flexibility in smart charging (you can ramp up and down more with a 22 kW charger then a 3.7 kW).

There is a market for faster chargers probably, but this is not part of their strategy. If the batteries are getting larger, there is even a lesser need for fast charging. The need might even fade for person cars (not for trucks and busses).

Future developments

Vision for the future

They are testing smart charging technologies with DSOs. This will be important in the future of EV charging and this is part of their strategy. The business case for energy storage will become positive around 2020-2025. There will not be a use of vehicle-to-grid technologies when energy storage is deployed otherwise (not in EVs).

Another factor that influences the charging infrastructure is that around 2035 we will have decentralized energy systems. When that happens, there is a need for smart charging and energy storage. A possible development is that energy grids will become DC, all appliances use DC, and this might be a good option for effectiveness and lowering the number of transformers.

Around 2025, a little before, induction charging will become a mature technology. They are not yet taking action in induction charging, but if that will become a popular and fitting technology, they are not ruling out the option to also look at that technology.

Barriers

The market of EVs and charging points should be regulated more and better. Policies with subsidies are not used effectively currently. Subsidies should be given out in the R&D phases to enable technology push. Now, they are given out in the deployment phase where many parties ask for subsidies, but this does not really work for stimulating and maintaining this. Better technologies and pilot projects should be sponsored more. This will increase accessibility for the people on the long term.

E10: Interview CPM 2

Organisation and partners

Core business

Producing chargers for electric vehicles. They are both doing AC, slower charging, and DC chargers. DC chargers are their strongest point. They are selling internationally, 95% outside of the Netherlands. They are expecting to innovate more in technology of fast chargers. AC is less innovative.

Partners

They are working with OEMs closely. This collaboration has multiple sides: they are customers as they buy charge points for their dealerships and testing grounds and they are R&D partner as they have to work together to make the charging possible technically. They are in contact with international advocacies, not with national ones. MSPs are sometimes contacts, only when they are combined with the CPO in a double role. They have to make sure the back offices of them and the MSP can connect. CPOs are their main customers. They are not in contact with regulatory bodies, since they are mostly doing fast chargers.

Types of charging points

Now

They are not deciding on the locations of the charging points. The CPOs, their customers, are the ones who buy and place the charge points, so they don't have influence on this. A lot of their sales are currently fast chargers (from 50 to 450 DC chargers) that are used as corridor chargers in the public domain. 'Other destinations' such as stores and concert halls are also places where their chargers are used. This could for instance be in a place where taxis top up. These are not public, but privately operated (without a CPO).

They are now focusing on producing 150 kW DC chargers. Their fast chargers often also have a 43 kW AC charger. Also on work locations, they see an increase in fast chargers. 50 kW chargers on work location are becoming more common. Sometimes these are privately operated (where employees or guests do not have to pay directly), but also semi-public solutions where there is a CPO, but the charge point is located on company grounds.

Destination chargers around shops and shopping centres are becoming a large market. They have a collaboration with a large supermarket, where they will provide 10% of their stores with fast chargers. People usually spend around 45 minutes for their weekly groceries. Also furniture shops like IKEA will install fast charging points. These locations are perfect for fast chargers of 50 kW, as spending an hour or so is ideal. EVs with larger batteries (with ranges 300-400 km) can fully charge on 50 kW chargers. This is an ideal replacement for public slow chargers on the streets. Also parking garages are customers for them (both fast and slower charging).

Future

Their customers are not only requesting fast chargers, but also 11 and 22 kW AC chargers. This depends on the type of customer. There is a market for fast chargers which is growing, but there also is a market for slow chargers that is increasing. They are expecting that the AC slow chargers are slowly fading out, as DC electricity networks chargers have a better potential. These will not use as many transformers in the cars, as the actual chargers can be placed outside the cars, which can decrease the costs. OEMs are already putting a focus on that. They are for instance planning to take out the on-board chargers from 2025.

The business case for slow chargers on the street is negative in some places. These costs are too much. When you take in costs for the charger itself, the installation costs, the O&M but also the fact that these don't pay parking costs, makes the business case negative. Some consultancies and CPMs will deny this, as they are making money on these chargers, but this is not realistic for the future. The public space in, where this is most valuable such as in city centre, should be reserved for all cars, not just for electric ones. When more cars become electric, this will still not help as these cars will not have on-board chargers anymore and they will charge on DC. AC chargers can have a positive business case, but those are for locations such as private home locations and workplaces.

People who live in city centres and people who do not have private parking spots, can be serviced with charging point on commercial locations such as shops. This is more cost-effective and also relives the EV drivers of finding charging points near their house that are available.

For urban (metropole) regions, the basis will be fast charging on convenient locations near the city and charging at the workplace. Charging on the street will not be a large part of charging. For the people that do have private parking spaces, up to 11 kW (taking the net connection into consideration) are relevant.

Future developments

Vision for the future

They are also active internationally, in the USA as well. There, they see different scenarios. Fast chargers around shopping centres are used a lot more and cheaper for EV drivers.

In this year (2017), the 35,000-euro EVs with a range of 400 km will be sold. This range is comfortable for everyday use. In 2018, more OEMs will offer EVs that are mainstream for their users. This will affect the charging infrastructure as more and more kilometres are driven with these (and not that many PHEVs after 2020 anymore). From 2020 on, it will become clear that PHEV are not cost-efficient. This causes that there will be a lesser demand for slower AC charging. After 2025, most OEMs will offer AC charging as an option, but will not put an on-board charger in every vehicle by default.

Induction charging also has potential after 2020, but not for public space as this is still very expensive. Fast charging on induction is too expensive, so induction might only be relevant for home charging. Car sharing will have an effect on the charging system as well. Shared cares need to be available as much time as possible, so this will increase the demand for fast charging.

Autonomous driving will create a demand for "robots that plug in the charger". For instance, when you arrive at a parking garage, the EV can park itself and plug in the charger. When you want to get your car, you signal it to unplug and come to the exit. This can create more effective use of parking spaces. The car doesn't necessarily need to fast charge, as it can drive itself anywhere when it isn't needed for transport.

For their strategy for the future, they follow the OEMs mainly. These are the best predicters of the market, and these are the ones that are ultimately influencing the demand.

Barriers

The tariffs for charging are very non-transparent in the Netherlands. Slow public charging has a positive business case now on a national level (for other CPMs), but they are focusing on a long-term international positive business cases. Standardization is a barrier, as there are too many standards for charging internationally. This is also a reason for OEMs to get rid of on-board chargers.

CPOs are heavily competing now, and all have different strategies. In the CPO landscape, there will be a battle between many organisations.

E11: Interview MSP 1 & CPO 1

Organisation and partners

Core business

They have a double role as MSP and CPO. They have contact with the EV drivers in their MSP role. But they are also placing and planning the placement of charge points. In some cases, they operate charge points that are not their own, but only connected to their back-office system. Their core business is providing services to EV drivers. As an MSP, they also offer their customers access to charge points of other CPOs. It is valuable to them to also have the CPO role, as they can provide the best service on their own charge points, and they can also learn and help to develop protocols.

Partners

They do not produce charge point, but are closely working together with CPMs to develop charge points that fit their requirements. They also have deals with leasing companies: when someone leases a car, they get an offer for charge point of this CPO/MSP. They do participate in some tenders, but this is not their main business.

Types of charging points

Now

They are big in the home charger field. When they offer charge points to EV lease drivers, these are placed at their home or their workplace. They are placing charge points up to 22 kW, all AC chargers. They are not placing a lot of chargers in the public domain, as they are not involved in many tenders.

The locations they operate charge points are home, work and other destinations (parking garages). They are placing home chargers as a CPO, where EV drivers could also just install a simple charge point. Having the CPO brings some advantages, as you can for instance settle the costs with your employer (for lease drivers). Also, this could be used in the future to adapt the charging in a way that you balance the electricity in a local energy management system. On work locations, when there are multiple chargers, it is useful to have intelligent charge points to balance the load on the different chargers.

Future

They expect their focus to stay on private and semi-public locations. They will not involve in public chargers on the street. The tenders for these with municipalities have already been won by other parties. Bigger parties, such as energy suppliers, have a better chance of winning the tenders.

In the semi-long future, charging might be free for EV drivers. The 22 kW chargers will be relevant for work places in the future. The grid connection costs do not allow for faster chargers on work locations. In other locations, 11 kW will usually suffice. This will fit the mobility needs, as people usually don't need to charge from 0 to 100%. They believe that most charging transactions in the future will take place in semi-public and private domains, as the costs for unsubsidised public chargers are too high.

Fast chargers might be effective for urban areas such as city centres, where private and semi-public chargers are not possible.

Future developments

Vision for the future

Flexibility on the electricity system is part of their strategy for the future. Main concern for now is that the hardware enables more flexible charging and protocols are developed. Connection charge points to a back-end system (not the simple charge points without CPOs) are needed for smart charging. They plan to service EV drivers with smart chargers, using financial incentives for people who use smart charging, this then at the same time prevents grid congestion, but preventing that DSOs have bigger costs is not their issue. They believe it might just be necessary to invest in more grid capacity. Main reason to enable smart charging is making sure the energy system can become renewable.

Around 2025, grid congestion will become a serious issue. At that time, the amount of EVs will be so large that we must use smart charging to balance the electricity grid. Before that Vehicle 2 Grid technology will develop for households.

Around 2022, autonomous driving will emerge as well as wireless (induction) charging in pilot projects.

Car sharing is a concept that is also developing, but not necessarily changes the charging infrastructure. Shared cars still need to charge. It is important that they can service car sharing EVs with their MSP services, with payments systems and smart apps.

Barriers

The OEMs are crucial to the entire system. They decide what types of chargers their cars are compatible with and they are the leading partner. CPMs and CPOs are to follow their decisions basically, as they need to service the EV drivers. This is not necessarily a barrier, but something to keep in mind.

E12: Interview MSP 2 & CPO 2

Organisation and partners

Core business

Providing services on EV charging and enabling third parties to provide these services is their core business. Third parties can use their back-office system and software to provide charging service. Development of their back-office IT system and some hardware is their main activity. They are CPO and MSP, but also provide technology for others. They arrange the payment system and the settlements for charge points they are not the CPO of. Their ambition is not to be a large CPO or MSP, they just want to gain experience but eventually just provide services and systems around EV charging that third parties can use. This in the form of controllers and extensive software development.

Partners

They partner with all stakeholder in the tool. All are considered important. The CPMs are their partners as their products need to be compatible. They do smart charging projects together with DSOs. They also partner up with OEMs, to provide EV buyers with a complete package of an MSP card and a charge point. A party they collaborate with that was not on the tool is RVO, the Dutch organisation for entrepreneurship. They arrange trade missions abroad. The Netherlands have many front runner companies regarding EV.

Types of charging points

Now

They already see that their software is crucial in some locations. When companies have multiple charging points, the software is needed to control the loads and use the grid connection in the most efficient way.

Their services are compatible with all types of charging points, as long as the OCPP protocol is used. They are not servicing fast charging points now. Only up to 22 kW AC chargers in the Netherlands. For home chargers, up to 11kW. But they are also expanding abroad.

Future

Their business case now is on controlling the load and using the grid capacity effectively. When more chargers are installed on one location, it saves a lot of costs to balance the loads effectively instead of paying for larger net connection. In the future, it might be on dynamic energy prices. This is now not very relevant. Who owns the flexibility depends on the contracts that are made? If an EV driver uses a charge point that is operated by a municipality for instance, and they use smart charging, the V driver does not have much say in this.

In the future, around 95% of charging transactions will be on destinations chargers and only 5% at corridor chargers. Fast chargers should be very fast, or otherwise they are unpractical.

If you cannot charge at home, having an EV makes less sense.

Future developments

Vision for the future

Their focus is to develop software is intelligent and provides all the services that are needed in the future. This enables smart charging. They believe in dynamic net connections. In 2030 they expect that gasoline cars will become outdated. If around 2020-2025 wireless induction charging is not commercially developed, it will become obsolete.

Static battery storage systems will be implemented and affect the energy system.

Car sharing, form a psychological point of view, will not become popular for the mainstream. People value ownership too much to start sharing their cars. Also the new generation will still want to have a car. Looking for a shared car is too much hassle. Only when there are fully autonomous cars, shared cars make sense. Autonomous cars will however be fully implemented in 2030. When there are autonomous cars, car ownership is not needed anymore. Also, smart charging will not be relevant as the basis of smart charging is using the time in which cars are not driving, using the fact that they are used ineffectively. Shared autonomous cars will be used way more effectively. In that scenario, it makes more sense to charge the cars centrally at a spot the grid allows.

Barriers

International interoperability is an issue, and it might take around 8 years to solve. Many parties are in the playing field. Dynamic energy prices are also an important issue. The DSOs need to take further steps in this, as they are not prepared. If they don't allow consumers and companies to settle electricity costs from one place to another. The DSOs are not taking into account incentives for people to use their net to how the DSOs prefer (lesser peak demand, smart charging).

The DSOs should develop virtual energy networks, besides the physical ones. The main concern is that the balance of the net (loads and demands) add up to 0, but it shouldn't matter where on the net these are. When I cave solar panels on a roof somewhere else, I should be able to charge my car without too much hassle. The DSO their strategy does not align with the vision for the future. Lots of times they say, 'we need to innovate' and other vague terms, but their ideas are not concrete enough to actually mean something. The DSOs are not aligned amongst each other as well, different DSOs have different strategies.

E13: Interview CPO 3

Organisation and partners

Core business

Their core business is CPO. They place charge points in Belgium, Germany and the Netherlands. They operate them and connect them to their own back-office system. They are not MSP.

Partners

They partner with MSP. With OEMs, they work together as they operate charge points for OEMs (dealers and garages). They buy the charge points that they operate at CPMs. They work together with more than 10 CPMs. They have to connect their chargers to the grid with DSOs. They have won tenders from municipalities, so when an inhabitant requests a charging point, they are the ones that place them and request the permits and net connections. They unburden municipalities. They are in contact with the EV drivers when the charging stations malfunction, but as they are not an MSP, they don't have any further contact.

They are also in contact with energy suppliers, as they are buying electricity from them. Them follow national policies and protocol development.

Types of charging points

Now

They are placing public and semi-public charging points, no private charging points at people's homes. They place chargers at workplaces and parking garages. They also deploy DC chargers. They have 20 kW DC chargers. These chargers are less expensive and can utilize more grid connections than 50 kW.

Future

They expect that chargers at shopping centres are a growing market. Also at restaurants and other destinations that are not home or work. Other destinations will go up to 20 kW chargers. They believe that 11 kW chargers will be deployed most often on the streets. The batteries of cars will become larger, also the charging rates will become larger.

Charging you EV should be incorporated in your daily routine. The charging should be adapted to the mobility needs and schedules of people, which would mean charging at home or at work. Fast charging is an option for shopping centres. Places where you spend an hour or so every week, where you can top up the car, are very promising. Charging should not be a thing you always have to consider. The infrastructure should be organised in a way that you shouldn't have to worry about it.

Future developments

Vision for the future

Autonomous driving has lots of advantages. It is most important that a new concept increases the comfort of the EV driver, otherwise it will not be a success.

Same goes for car ownership. Car sharing is a popular term now, but in practice it will not be used that often, even for the newer generation. Only in cities this can be a solution. When there are lesser costs for parking and no expensive gasoline, everyone would still be more comfortable with owning their own car. Ownership of a car stands for ultimate freedom.

From 2019 and 2020, 300 kW chargers will become more relevant for the top-class cars. This might not be the same for the mainstream cars. Fast chargers with 300 kW still have technical implications.

They follow the OEMs, and also the CMPs when deciding on their strategy for the future. Also, the EV drivers' preferences determine the demands for charge points.

Barriers

A system where cars are not parked by the people themselves, but the cars automatically drive and plug themselves in, has some psychological barriers. People will not always want to give their car to a system. If this fails, it causes a lot of inconvenience.

A main concern is that charging now is simply not comfortable enough. The driving is comfortable, but finding charging points and connecting the cables can still be very uncomfortable. The cables can be unplugged, they need replacement because they break.

E14: Interview DSO 1

Organisation and partners

Core business

They DSO and their main activity. They operate and manage electricity and gas nets in the Netherlands. They have some CPO activities as well, but this is not the core business. In this role, the software of the charger is essential. Servicing all EV drivers that are customers of different MSPs is essential. Their strategy considers that they should not make unnecessary investments for charging points. But their main starting point is offering choices for EV drivers. Open markets enable this.

Partners

They collaborate with all stakeholders in the stakeholder interview tool. All in different ways. There is not enough international collaboration. There should be worldwide collaboration and standards. Not just on an EU level, but also worldwide. The municipality of Amsterdam has an exemplary role, as they have international leverage.

Types of charging points

Now

Now, business drivers with lease cars are the main group with EVs. From 2018 on, there will be electric cars for the mainstream. These drivers will have different charging behaviours (they drive less km per day). Autonomous shared cars will be implemented about 15 years from now. Electric taxis are a bit of an example of how autonomous cars will charge in the future, as they will have the same type of behaviour as autonomous cars will have. The current shared cars in Amsterdam can also serve as an example. These cars will charge more often and be fully charged for practical reasons. The behaviour of these types of cars and drivers should be investigated, not the behaviour of the current lease drivers. The current pattern should not be extrapolated, but it should account for new profiles of drivers.

Future

Charging points will change. It does not matter to the DSO what types of charging points will be deployed. The charging points that fit the cars will be deployed, so the OEMs have a leading role. Net capacity is something that should be taken in mind when deploying fast chargers. But DSOs and CPOs should find the right locations on the energy nets for the deployment of these fast chargers. Requesting the charge points have tariffs that are suiting for the actual costs. There are some improvement areas, but the model is working. They have a lot of experience in net connections, and don't see an insuperable issue. It will bring costs inevitably.

Flexible energy prices are needed in the future to enable demand side management (not charging in the peak times). In 2018, flexible tariffs should be possible. There might be some small charges needed in legislations to enable dynamic energy pricing. Then, the costs for charging can be lower.

In 2035, electricity will be extremely cheap compared to now. In that case, hydrogen cars can have a market share, as the inefficiency does not matter that much anymore.

Future developments

Vision for the future

The MSP-role should not be a role that CPOs have as a double role. The MSP will be an important role of the future, for smart charging amongst other things. Now, municipalities, in their tenders, block the MSP from coming up with proposals for smart charging as there are the wrong demands in the tenders. Municipalities have not enough expertise on EV charging. They unknowingly block some innovations. They should have a facilitating role. It should be EU-policy that an MSP and CPO role should not be combined. The CPO should focus on software and data processing. They would need to facilitate all MSPs. This is regulatory easier.

Energy suppliers can, in that scenario, provide MSPs with smart charging, who then provide it to the EV drivers. This is an energy market issue. The EV driver should be able to choose their type of energy. In this case, the MSP facilitates the energy supply.

After 2020, but maybe before, car sharing will start becoming relevant. In 2030, autonomous driving will come up. This could also be sooner, but it is unsure. It will develop in steps.

Barriers

International (worldwide) standardisation is also crucial. If in California, the Netherlands and Germany within a few years agreements are made, this would serve as worldwide standards. If this is done after 5 years, it is too late.

The roles of stakeholders are crucial. Some have double roles which block the transitions. Municipalities are choosing the wrong roles. They will eventually sell the infrastructure, but this might be to the wrong parties (multinational companies). Open source software should be used. They have already developed software that is open source for charge points.

E15: Interview DSO 2

Organisation and partners

Core business

The goal of this department is enabling the energy transition (that is the strategy of the entire DSO), creating societal value. They are in group with the DSO, but they work in the resolutions of the DSO. The DSO is strongly regulated, they work on long-time societal issues. They can do pilot projects where they charge less for net connections (the DSO is not allowed to charge less for certain connections, they must treat al net connection requests equally).

Partners

They work together with all parties (municipalities, provinces, national government, consultants, ES, CPO, MSP). Not directly with OEMs. They do pilot projects in which they need to collaborate with different parties.

Types of charging points

Now

They are looking at private and public ownership mostly, not too much on locations. They are researching the entire spectrum. The public chargers were their first focus point. They have no preference for the charging rates. Charging at home will be on 22 kW (max utilisation of their net connection). They expect OEMs to take this into account when developing the cars.

Future

Where public chargers were first their main focus, not they also include private chargers in their research portfolio. In the future, there will be a large demand for public chargers, as not many people have their own driveway. This depends a lot however on the geographic area. In less urbanized areas, more people have driveways.

Net connection costs will determine charging capacities of the future. Also, the OEMs in Europe will facilitate AC charging. For everyone who can, charging at home should be facilitated.

Future developments

Vision for the future

EV drivers should be able to choose their own charge point and their own energy supplier. The EV driver has the main role in the development of the future system. They have interests in smart charging.

The OEMs will lead in determining the charging speeds. They include the 3 or 1 phase charger options, which each bear its own costs. They see the DSO as well as a determining factor, next to CPMs and EV drivers. Municipalities also play a role in the public domain, as they can set demands.

There are more practical issues with autonomous driving and car charging than that are mentioned now mostly. An open market system is very desirable in many points of view.

Barriers

In the smaller net connections, the successful implementation of EV charging is dependent on smart charging. The costs are higher, and DSOs will have to bear these costs. There is no structural solution to the future problem.

Grid congestion (regional/national and local) is an issue that needs to be solved. A flexible energy system will include different systems: national flexibility on a larger scale, and the local management systems. Their starting point is that as much as possible should be solved locally, so there are less congestion issues on the larger scale nets.

Up to 2020, there will be no standardized charging amongst OEMs concerning the charging rates. There are many investments in the charging infrastructure needed, and depreciation is also an issue. Because of longer depreciation times of investments, there is a delaying factor.

Cheaper and more EV cars are also a main issue. The prices of EVs need to drop still for the mainstream public.

E16: Interview ES 1

Organisation and partners

Core business

The ES has a triple role as CPO and MSP as well. Their main activity as an organisation is supplying energy.

Partners

They partner with a CPM and the installation and O&M of charge points is also done by another company. They partner with lease companies and OEMs as well. The DSOs have big roles in the tenders that municipalities put out, so they are forced to work with them as well. The DSOs are not always influencing this that is in the best interest of the EV driver however. Municipalities and provinces are also in a way their customers. They also talk to regulators in The Hague and Brussels.

Types of charging points

Now

Both public and private charge points are in their portfolio now. They place charge points on private home locations. But also on work locations. They now offer 22 kW chargers, that have two sockets (so 11 each). They are involved in all AC charge points from the tool, except for corridor chargers.

Future

They do not foresee a large market share for corridor chargers. Destination charging will have the largest market share. Charging on locations where people park their cars, such as home and work. This will be both public and private charging. The charging rates of destination chargers will become larger, unsure what rate but possibly up to 43. Increasing the rate, increases the flexibility they can offer.

Future developments

Vision for the future

Smart charging will be an important issue. Until 2025, the charger types that are deployed now, using them efficiently, will service the EV drivers. Larger net connections allow for more flexibility and smart charging. Smart charging on public chargers is not their strategy, as this can cause people to charge less. They see smart charging as good services for home and work chargers.

In 2023, EVs will start to reach the main public. Vehicle to grid is also an interesting development, but battery technology is something that depends on.

Barriers

For now, the public chargers are occupied too often with cars that are already fully charged. This is a major challenge. There will be costs involved in the future for keeping parking places with chargers occupied while you are not charging. There is a need for "social charging" where EV drivers do not occupy public charging points.

Some municipalities (most larger cities) are engaged in charging, but not all.

Car sharing will become popular with the younger generation within 2025 (then it will become a bigger movement). OEMs will need to come up with affordable mainstream cars.

E17: Interview Advocacy 1

Organisation and partners

Core business

They are an association of EV drivers. They advocate the interests of EV drivers. They want to stimulate people to drive electrically. They also want to connect EV drivers with each other, as part of a community where they can share experiences and organize events. Within the association, more than half of the members are not yet EV drivers, but are interested in EVs. They are also lobbying in the Hague. They are not an advocacy organisation in the way that they advocate interests for the industry, because they are only advocating the interests of EV drivers. They do not have commercial interests. The demands of EV drivers should be leading in developing regulations for charging infrastructure, not the interests of industry.

Partners

They are collaborating with industry advocacy organisation. Their events can be sponsored by industry parties, such as energy suppliers, OEMs, a DSO and a lease company. They are also in contact with CPMs, CPOs and MSPs. The municipalities can get information with the advocacy as well. Only organisations that they are not in contact with are provinces.

Types of charging points

Now

They are not focusing on certain types of charge points themselves. They only collaborate with partners who do. They have an interest in the developments but watch the developments closely.

Future

They see that there is a demand for fast charging, since fast charging allows for the maximum amount of flexibility. Drivers should not be limited, whatever their plans are. They should not have to plan.

They do not believe in charging according to mobility needs, but an EV needs to be charged fully every day. In that case, people won't have to change their behaviour (which is difficult to change). Bigger battery packs solve this partly. Smart charging according to planned mobility needs is not comfortable, since range anxiety is still an issue amongst EV drivers.

At home, there will be no need for fast chargers, since you usually stay there long. At work locations, we should be able to charge at 22 kW at least, since you spend less time there. They believe that DC chargers are going to be very popular in the future. The corridor chargers will all be DC.

Future developments

Vision for the future

Induction charging will be relevant in the future. In 2035, 100% of new sales should be electric. In 2025, 50% of sales should be electric. In 2019-2020 there will be more mainstream EVs, which will increase the demand for charging. Autonomous driving will increase the deployment of induction charging. This is a very logical combination.

OEMs and EV drivers are the most influential groups.

Barriers

The national government also has an impact on the speed of deployments of EVs.

E18: Interview CPO fast 2 & MSP 3

Organisation and partners

Core business

One of their main activities is placing charging stations. They also focus on building the stations in a recognizable way: they believe that this will help their branding. They are currently CPO and MSP combined for fast charging stations in the Netherlands and abroad. They have deployed around 60 fast charging stations in the Netherlands and are expanding within the country, as well as abroad (mainly Germany, Belgium and UK now). One of their main activities is also finding the right locations and the entire process of getting permits. Servicing the customers is also important. That is why they have both the CPO as MSP role: to provide the customer with the best and most complete service.

Partners

They work together closely with a CPM, who is their sole charge point technology provider. Through this CPM, who has contact with all of the OEMs, they make sure their charge points are compatible and comfortable to use for the EV drivers. Through a knowledge platform they share information with OEMs, CPMs and themselves. They also work together with their energy provider and the DSOs for the electricity connections. They have not had that much contact with municipalities, as their focus has been on charging near highways (where space is operated by Rijkswaterstaat). Now, they are also deploying charge points near urban areas and are therefore in contact with some municipalities. This have now been only municipalities with a pioneering role. The municipality of The Hague is pioneering in offering both slow and fast charging stations to their residents and visitors.

Types of charging points

Now

They now have only 'corridor' fast charging stations. These are combined charging stations, where most cars charge on DC, but also 43.5 kW AC is offered to charge Renault Zoë cars. They will keep servicing these cars but want to go up in their range and also offer faster charging then they do now.

Future

They are planning to keep offering these types of charging points. They have a leading role in the development of fast charging stations and will continue this development. They want to combine the production of electricity with their charging stations.

Also, they are now developing fast charging stations in urban areas. Fast charging is not only of use at highways, but also around and in cities. This is where people are centred around and there the demand for fast charging will also increase.

Future developments

Vision for the future

The CPO and CPM will be more of a player on the energy market as well. This means arbitrating on the energy market and producing energy. This would happen on a semi-long term, anywhere between 5 to 10 years.

Charging in the future will include both destinations charging as well as corridor charging. Charging at work will also be a good option for a large group of people. Charging on the streets however is a lesser extend as they foresee a charge point on every street, but not on every parking place on the street. This would not be viable looking at public space or costs. For the DSOs this would also not be a viable solution. In urban areas, people will use mobility services such as car2go or Uber. When and if these types of services reach a tipping point, the entire industry of charging can change. For these serviced cars that are not owned by one person, it is not economical to charge slowly. Even at night, there still is a demand for mobility. It the night between 5 and 7, there is a lesser demand. But even then, this is not enough time for slow charging.

Factors that will influence the charging are autonomous charging, car sharing, and the services mentioned before. These movements will start at around 2020. Car sharing is already happening today. These developments will increase the demand for fast charging.

Barriers

The barriers for the foreseen future are inertia of the car industry. They should not focus on intermediate solutions such as plug-in hybrids. They are used to selling gasoline and diesel cars and their entire production chain is fine-tuned. It will be a challenge for them to find ways to change their business around and start making money on full electric cars.

One way to partly overcome this barrier is to develop EU or worldwide emission criteria. The prices of batteries that are decreasing are also a big factor. The OEMs are already coming around and realizing that EVs can be profitable. Not all of them are yet realizing this, but more and more are slowly coming around.

F. Hierarchical Bayes analysis runs

The Hierarchical Bayes analysis is carried out using the Sawtooth Software Lighthouse software package. Summaries of the runs of the part-worth estimations can be found below. Figure 17 shows the HB run for the Urgent Charging scenario and Figure 18 for the Optional Charging scenario.

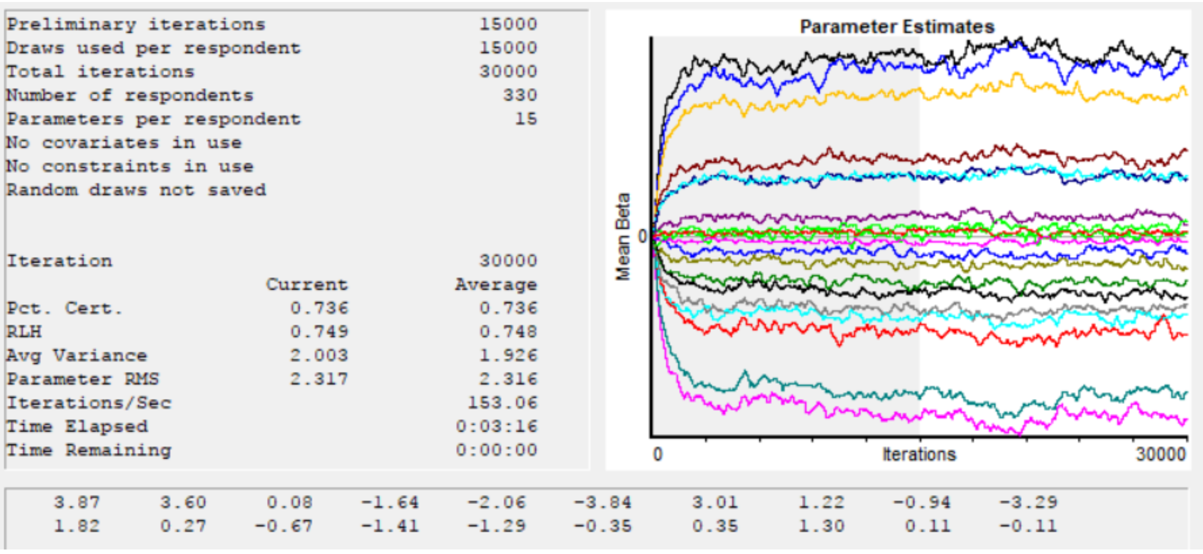

Figure 17: Iterations of HB analysis for Urgent Charging scenario

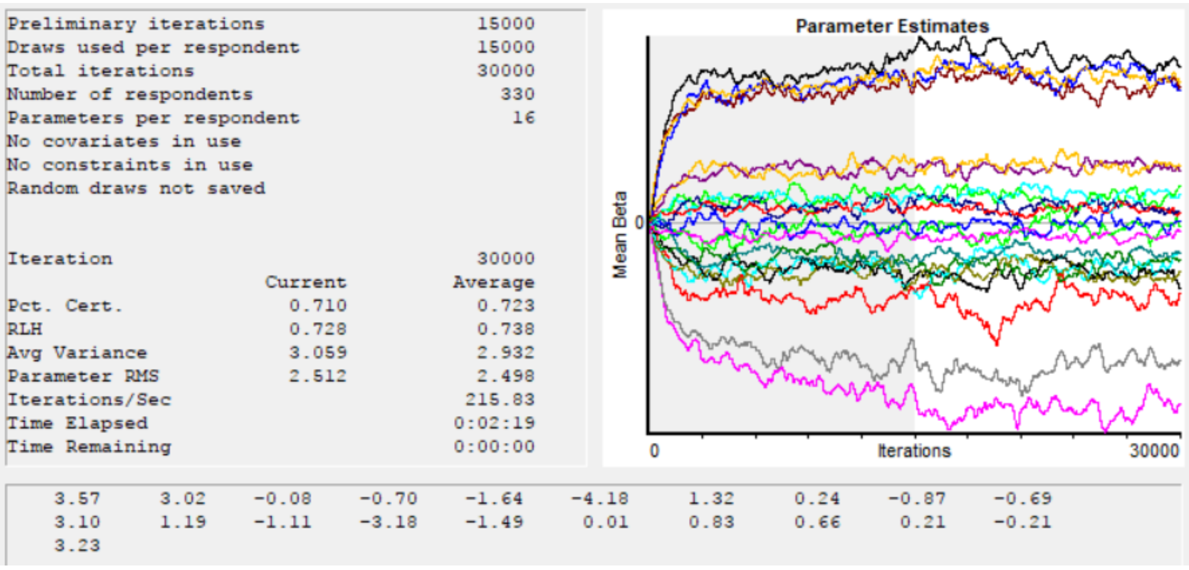

Figure 18: Iterations of HB analysis for Optional Charging scenario

The iterations for the Urgent Charging scenario show visibly less variance for all parameters then the iterations in the Optional Charging scenario. The average variance of the Optional Charging scenario is 2.932 where the variance for the Urgent Charging scenario is 1.926 on average. This implies that there was less variance between the EV drivers' preferences in the Urgent Charging scenario then in the Optional Charging scenario.

G. Utilities and confidence intervals

Table 11 contains the results of the HB analysis of the DCE experiment, showing the utility values in the Optional Charging scenario including the standard deviation.

Table 11: Average utility values for Optional Charging scenario with confidence intervals

Average Utility Values				
Utility Scaling Method	Zero-Centered Differences			
Respondent Count	330			
Label	**Utility**	**Std Deviation**	**Lower 95% C.I.**	**Upper 95% C.I.**
Home	91.61	22.02	89.24	93.99
Workplace	82.22	25.55	79.46	84.98
Shopping centre	-3.16	20.55	-5.38	-0.94
Corridor	-24.19	14.06	-25.71	-22.67
Corridor 5m detour	-43.14	21.80	-45.49	-40.79
Corridor 15m detour	-103.34	19.26	-105.42	-101.27
3min	31.40	28.50	28.33	34.48
20min	9.80	17.43	7.92	11.68
90min	-24.39	18.44	-26.38	-22.40
300min	-16.82	25.64	-19.58	-14.05
2.5eur	77.47	24.28	74.85	80.09
5eur	30.59	10.42	29.47	31.71
7.5eur	-27.39	16.87	-29.21	-25.57
10eur	-80.67	20.03	-82.83	-78.51
40%	-27.97	13.12	-29.38	-26.55
60%	-1.93	15.93	-3.65	-0.21
80%	14.36	11.97	13.07	15.65
100%	15.54	11.01	14.35	16.73
Yes	7.73	10.72	6.58	8.89
No	-7.73	10.72	-8.89	-6.58
None	88.33	102.68	77.25	99.41

Table 12 contains the results of the HB analysis of the DCE experiment, showing the utility values in the Urgent Charging scenario including the standard deviation.

Table 12: Average utility values Urgent Charging scenario with confidence intervals

Average Utility Values				
Utility Scaling Method	Zero-Centered Differences			
Respondent Count	330			
Label	**Utility**	**Std Deviation**	**Lower 95% C.I.**	**Upper 95% C.I.**
Home	86.08	41.82	81.57	90.59
Workplace	83.29	25.30	80.56	86.02
Shopping centre	1.93	31.46	-1.47	5.32
Corridor	-38.39	19.34	-40.48	-36.31
Corridor 5m detour	-46.01	19.43	-48.11	-43.91
Corridor 15m detour	-86.89	27.67	-89.88	-83.91
3min	69.59	21.97	67.22	71.96
20min	30.20	13.19	28.78	31.62
90min	-22.01	14.88	-23.61	-20.40
300min	-77.78	19.74	-79.91	-75.65
2.5eur	39.56	25.53	36.81	42.32
5eur	9.17	17.05	7.33	11.01
7.5eur	-13.17	16.53	-14.95	-11.38
10eur	-35.56	23.50	-38.10	-33.03
40%	-27.66	30.07	-30.90	-24.42
60%	-8.38	14.91	-9.99	-6.78
80%	5.44	18.16	3.48	7.40
100%	30.60	25.65	27.84	33.37
Yes	2.29	7.85	1.44	3.14
No	-2.29	7.85	-3.14	-1.44

H. Stakeholders’ views on types of chargers in colour scales

Below, the colour scale for the comparison with the stakeholders can be found in Table 13. These are shown separately for all types of organisations, domains and relations to technology.

In the right column, the amount of stakeholders that represent each group is noted.

Table 13: Colour scaling of stakeholder groups visions

SUM - ALL	Home	Work	Shop	Corridor	# of stakeholders in table
					18
Slow	8	5	3	0	
Medium	15	15	9	0	
Fast	0	3	2	3	
Ultra-fast	0	0	1	9	

Type of organisation

PUBLIC ORGANISATIONS	Home	Work	Shop	Corridor	4
Slow	1	1	1	0	
Medium	2	2	1	0	
Fast	0	1	1	0	
Ultra-fast	0	0	0	2	

SEMI-PUBLIC ORGANISATIONS	Home	Work	Shop	Corridor	2
Slow	1	1	0	0	
Medium	2	2	0	0	
Fast	0	0	0	0	
Ultra-fast	0	0	0	0	

PRIVATE ORGANISATIONS	Home	Work	Shop	Corridor	12
Slow	6	3	2	0	
Medium	11	11	8	0	
Fast	0	2	1	3	
Ultra-fast	0	0	1	7	

Relation to technology

NOT DIRECTLY RELATED TO TECHNOLOGY	Home	Work	Shop	Corridor	6
Slow	2	1	1	0	
Medium	4	4	2	0	
Fast	0	1	1	1	
Ultra-fast	0	0	0	4	

WORKING WITH TECHNOLOGY	Home	Work	Shop	Corridor	8
Slow	4	2	1	0	
Medium	7	7	4	0	
Fast	0	0	0	1	
Ultra-fast	0	0	0	2	

PRODUCING TECHNOLOGY	Home	Work	Shop	Corridor	4
Slow	2	2	1	0	
Medium	4	4	3	0	
Fast	0	2	1	1	
Ultra-fast	0	0	1	3	

Domain

ENERGY DOMAIN	Home	Work	Shop	Corridor	3
Slow	2	2	1	0	
Medium	3	3	1	0	
Fast	0	0	0	0	
Ultra-fast	0	0	0	0	

VEHICLES DOMAIN	Home	Work	Shop	Corridor	4
Slow	3	1	0	0	
Medium	4	4	1	0	
Fast	0	1	0	1	
Ultra-fast	0	0	0	4	

REGULATORY DOMAIN	Home	Work	Shop	Corridor	4
Slow	1	1	1	0	
Medium	2	2	1	0	
Fast	0	1	1	0	
Ultra-fast	0	0	0	2	

CHARGING DOMAIN	Home	Work	Shop	Corridor	8
Slow	3	1	1	0	
Medium	7	7	6	0	
Fast	0	1	1	2	
Ultra-fast	0	0	1	4	

I. Using the gathered data in an agent-based model

Agent-based modelling

Agent-based models are bottom-up simulation models. In an agent-based model, each entity is an agent. Each agent has a set of rules that describe the behaviour of this agent towards other agents or the environment. Agents thus represent autonomous decision-making entities that interact and they have certain characteristics (Macal & North, 2015).

Van Dam et al. (2013) describe the basic concept of agents and their interactions. The agent is in a state, has behaviour described with rules and actions effect agents and the agents and the environment. The behaviour of an agent can encompass a model that has an aim, such as maximisation. For instance, an agent can be a company that aims to maximize its profit. An agent can also have a behaviour that happens in a certain period of time or when a certain event happens in the environment.

By simulating all agents and the environment over a period of time, one simulates the system. This simulation represents the prediction of what the future can look like. As any model, it does not represent the real-live system, but it provides an approximation of the system. The Eindhoven University of technology is developing the ABCD model (Agent-based Buying Charging Driving) and below, the two ways in which this research can contribute to the ABCD model are described.

Interview data for conceptual basis of stakeholder agents

In general, the stakeholder interviews lead to a better understanding of the different actors in the socio-technical system. Van Dam et al. (2013) argue that this is very important in the first steps of developing an agent-based model. More specifically, the general behaviours and rules of agents should be determined.

In many interviews, with all DSOs, CPOs and CPMs, it is argued that car manufacturers (OEMs) have the biggest role in determining what charging rates will be developed and used. The other stakeholders must follow them, as they ultimately have the goal of services the EV driver and the OEMs decide on what charging point types the EV can connect with. This agent should have this decisive power in the ABCD model. The interactions between for instance the CPMs should be that the CPMs should take over the specifications that the OEMs provide.

One example of a conceptual basis for an agent (the OEM in this case) is given in Figure 19. This application illustrates how these interviews can be used in developing the ABCD model, but the practical modelling is out of the scope of this research.

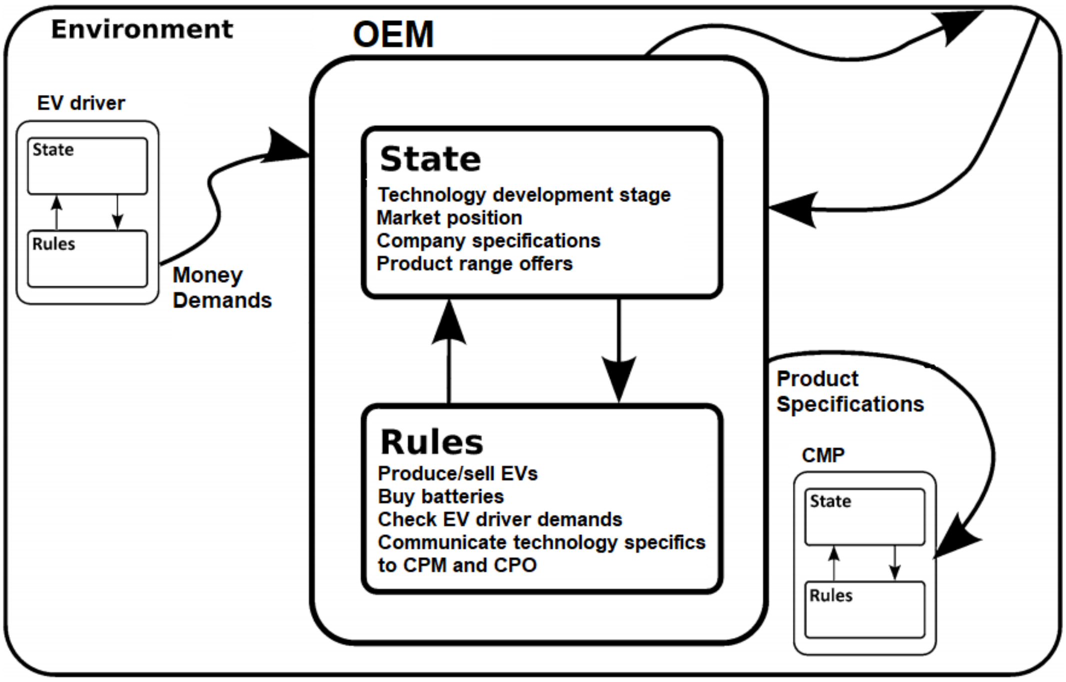

Figure 19: Schematic overview of OEM agent to an example of van Dam et al. (2013)

Using a choice model in an agent-based model

In literature, many ABMs can be found that use some kind of model in the agents' decision process (Holm, Lemm, Thees, & Hilty, 2016). Data for these models comes from a wide range of sources and are in some cases just assumptions. However, a few researchers used discrete choice experiments to enhance their agent-based model with a choice model. This improves the empirical foundation and internal validity of the model (Holm et al., 2016; Günther, Klein, & Lüpke, 2018).

Using a choice model, resulting from a DCE experiment, to enhance an agent-based model has been done before. For instance, Holm et al. (2016) have implemented HB analysis data from a DCE into an agent-based model on a Swiss roundwood market. Furthermore, a DCE also complemented an agent-based model on the EV buying behaviour of consumers in Germany (Günther et al., 2018). ABM, amongst other applications, also used as a method to investigate market dynamics. It allows modelling the behaviour of all stakeholders individually.

To simulate the choices of the EV driver agents in the ABCD model, the choice model can be implemented in the ABCD model. As the ABCD model is a simulation model which will be used for what-if scenarios, they can adapt it to different alternatives for charge points. In one simulation, it can be simulated what an EV driver would choose if they had to choose between a slow charger at home or a 20-min fast charger near the highway. In the next simulation, we can compare the results with the same scenario, but with a 3-min fast charger.

Creating choice models

In the logit model used in the Sawtooth Software, the utility of each alternative is considered as the sum of the part-worths of its attribute levels (Johnson, 2000). The part-worth utilities can then be used for creating a so-called choice simulator. This simulator predicts the preferences for different charging point alternatives when multiple options are available. The Sawtooth Software incorporates a tool for creating market simulators (or so-called choice models). Different market simulators can be created, where some take into account complex effects like two-way interactions and cross-effects (Orme, 2006). Using the manual provided by Sawtooth (Orme, 2006) several market simulators were created.

Figure 20 shows a simulator created in the Sawtooth Software for the Urgent Charging scenario. In this case, three different chargers were compared to each other. The first one is a home, second one a work and the last one a corridor charger. The levels of the attributes of the chargers are chosen and these are shown below the options. They have been coded with numbers and the coding table is shown at the bottom of the simulator. In this case, roughly 23% of EV drivers (found in the blue cells) would choose the home charger, 72% would choose the work charger and 5% would choose the corridor charger.

These options can be changed for every possible scenario, comparing from 2 up to 6 charge points with each other. The agent-based model can adopt this simulator and use it as a choice model for the EV driver agents. The implementation and results of the choice model are out of the scope of this research.

	Product 1	**Product 2**	**Product 3**	**Product 4**	**Product 5**	**Product 6**
Include (0/1)?	1	1	1	0	0	0
Location	1.00	2.00	5.00	1.00	1.00	1.00
Charging rate (min)	4.00	4.00	2.00	1.00	1.00	1.00
Price (eur)	3.00	1.00	4.00	1.00	1.00	1.00
Availability (%)	4.00	4.00	3.00	1.00	1.00	1.00
Familiarity	1.00	1.00	2.00	1.00	1.00	1.00
Shares of Preference	23.44 %	71.89 %	4.67 %	0.00 %	0.00 %	0.00 %
Standard Error	1.48 %	1.61 %	0.80 %	0.00 %	0.00 %	0.00 %
Code	**Attributes**					
	Location	**Rate (min)**	**Price (eur)**	**Availability**	**Familiarity**	
1	Home	3	2.5	40%	Yes	
2	Workplace	20	5	60%	No	
3	Shopping cer	90	7.5	80%		
4	Corridor	300	10	100%		
5	Corridor +5 min					
6	Corridor +15min					

Figure 20: Choice model example in Urgent Charging scenario

Discussion on using a choice model in the ABCD model

A short point of discussion should be noted: the market simulations of the current situation should be compared to real-life data of current charging points and electric vehicles to test the choice model. This could be done in further research to validate the data before implementing it in the ABCD model.

The discrete choice experiment predictions do not take real-world factors that shape market shares into account and also assume that all relevant attributes that influence a choice have been measured. Therefore, the share of preference predictions resulting from a choice model should not be interpreted as market shares, but as relative indications of preference (Orme, 2010b). However, the indicators of preference will enhance the ABCD model and improves its empirical foundation and internal validity.