Solidarity in EV charging

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A discrete choice experiment to assess interest in charging schemes

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Preface

This report describes the research "Solidarity in EV charging: A discrete choice experiment to assess interest in charging schemes" that was carried out to complete my Master's degree in Complex Systems Engineering and Management (CoSEM) at the Delft University of Technology. This research was carried out individually during the period from February to July 2023 under the supervision of Dr. Baiba Pudāne and Dr. Ir. Roel Dobbe.

During my bachelor and master study, I have been working on multiple projects related to the transport sector. These projects regularly concerned topics related to the transport of the future. During this period I created a considerable interest in innovations related to mobility and enjoyed working on topics related to this. When I saw this master thesis topic passing by, I thought that this could be an interesting one to write my master thesis about. Furthermore, the topic description also stated that choice behaviour modelling would be used in this study. This stimulated my choice, since I followed the course linked to this method successfully and with great pleasure. All in all, it turned out to be a good choice. I carried out the research with great pleasure and learned plenty of new skills.

The pleasure I experienced while conducting the research is also partly due to my supervisors. I received good guidance during the research, which helped me a lot in improving the work. In addition to my supervisors, I would also like to thank Jerico Bakhuis who took on the role of advisor and provided me with useful feedback during the first half of the project. Furthermore, I would also like to thank Teodora Szep, a former PhD student at the Delft University of Technology. Despite the fact that she had already left the university, she helped me with the questions I had regarding the choice behaviour modelling software. Finally, I would also like to express my gratitude to the experts who participated in an interview and the people who helped me with the distribution of the survey.

I wish you a lot of reading pleasure!

Joery Zandstra

Abstract

Currently, the electricity grid in the Netherlands is reaching its capacity, resulting in congestion issues. One of the factors that causes the electricity grid to become overloaded is the increasing use of EVs (electric vehicles). A situation in which a large number of EV users in a certain area charge their EV at the same time can significantly increase the risk of congestion in the electricity network. To avoid such situations it is necessary to change the charging behaviour of the EV users.

The literature shows that smart charging systems, such as charging schemes, are having a high potential to solve these grid capacity problems. In the context of this study, a charging scheme is defined as a contract between an EV user and the charge card provider/electricity supplier stating, among others, at what times an EV user could charge his/her EV. However, to ensure that charging schemes can effectively contribute to solving the grid capacity problems, it is important that many EV users are willing to participate in such schemes.

Therefore, the research objective is to study how EV users will react to various charging schemes. In particular, the aim is to assess the effectiveness of appealing to someone's intrinsic motivation versus providing extrinsic incentives. First of all, with regard to the extrinsic incentives, this study specifically concerns monetary incentives that are expressed in a discount per kWh. By presenting different discounts, it is possible to test whether a monetary compensation influences the willingness to participate in a charging scheme. Secondly, with regard to someone's intrinsic motivation, this study focuses on appealing to someone's solidarity as a form of an intrinsic motivation. EV users with a certain degree of solidarity can be motivated to participate in a charging scheme when solidarity incentives are obtained (social recognition, togetherness and the development of friendships). By emphasizing the social benefits of a charging scheme, solidarity incentives could possibly increase the willingness to participate in a charging scheme. Furthermore, the research objective also includes an examination of the influence of the charging scheme attributes on the choice to participate in a charging scheme. In addition, the role of the characteristics of the EV users in the choice to participate in a charging scheme will also be discussed.

Since the objective of the study is to research how EV users will react to various charging schemes, a survey containing a discrete choice experiment is used. To be able to examine the effectiveness of providing an extrinsic incentive (monetary compensation) versus appealing to someone's solidarity by emphasizing the social benefits of a charging scheme, the survey contains two charging scheme versions, an incentive-based version and an intrinsic-based version. By using two survey versions, it is possible to examine separately whether it is more effective to appeal to someone's intrinsic motivation versus providing a financial compensation. In addition, it is also possible to examine the influences of the charging scheme attributes for both charging scheme versions. Finally, the survey also asks for a number of characteristics with which EV users can be characterized. By using this data, it is possible to examine whether certain characteristics play an explanatory role in the choice to participate in a charging scheme. Ultimately, 130 valid responses were obtained from fully electric and plug-in hybrid vehicle users. The respondents were approached through various social media platforms with the help of many individuals and organizations, such as the Dutch association for electric drivers and Fastned.

The results show that the willingness to participate in a charging scheme was generally higher in the intrinsic-based version than in the incentive-based version. Based on this, it can be concluded, within the boundaries of the selected attribute ranges, that appealing to someone's solidarity by emphasizing the social benefits is more effective than offering a financial compensation. This is also substantiated by the fact that the financial compensation attribute included in the incentive-based charging schemes does not influence the willingness to participate. Furthermore, by looking at the utility ranges of all attributes, it was found that a restriction on the ability to fully charge the vehicle had the most influence on the choice to participate in a charging scheme followed by a restriction on when charging can take place. The willingness to participate in a charging scheme decreases when the guaranteed battery level

decreases and when there is a limitation in the charging times. With regard to the charging time restriction, the willingness to participate in a charging scheme is also considerably lower when there is an evening restriction than a morning restriction. In addition, the results also show that the attributes in the intrinsic-based charging schemes have a smaller influence on the choices with regard to charging scheme participation than in the incentive-based charging schemes. Finally, with regard to the role of the characteristics of the EV users, the results show that EV users who have a good connection with their neighbours, who live in a detached house and/or work full time, showed a considerably higher willingness to participate in a charging scheme. However, as most interaction effects were insignificant, it can be concluded that the characteristics of EV users generally do not play a role in the EV user's choice to participate in a charging scheme.

Next, as it became clear that solidarity incentives weigh more heavily than financial incentives in the choice to participate in a charging scheme, it may be interesting for policymakers to respond to this or for researchers to conduct a follow-up study on this. To begin with, policymakers are advised to take advantage of the fact that appealing to the EV user's solidarity is an effective means to encourage an EV user to participate in a charging scheme. By using the investment capacity of the Dutch Climate Fund, it is possible to explain to EV users that charging scheme participation is important, that no big sacrifices have to be made and that participation is accompanied by many social benefits. In addition, the research also showed that EV users who have a strong connection with their neighbours are more willing to participate in a charging scheme. On the basis of this, it is also interesting for policy makers to invest in social connectedness within certain neighbourhoods. Organizing social activities could then indirectly lead to an increasing will to participate in a social scheme, such as a charging scheme.

Finally, the study also has some limitations. The study is first of all limited to the fact that this study looked at the stated intentions of EV users and not at the actions in practice. Secondly, the experiments included static charging schemes instead of the more realistic dynamic charging schemes. Based on the limitations, it might be interesting to do a follow-up study in which charging scheme participation will be examined in a real-life situation including both static and dynamic charging schemes. Furthermore, a follow-up study regarding the characteristics of EV users could also be interesting. Instead of only looking for the interaction effects, it might also be interesting to research what kind of charging scheme designs are preferred by a certain group of EV users. This could allow policy makers to form tailored-made policies for specific groups of EV users.

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1. Introduction

1.1 Research context

To achieve the various climate objectives worldwide, it is important that energy from renewable sources becomes affordable and accessible. The EU policy drawn up in 2014, with the aim of reducing greenhouse gas emissions by 40% compared to the amount of emissions in 1990, states that the share of renewable energy consumption must increase (Shivakumar et al., 2019). However, the increasing supply of energy from renewable energy sources can cause grid capacity problems, resulting in congestion. Various papers discuss this problem when it comes to, for example, the realization of offshore wind farms (Simão et al., 2017) or the realization of PV systems (von Appen et al., 2013).

A well-known solution that can contribute to balancing the electricity grid is the realization of an energy storage (Strbac et al., 2017). However, an energy storage system is quite expensive and is therefore less attractive to realize (Zhang et al., 2018). Another solution for balancing the electricity grid is changing the consumer’s behaviour. To clarify, this changing of behaviour of the electricity network users concerns a situation in which the grid operators can use the possible flexibility of consumers and producers to optimize the energy flows in the network from moment to moment (Mata et al., 2020). When these system operations take place, the current infrastructure can be used more efficiently, which will support the transition to renewable energy sources.

For this study, a specific group of users of the electricity network will be examined, namely the electric vehicle (EV) users in the Netherlands. The increasing use of EVs makes an important contribution to achieving the EU policy mentioned earlier (European Environment Agency, 2014). However, an increase in EV usage also leads to problems with the urban distribution network. If many EV users in a certain area are charging their EVs at the same time, the quality of the electricity supply will be affected (Li & Bai, 2011). Therefore, ways must be sought to change the charging behaviour of EV users.

1.2 Research problem

Several studies have already been conducted on the impacts of the increasing adoption of EV charging on the power systems (Andersen et al., 2021; Lauvergne et al., 2022; van der Kam et al., 2020; Gschwendtner et al., 2023). The studies show that an increase in EV charging is mainly a problem in urban areas and that this also means that these areas have the biggest potential for changing the charging behaviour of EV users. This shows that it is therefore necessary to make use of a measure that ensures that the charging behaviour of EV users in urban areas will change. An example of such a measure is a charging scheme. In this study, a charging scheme will be defined as a contract between the EV user and the charge card provider/electricity supplier stating, among others, at what times an EV user could charge his/her EV.

In other words, a charging scheme is a smart charging system that can be used to control the charging behaviour of EV users, resulting in a reduced peak load on the electricity network (Yi et al., 2020; Tuchnitz et al., 2021; Gunkel et al., 2020; Hogeveen et al., 2022). To clarify, the term "smart charging system" can be seen as an umbrella term for possible solutions that make the charging of an electric vehicle more efficient or more sustainable. For this reason, a charging scheme can be seen as a smart charging system. Another example of a smart charging system is V2G (Parsons et al., 2014). In this smart charging system, the electricity can be supplied both from the network to the vehicle and vice versa. However, due to this interaction, it might happen that the vehicle is not fully charged when the user needs it.

The effectiveness of a charging scheme depends on the acceptance by the EV users, it is therefore important to investigate how EV users can be encouraged to participate in a charging scheme. The literature with regard to smart charging systems already includes studies into ways in which charging schemes could be designed and the acceptance of certain smart charging systems (Libertson, 2022; Kubli, 2022; Daina et al., 2017; Lagomarsino et al., 2022; Pan et al., 2019; Schmalfuß et al., 2015;

Schmalfuß et al., 2017; Parsons et al., 2014; Jimenez, 2019; Will & Schuller, 2016) As an example, some studies looked at the participation rate in different smart charging situations. These situations included, among others, sacrifices in charging timings, charging duration and guaranteed battery level.

These examples show that a participant in a smart charging system is being tied to agreements that to some extent may impede their mobility. In other words, smart charging measures have to do with reduced flexibility for the participant as a cost. This means that the participants in a smart charging system need to think ahead, which in turn leads to a reduction in spontaneity. This decrease in spontaneity is seen by many EV users as an important risk, because a decrease in spontaneity could, among others, lead to an increase in the need for flexible mobility or plug-in hybrid electric vehicle drivers that must rely on the gasoline engine, resulting in an unnecessary cost for them and the environment.

In addition to presenting the sacrifices associated with participation in a smart charging system, some studies that conducted a choice analysis also included extrinsic incentives to see whether these incentives influence the choice of the EV users. More specifically, financial compensations are used with the aim of convincing EV users to participate in a smart charging system. As an example, the study by Lagomarsino et al. (2022) asks EV users whether they will choose smart charging (with the associated sacrifices) or immediate charging in a given situation. If smart charging is chosen, the EV user will be compensated for this.

However, next to extrinsic incentives, no other forms of motivations to participate in a charging scheme have yet been included in these studies. In addition to appealing to someone's extrinsic motivation it is also possible to appeal to someone’s intrinsic motivation. The difference between these motivations is that an intrinsic motivation comes from within and extrinsic motivations from external factors (Hung, 2011). Furthermore, someone's extrinsic motivation will be evoked by tangible rewards, while someone’s intrinsic motivation will be evoked by intangible rewards.

So, as an example, monetary incentives (e.g. discounts and subsidies) can be seen as tangible rewards and solidarity incentives (as a form of intrinsic benefits) as intangible rewards (Clark & Wilson, 1961). Examples of solidarity incentives that a person could experience from participating in a scheme with social benefits, such as a charging scheme, are social recognition, togetherness and even the development of friendships (Hirsch, 1986). Someone’s preference for a type of return varies with their social connectedness and thus solidarity with others (Singh et al., 2018). When someone has a strong sense of social connectedness, this person may be more likely to make decisions based on his/her intrinsic motivation. This suggests that people who are willing to participate in a charging scheme based on their intrinsic motivation would show a higher degree of solidarity. By examining the effectiveness of appealing to someone's intrinsic motivation, by mentioning the social benefits of a charging scheme, versus the provision of extrinsic incentives, it is possible to examine the solidarity of EV users.

In short, no research has yet been conducted into the effectiveness of providing extrinsic incentives versus appealing to someone’s intrinsic motivations in case of smart charging systems. Given this knowledge gap, the objective of this research is therefore to study how EV users would react to various charging schemes, while assessing the effectiveness of appealing to someone's intrinsic motivation versus providing extrinsic incentives.

1.3 Research design

Based on the knowledge gap identified in the previous section, this section discusses the chosen main research question, which is subsequently split into various sub research questions. After that, a research approach was chosen on the basis of these research questions. This research approach is discussed later in this section.

1.3.1 Research questions

In the previous section it became clear that the motivations influencing the acceptance of a charging scheme can be distinguished in either extrinsic or intrinsic motivations. However, it is not yet clear whether it is more effective to appeal to someone's intrinsic motivation, and then specifically solidarity, or to provide extrinsic incentives. The aim of this study is therefore to learn more about the effect of these types of motivations on the participation in a charging scheme. In addition to investigating the effect of these motivations, it is also interesting to investigate the influence of other factors, namely the charging scheme attributes (components of a charging scheme including the sacrifices) and characteristics of EV users, on the choice to participate in a charging scheme. Ultimately, on the basis of this research, an overview could be created of the different factors that influence the willingness to participate in a charging scheme. This results in the following main research question:

- *MRQ: "How do the different motivations, charging scheme attributes and characteristics of EV users play a role in the choice of the EV user with regard to charging scheme participation?"*

Before conducting an in-depth research into the various factors that may play a role in the EV users' choice to participate in a charging scheme, it is important to learn more about the perceptions of experts that work on EV-related topics. By identifying this perception, it is possible to form a better picture of what a charging scheme could entail. A clear picture of what a charging scheme could entail is important for determining the elements that belong to a charging scheme. In addition, it is also interesting to find out at a higher level which factors may play a role in the acceptance of an innovation such as a charging scheme. This leads to the first sub research question:

- *RQ1: "What is the current perception of experts working on EV-related topics with regard to charging schemes and the acceptance of such schemes.*

The second step of the research is to get insight into the different factors that might play a role in de choice of the EV users with regard to charging scheme participation. It has previously been stated that the type of motivations that will be included in this study are either factors that appeal to someone's intrinsic motivation or incentives that may extrinsically influence the EV users choice to participate in a charging scheme. For this reason, it is first of all interesting to see which types of intrinsic motivations and incentives are relevant to include in this study. Subsequently, when there is an overview of the factors that may appeal to someone's intrinsic motivation and the incentives that may influence the choice of EV users to participate in a charging scheme, it is possible to conceptualize the different factors and incentives into charging scheme designs.

Next, since I am also willing to investigate the influence of the charging scheme attributes and the characteristics of EV users on the choice to participate in a charging scheme, the next step of the research is to find out which attributes, with the corresponding attribute levels, and characteristics of EV users are relevant to include in the study. With regard to the charging scheme attributes it is also possible to translate the factors and incentives found into attributes of different charging schemes. Furthermore the term "characteristics of the EV users" might sound very broad and therefore also vague. To clarify, the characteristics of EV users could, among others, include vehicle-related characteristics such as the type of EV someone owns and the socio-demographic characteristics such as age. This search for relevant factors to include in the study leads to the following sub research question:

- *RQ2: "What motivations, charging scheme attributes and characteristics of EV users might be relevant to include in the study?"*

Once the second research question have been answered, the next step is to design the charging schemes. As mentioned earlier, this concerns contracts with attributes that could influence the charging behaviour of an EV user. The attributes of a charging scheme can influence an EV user's choice to participate. For this reason, it is first of all interesting to investigate which attributes significantly influence the choice of an EV user to participate in a charging scheme.

Furthermore, the article by Szep et al. (2023) shows that it is also possible to distinguish schemes by framing them. In this article it became clear that the way in which a social routing scheme is framed, can influence the choice to participate in the social routing scheme. Framing is about the way in which a scheme is presented to someone. This method provides a convenient way to investigate the effectiveness of appealing to someone's intrinsic motivation versus providing extrinsic incentives. By on the one hand providing a group of respondents with "incentive-based charging scheme designs" in which extrinsic incentives are explicitly communicated and on the other hand providing a group of respondents with "intrinsic-based charging scheme designs" in which social benefits are explicitly communicated, it will be possible to properly examine the effects of both types of motivation.

In addition, the motivation crowding theory (Niza et al., 2013) states that the provision of an incentive can lead to an undermining effect on someone’s intrinsic motivation to do something. Research has shown that people who have never previously received an incentive to do something have a higher intrinsic motivation to do that certain thing than the people who previously received an incentive to do the same. With regard to this study, it could be that EV users that are presented with a monetary compensation for participating in a charging scheme would have a lower intrinsic motivation to participate in a charging scheme than EV users who were not presented with this compensation. By setting up two different charging scheme versions, it is possible to investigate the pure effectiveness of appealing to someone's intrinsic motivation versus offering incentives on charging scheme participation.

The attributes in combination with the way in which a charging scheme is framed form the characteristics of a charging scheme. For this reason, it is interesting to examine the influence of these two elements and the associated factors on the choice to participate in a charging scheme. This leads to the next sub research question:

- *RQ3: “How do the characteristics of a charging scheme influence the choice of the EV users to participate in a charging scheme?”*

Finally, in order to distinguish between the different EV users, the factors that could characterize the EV users will also be examined. By examining the role of the different characterizing factors with regard to charging scheme participation, it will be possible to say something about the willingness to participate in a charging scheme for a certain group of EV users. As an example, the study by Szep. et al. (2023) showed that people for whom fairness is an important moral motivation primarily chose to participate in the social routing scheme that was framed as a common good. All in all, it is therefore interesting to look for the influence of the factors that could characterize the EV users on the choices they make. This leads to the final sub research question:

- *RQ4: “How do the characteristics of EV users play a role in the choices made with regard to charging scheme participation?”*

1.4 Research approach

In the previous section, a number of sub-questions were formulated that can lead to an answer to the main research question. This section looks at what data is needed to answer the sub questions and what research methods are needed to gather the data.

1.4.1 Literature research and interviews

The research starts with online open-ended interviews with both researchers and consultants that work on EV-related topics in order to answer RQ1. An open-ended interview is an interview in which open-ended questions will be asked. The aim of these interviews is to gain knowledge about the current situation regarding charging schemes. It is interesting to learn from the perceptions of experts with regard to charging schemes and use their knowledge to increase the societal/scientific relevance of this paper. In addition, the knowledge gained during the expert interviews could also be of added value for the development of the experimental design.

Parallel to these interviews, a literature research was conducted in which answers were sought to RQ2. To begin with, this research question stated that it is important to gain insight into the factors that appeal to someone's intrinsic motivation and the extrinsic incentives that may influence the EV users willingness to change their charging behaviour. With regard to this, a literature research could help to identify the different influential factors.

Secondly, this research question also concerned the search for attributes that are most relevant to include in the charging scheme designs. By conducting a literature research, insights could be gained into potential charging scheme attributes that are relevant to include in the charging scheme designs used for this research. These insights will be gained by searching for other schemes or studies that already cover attributes that are relevant to include in the charging scheme designs. If certain attributes are already conceptualized in existing schemes or covered in similar researches, these conceptualizations could be transferred into the charging scheme designs that will be used during this research. In addition, the existing conceptualizations can also function as an illustration of how the attributes could be conceptualized. This illustrative function could help with translating the factors that appeal to someone's intrinsic motivation and extrinsic incentives into charging scheme attributes.

Finally, a literature research will also be used to find the factors that could characterize the EV users and may influence their choices. By searching the internet for empirical data, it is possible to find different factors and learn how to place them in the relevant context. A literature research was chosen, as it is an efficient and effective way of searching for the potential influence of these different factors.

1.4.2 Discrete choice modelling

After the charging scheme designs have been created based on the findings in the literature, it is possible to move on to the next sub research question (RQ3). This research question is about the assessment of the charging schemes and the attributes that may influence the choice of the EV users to participate. Since the objective of the study is to research how EV users will react to various charging schemes, a quantitative research approach is selected as it enables a researcher to evaluate the support of EV users for certain charging scheme designs. More specifically, it is decided to use a discrete choice experiment containing hypothetical charging schemes.

A discrete choice experiment is a research technique that reveals individual preferences. This research technique allows researchers to discover how individuals value the selected attributes by presenting them with different choice sets (Mangham et al., 2009). In other words, by conducting a discrete choice experiment it will become possible to understand which characteristics of a charging scheme are most determining for EV users to participate in a charging scheme.

The usefulness of a discrete choice experiment can be seen in the research by Nyarko & Baidoo (2015) into the commuter's attitude to the importance of certain bus service quality attributes. In this study, various attributes have been selected that can determine the bus service quality on public transport. After performing a discrete choice experiment it was possible to determine which service quality attributes were considered as most important by the commuters. However, this research method also has a number of limitations. The main limitations are: a lack of representation of the target audience, insufficient resources available for data collection and limited outcomes due to the close-ended questions (Chetty, 2016). To resolve these limitations as much as possible, it is of the utmost importance to allocate sufficient time for conducting the research.

All in all, with regard to this study, the respondents will be presented a survey containing binary choice situations for each of the charging scheme designs. The intention is that a respondent indicates per charging scheme design whether the respondent is willing to participate in that charging scheme. Furthermore, in order to answer the final sub research question (RQ4), the survey will also include questions with regard to the characteristics of the EV users. When obtaining this data it will become possible to examine the interaction effects between the different factors that characterize the EV users and the participation rate. By looking for these interaction effects, it is possible to see whether there are other factors besides the attributes that influence the participation rate of an EV user. For example, it can be examined whether there is a connection between certain characteristics of an EV user, e.g. age, and the participation rate.

1.5 Outline of the report

The remainder of this report is organized as follows: Chapter 2 discusses some insights regarding the current situation around charging schemes that have been obtained from a set of conducted interviews. Chapter 3 discusses the main findings from the literature that are relevant to the setup of this study. Chapter 4 discusses the way in which the research was carried out and the choices that were made with regard to the implementation. Chapter 5 presents the model estimations and interprets the results based on the previously formulated research questions. Finally, in chapter 6 conclusions are drawn, implications are discussed and recommendations are made for possible further research.

2. Present state of charging schemes (expert interviews)

At the start of this study, five interviews were conducted to learn more about the present situation with regard to the electricity grid capacity problems and smart charging. The interviews were conducted with researchers from various major universities in the Netherlands and consultants working on EV-related topics. To determine whether an expert was suitable to participate in an interview, it was checked whether the interviewee had knowledge with regard to the grid capacity issues and the role of smart charging in this. In addition, based on the advice of a supervisor, an interview was also conducted with an expert in the social psychology of mobility technology.

All interviews were conducted online and lasted between 30 and 60 minutes. Before the interviews could be conducted, the interviewee had to sign an informed consent form. This makes it clear to the researcher that the interviewee agrees with the way in which his/her data is handled. The consent points are show in Appendix A. With regard to the structure of this chapter, some of the questions asked will be presented below, followed by a summary of the answers obtained during the interviews.

"What can you tell me about the current situation regarding capacity issues in the electricity network?"

In the current situation, not many people are yet confronted with grid capacity problems, such as energy shortages, but these problems will certainly arise more frequently if no measures will be taken. These problems will not only arise as a result of an increasing number of EV users, but also, among others, due to a growing demand for electricity as a result of the growing economy within a country and the associated increase in commercial buildings. In addition, due to the fact that the electricity cables have been realized based on the function of a certain area at that time, the risk of grid capacity problems will also differ per area.

To ensure that the capacity problems can be solved, it is important to thicken the cables or to construct new ones. However, the thickening of cables is not progressing quickly due to a shortage of specialized personnel and the granting of permits. As a solution, the personnel will be provided with a more specialized training, so that the personnel can start to work in an earlier stage of their education. However, the thickening of cables is just a solution for the long term, while faster solutions are required. One of these faster solutions is to change the behaviour of the user of the electricity network and then as an example that of the EV users.

“What is your knowledge regarding smart charging?”

Among others, research has been conducted into smart charging in the public space and the charging profiles of EV users. First, with regard to smart charging in the public space, it was stated that realizing smart charging in public space is more complex than in private space, since you are dealing with many different charging stations and suppliers. As an example, research has been conducted in the amount of EV users that would make use of public charging stations at the same time. The number of users determined the speed at which a vehicle will be charged. They wanted to find out the effectiveness of applying smart charging in this way, without emphatically involving the user. This involvement would in fact entail much more complexity. Next, with regard to the charging profiles, the aim was to discover at what times of the day the peaks arise in vehicle charging. In addition to determining the charging profiles, this research also investigated the best charging times in order to reduce the peak load.

"What is your perception of a charging scheme and what do you think a charging scheme entails?"

The different perceptions showed that a an ideal setup for the charging scheme could be seen as a contract between the EV user and the charge card provider/electricity supplier (depending on whether the situation involves public charging or private charging). The charge card provider, a company that provides a card with which an EV user could make use of public charging points, would then be in contact with the various charging point operators within a certain area. It may also be the case that the same charging point operator provides a large area with charging stations and that the contract is therefore negotiated with the same charging point operator. However, it was discussed in the interviews that it might be easier for the research to delineate to the usage of a contract between the charge card provider and the EV user, because an EV user would probably have more contact with the charging card provider than with the charging point operator.

Furthermore, with regard to the possible restrictions that could be imposed on the charging scheme users, it can be concluded from the interviews that it is first of all realistic to impose restrictions on EV users with regard to charging timings. However, such a restriction should be communicated in a very clear way and it should be clear to the EV users that they can already connect their EV to the charger at any time. Secondly, it is probably not a problem for most EV users if their car cannot be fully charged as a result of smart charging, since it is also not usual for a normal car user that this person fills up his car every day. In addition, a 50% battery is for most EVs already equivalent to a range of 150 to 200 kilometres, which is often more than enough.

"Can you name factors that you think may play a role in the acceptance of a charging scheme?"

Next, with regard to the acceptance of charging schemes, one of the interviewees used the following example: *"despite the fact that we see more and more electric vehicles around us, it is still a relatively new phenomenon and many people could find that scary"*. With this similar example, the interviewee was trying to say that acceptance could possibly be lower due to the fact that many people do not know what a charging scheme exactly entails. The same person also mentioned a similar situation in which people were asked if they were willing to let their energy consumption be managed in a smart way. People initially responded to this with: *"why are you going to determine how I should regulate my energy consumption at home?"*. This reaction also arose because this was a new phenomenon for people and was therefore perceived as undesirable. In a later phase, it turned out that once the phenomenon became more known, the willingness to relinquish control increases. As mentioned earlier, in the case of the electricity network, not many people experience grid capacity problems. Since this is not yet the case, it is possible that people do not yet understand the need for a charging scheme, which could result in a lower acceptance.

In addition, due to the fact that people may not yet see the added value of measures such as charging schemes that counteract grid capacity problems, it may therefore be necessary to compensate people for participating. During the interviews, several examples came up of situations in which people were compensated for the adoption of an innovation. For example, one of the interviewees told me about the free toll roads in Norway for EV drivers. This was an excellent measure to convince the first potential EV drivers. However, this is a fairly expensive measure and it is important that growth eventually continues, without it costing a lot more money. For this reason it is therefore interesting to see whether people can have other, non-monetary, motivations to participate in something like a charging scheme. By appealing to these motivations a considerable amount of money could be saved.

Finally, in one of the interviews specific attention was paid to the intrinsic motivations that can play a role at a local level when residents themselves want to participate in a social initiative. A charging scheme could be seen as a social initiative that can be set up within a neighbourhood, as the neighbours want to help each other. A practical example of a social initiative is the Groene Mient in The Hague. This is a neighbourhood that is getting more sustainable from its own intrinsic motivation. Characteristic of this neighbourhood is that the residents do also communicate in a proper way about things that can be improved in the neighbourhood. This shows that social connectedness, and possibly also friendship, might be a factor that appeal to someone's intrinsic motivation to participate in a social initiative. This is a type of intrinsic motivation in which people really want to do something for the other person. However, it could also be the case that someone wants to participate in a social initiative as this is beneficial for the individual.

All in all, an answer to RQ1 can be given on the basis of the interviews. In various ways, the interviewed experts have already worked on topics regarding smart charging and most of them were already familiar with the term "charging scheme". Based on the perceptions of the interviewees, an ideal charging scheme setup would look like a contract between the EV user and the charge card provider/electricity supplier stating, among others, at what times an EV user could charge his/her EV. Subsequently, various factors that may play a role in the acceptance of the charging schemes were also discussed. The willingness to participate in a charging scheme could possibly be low, because EV users do not really know what a charging scheme entails and may not see the need for it. As a result, EV users may find it remarkable that they have to hand over their flexibility. However, this willingness to participate could be increased in several ways. Examples discussed in the interviews show that both financial incentives and social incentives could play a role in the acceptance of charging schemes. The next chapter will discuss the results of the literature research including an in-depth discussion of these different types of incentives.

3. Literature research

This chapter discusses information found in the literature that is relevant for this study. When conducting the literature research, various combinations of search strings and Booleans were used. I first searched for articles that wrote about intrinsic and extrinsic motivations in smart charging systems or other similar social schemes. Subsequently, I searched for articles that wrote about attributes of a charging scheme and similar studies that had performed a choice analysis. Finally, papers including a similar choice analysis with regard to smart charging were sought. These papers were searched for characteristics of EV users that might be interesting to include in this study as well.

3.1 Motivations influencing the acceptance of smart charging systems

As has become clear in the chapter 1 and 2, there can be different motivations for EV users to participate in a charging scheme. The motivations that will be investigated in this study are extrinsic motivations and intrinsic motivations. In order to be able to conceptualize the different motivations into the experimental design, i.e. the hypothetical charging schemes, it is important to clearly formulate the potential extrinsic incentives and the factors that could appeal to someone's intrinsic motivation. To find out which extrinsic incentives and factors appealing to someone's intrinsic motivation may be relevant in the choice of EV users with regard to charging scheme participation, a literature research has been carried out.

3.1.1 Extrinsic and intrinsic motivations in other types of social schemes

Before looking for possible extrinsic incentives and factors that can appeal to someone's intrinsic motivation in the case of charging schemes, I also looked for other social schemes in which extrinsic motivations and intrinsic motivations could both play a role. Based on this, it is possible to form a better picture of what these motivations entail and how they influenced the participation rate in these social schemes.

To begin with, a well-known social scheme within the mobility sector that is also aimed at changing the car owner's behaviour, is the social routing scheme. With regard to social routing, the articles by van Essen et al. (2020) and Mariotte et al. (2021) show that the sacrifices a driver has to make, have a significant impact on whether or not to choose for the more socially responsible route. An example of a sacrifice faced by potential users of a social routing scheme is the travel time sacrifice. The extent to which a driver has to sacrifice his travel time can be a decisive factor in the choice of taking the more socially responsible route. In this case, it is shown that extrinsic incentives, such as discounts or rewards, could lead to an increase in acceptance of the intervention.

However, the impact of extrinsic incentives on the acceptance of an intervention may not always be as important as expected when implementing it in a real life context (Schuitema et al., 2010). A performed regression analysis revealed that the acceptability of the intervention, in this case a congestion charge, was lower when the respondents believed that their travel costs would increase, while the impact of the travel costs after implementing the charge was not significantly related to the acceptance.

On the other hand, the perceived social benefits of an intervention can ultimately have a greater influence on its acceptance than was expected beforehand. The problem, however, is that the social benefits of an intervention may be underestimated before implementation. When the social benefits of an intervention are not clearly communicated to the participants of a survey, the participants will tend to only look at the sacrifices that have to be made or the direct benefits (e.g. time savings and monetary compensation) that they will receive (Klein & Ben-Elia, 2018).

An example of a situation in which the social benefits are clearly communicated could be seen in the route recommendation service as discussed in the article by Anagnostopoulou et al. (2020). The recommendation service shows how many grams of CO_2 will be emitted when a certain route is chosen. As the social benefits are communicated more clearly, a person could choose one of the more sustainable routes based on his/her intrinsic motivation.

All in all, it could be concluded that the acceptance of an intervention could be influenced by both extrinsic incentives (such as lower costs) and clearly communicated social benefits of an intervention. As a next step, it is therefore important to discover which possible extrinsic incentives and factors appealing to someone's intrinsic motivation could play a role in the EV user's choice to participate in a charging scheme. Subsection 3.1.2 discusses the extrinsic incentives and subsection 3.1.3 the factors appealing to someone's intrinsic motivation.

3.1.2 Extrinsic incentives

As mentioned in the introduction, some studies related to smart charging systems already included extrinsic incentives that could also be used to possibly increase the charging scheme participation. First of all, the articles by Will & Schuller (2016), Libertson (2022) & Lagomarsino et al. (2022) mention different monetary incentives. The first incentive concerns a compensation on the kWh price resulting in lower charging costs. Secondly, a discount on the monthly electricity bill is mentioned as a similar incentive. These two monetary incentives are about reducing the direct costs of charging an electric vehicle. In addition to giving discounts on the controlled charging session, it is also possible to provide free parking spaces at locations where this is normally not the case.

Furthermore, the articles by Kubli (2022) & Libertson (2022) also talk about other types of extrinsic incentives that can also lead to an increase in the chance of participation in a smart charging system. An improved charging infrastructure can lead to an increase in the willingness to participate because it can provide guaranteed access to charging stations, the possibility to use better localized charging stations, the possibility of having private charging stations available and the provision of fast chargers, which will decrease the overall charging duration. In addition to this, offering the option to flexibly adjust the agreements between the EV user and the supplier could also form an extrinsic incentive for potential users to participate. This may involve adjusting the time ranges within which charging can take place and the desired minimum mileage. The possibility of interim customization will give users a sense of safety and co-control.

The extrinsic incentives discussed in the last two paragraphs are all related to participating in a smart charging system. A smart charging system can be set up in different ways and can also be implemented in many ways. As discussed earlier, a charging scheme as intended in this study can also be seen as a smart charging system. For this reason, the extrinsic incentives discussed above are interesting to possibly include in the charging scheme designs that will be used during this research.

3.1.3 Factors appealing to someone's intrinsic motivation

In section 1.2 it was discussed that someone's intrinsic motivation can be appealed by solidarity incentives. These intangible rewards can be obtained when someone participates in a social initiative. For this reason, it is important to look for factors that could frame the charging schemes as a social initiative. Interventions can be framed as a social initiative for several reasons. Examples of reasons for the emergence of a social initiative are the prevention of environmental problems (e.g. air pollution, noise pollution, climate change, and loss of biodiversity) and the maintenance of the common good (e.g. scarce energy sources) (Huijts et al., 2012).

To begin with, a smart charging system, such as a charging scheme, is not a measure that directly combats the environmental problems. However, potential participants in such smart charging systems could consider it important that these systems get off the ground, because these systems can contribute to a smooth integration of EVs and the integration of energy from renewable energy sources into the grid (Schmalfuß et al., 2015; Will & Schuller, 2016; Kubli, 2022). Next, with regard to maintaining the common good, a smart charging system could help with balancing the electricity grid. Contributing to grid stability might be an important motivation on the consumer side to participate in a smart charging system as this ensures an increased security of supply for all electricity grid users (Schmalfuß et al., 2015; Will & Schuller, 2016). Considering that a smart charging system as a charging scheme could therefore contribute to the prevention of environmental problems and maintaining the common good, these factors could be interesting to include in the charging scheme designs.

3.2 Attributes in smart charging systems

The next step in the literature research was to investigate which attributes might be relevant to include in the charging scheme designs. By looking for scientific studies in which choice situations were also compiled that correspond to some extent to the context of this study, it was possible to review attributes influencing the acceptance of smart charging systems.

First of all, the previous section showed that charging scheme participation could include a shift of control from the EV user to the charge card provider. When an EV user chooses to charge his/her vehicle, the charge card provider determines, in consultation with the charging point operator, when this will happen. In the articles by Kubli (2022), Daina et al. (2017), Lagomarsino et al. (2022) & Huang et al. (2021), the so-called state of charge (SOC) is discussed as an attribute in the various smart charging services. The SOC is about the extent to which a car will be charged. For example, it may be the case that an EV will be charged to a certain battery level and will stop charging after this battery level has been reached. This charging stop would occur if the electricity network is reaching its capacity. In the articles, different examples are shown for the application of this attribute. For example, in the article by Kubli (2022), the guaranteed driving range is given after 50% of the charging duration, while in the article by Daina et al. (2017) not only a variation in the guaranteed battery level is included in the choice situations, but also a variation in time to reach a certain battery level (charging speed).

Secondly, the articles by Pan et al. (2019), Schmalfuß et al. (2017), Parsons et al. (2014) & Lagomarsino et al. (2022) show examples of ways in which EV users, when participating in a smart charging system, have to make sacrifices with regard to time. More specifically, the article by Lagomarsino et al. (2022) gives examples of smart charging situations in which the time of the day that someone should charge is included. This article examines how the time of day can influence their choice to apply smart charging. The results of this research showed that participants were significantly more likely to choose to apply smart charging in the evening/night than during the day.

Thirdly, participants in a charging scheme could also have to deal with a required plug-in time. As can be seen in the articles by Parsons et al. (2014), Huang et al. (2021) and Kubli (2022), this concerns the time that an EV must be connected to the electricity network. Within this time the vehicle will be charged to at least the guaranteed battery level set in the charging scheme. As an example, the research by Kubli (2022) deals with situations in which vehicles will be charged up to a range of 120 km after a maximum plug-in time of 2, 4 or 6 hours.

Fourth, in the previous section it became clear that there can be different motivations for participating in a social initiative. One of these motivations is that someone decides to participate in a social initiative when it benefits the common good. However, the strength of this motivation can vary and may also depend on the actions of others. When a large proportion of the potential participants in a social initiative already participates in the initiative, this could possibly also convince the other potential participants to participate as well. As an example, the article by Szep et al. (2023) looks at the influence of the participation rate on participation in a social routing system. The participation rate varied in this study with the values of 20% and 80%. However, it should be noticed that this is not a characteristic of a smart charging system, but a characteristic of the surrounding situation.

Fifth, section 3.1.2 showed that the possibility of making adjustments to the agreements between the EV user and the supplier could be a motivation for potential EV users to participate. The article by Huang et al. (2021) shows that contract duration is also included in a V2G contract to indicate flexibility of the contract. In order to conceptualize the possibility of making an adjustment in the agreement to a charging scheme design, a contract duration could also be included in this study. As an example, the article by Huang et al. (2021) deals with contract periods of 6 to 24 months.

Finally, an important extrinsic incentive is the provision of monetary compensation for participating in a charging scheme. The articles by Jimenez (2019), Will & Schuller (2016) & Daina et al. (2017) show examples of situations in which financial compensation is used for participating in a smart charging system. In the study by Jimenez (2019) the respondents are presented with a financial discount on a monthly basis when someone choses smart charging, the study by Will & Schuller (2016) uses a discount per kWh and the study by Daina et al. (2017) uses a difference in total price for the charging operation.

3.3 Characteristics of EV users

As a final part of the literature research, it is important to look for factors that could characterize EV users. As has become clear earlier, these characteristics might influence the choices made with regard to charging scheme participation. There are a huge number of characteristics that could be included in this study. To be able to make a choice as to which characteristics are relevant enough to be included in this study, it is helpful to look at other studies involving EV users.

3.3.1 Socio-demographic characteristics

To begin with, the literature showed that there are many different socio-demographic characteristics that might be interesting to include in this study. One of the most frequently used socio-demographic characteristic in the other EV-related studies is the age of the respondent. Someone's age could possibly influence someone's willingness to participate in a charging scheme. The study by Grisolía et al. (2015), for example, shows that young people (18-24 years old) have a more negative attitude towards a congestion charging scheme than older people. Furthermore, the articles by Huang et al. (2021) and Grisolía et al. (2015) show that age can also be asked for in steps of 10 to 20 years to make sure that the respondents cannot be identified. Furthermore, just like age, there are also some other demographics that were frequently used in the studies discussed in the previous two sections. These demographic characteristics are: gender, education level, place of residence, house type and employment status. The literature shows that most EV users are middle-aged, male, highly educated, live in a suburban area and work full-time.

In addition to this, another less frequently used, but still interesting, socio-demographic characteristic is the political orientation of the respondent. Examples of studies in which the political orientation of the respondent is used are the studies by Lagomarsino et al. (2022) and Krupa et al. (2014). As an example, in the study by Krupa et al. (2014) the respondents were asked whether they feel left-, right- or center-oriented with regard to politics.

3.3.2 Vehicle-related characteristics

As a next step, the literature research showed that it might also be interesting to present the respondents with vehicle-related questions. The characteristics discussed earlier were more about the individual itself, these questions are more about the EV user. Other electric vehicle-related researches often ask about such characteristics in order to distinguish between the different EV users.

To begin with, EV users can be distinguished in the type of EV they drive. In the articles by, among others, Huang et al. (2021), Libertson (2022) and Egbue & Long (2012) the respondents are asked to indicate which type of EV they drive. In these articles, respondents are asked whether they own a Battery Electric Vehicle (BEV), a Plug-in Hybrid EV (PHEV), or another type of vehicle.

Secondly, in the articles by Wolbertus & Gerzon (2018) & Wong et al. (2022) the respondents are asked for what type of car ownership they have. These articles show that a distinction can be made between vehicle ownership and vehicle leasing (through work). In addition, it may also be the case that a respondent previously owned or leased an electric vehicle. To validate the respondents' answers, it is also interesting to know whether a respondent has used an electric vehicle in the past. Despite the fact that this person no longer owns an electric vehicle, this person could still be part of the target audience.

Thirdly, several articles also talk about the experience of an EV user. This can be expressed in various ways. For example, the articles by Libertson (2022) and Wong (2022) asked for the amount of years that someone has used an EV. This question could be used to test the influence of someone's experience with an EV on the acceptance of a smart charging system such as a charging scheme.

Fourth, the literature has also shown that it can be interesting to ask whether someone owns a private charging pole and whether someone charges their EV with any regularity at work. According to the articles by Visaria et al. (2022), Geschwendtner et al. (2023) and Pan et al. (2019), the charging location can influence the choices someone makes. Therefore, it might be interesting to examine whether the availability of a personal charging station at home and/or a charging station at work could influence the acceptance of a charging scheme.

Fifth, the articles by Daina et al. (2017), Delmonte et al. (2020), Krupa et al. (2014) and Chen et al. (2020) also show that one's commuting distance can also be a factor that can influence one's choices. In these articles, a distinction is made between someone's daily, weekly and monthly commuting distance. As an example, in the article by Krupa et al. (2014) the respondents are asked about their average travel distance on a daily basis. By asking the question on a daily basis, it is possible to get a good idea of how much distance someone travels and how often. As an example, in the article by Krupa et al. (2014) the answer options vary between <10 and 50+ miles per day.

Sixth, the studies by Langbroek et al. (2016), Westin et al. (2018) and Jia & Chen (2021) also ask about the number of cars in a household. A hypothesis within this research could be that the availability of several vehicles in a household reduces the risks of not having a fully charged EV. This could possibly increase the willingness to participate in a charging scheme.

Seventh, it can also be interesting to know how often someone charges their EV per week. If someone has to or wants to charge their EV many times a week, this could possibly influence this person's choice to give up flexibility with regard to charging their vehicle. As an example, in the study by Wong et al. (2022) the respondent is asked to indicate how many times per week he/she charges his/her EV, choosing from four different options.

3.3.3 Social characteristics

In addition to asking the EV users about their socio-demographics and vehicle-related characteristics, the literature shows that it is also interesting to present the respondents with social and environmental statements to investigate their social attitude and environmental awareness. The knowledge gained from this could be used to examine the influence of the respondent's social attitude on the choice made with regard to charging scheme participation.

First of all, the articles by Singh et al. (2018), Szep et al. (2023), Smith et al. (2017), Liao et al. (2017), White & Sintov (2017), Krupa et al. (2014) and Westin et al. (2018) discusses several social motivations that can significantly influence the choices made by the respondents. Examples of social motivations used in these studies to form a picture of someone's social attitude are motivations related to:

- The respondent's sense of social connectedness with a certain group
- The extent to which someone considers it important to do something good for others.
- Whether someone feels social pressure to contribute to social initiatives.
- Whether someone finds it important to be seen as a good person.

Secondly, the articles by Peters et al. (2018), Wong et al. (2022), Loengbudnark et al. (2022), Smith et al. (2017), White & Sintov (2017), Krupa et al. (2014) and Chen et al. (2020) discusses several things that may be illustrative of one's environmental awareness. For example, people are asked in different ways about their energy consumption (e.g. shower duration, light usage and washing machine usage), the extent to which someone recycles (e.g. separating plastic from other waste), the extent to which someone sees climate change as a serious threat and whether someone thinks it is important to show that they are environmentally conscious.

3.4 Conceptual model

The purpose of this chapter was to work towards an answer to RQ2. In the different sections of this chapter motivations, charging scheme attributes and characteristics of EV users have been discussed that may be interesting to include in this study. Since many different factors are involved, figure 1 provides an global overview of the factors that might be relevant to include in this study. The conceptual model shows that for each of the factors could be tested whether they have a significant influence on the participation of an EV user in a charging scheme. In addition, the conceptual model also shows that only the direct effect of the characteristics of EV users on participation in a charging scheme will be considered and thus not the possible interaction effects of these characteristics with the other factors such as the charging scheme attributes. The next chapter will discuss which of the identified factors will be included in this study.

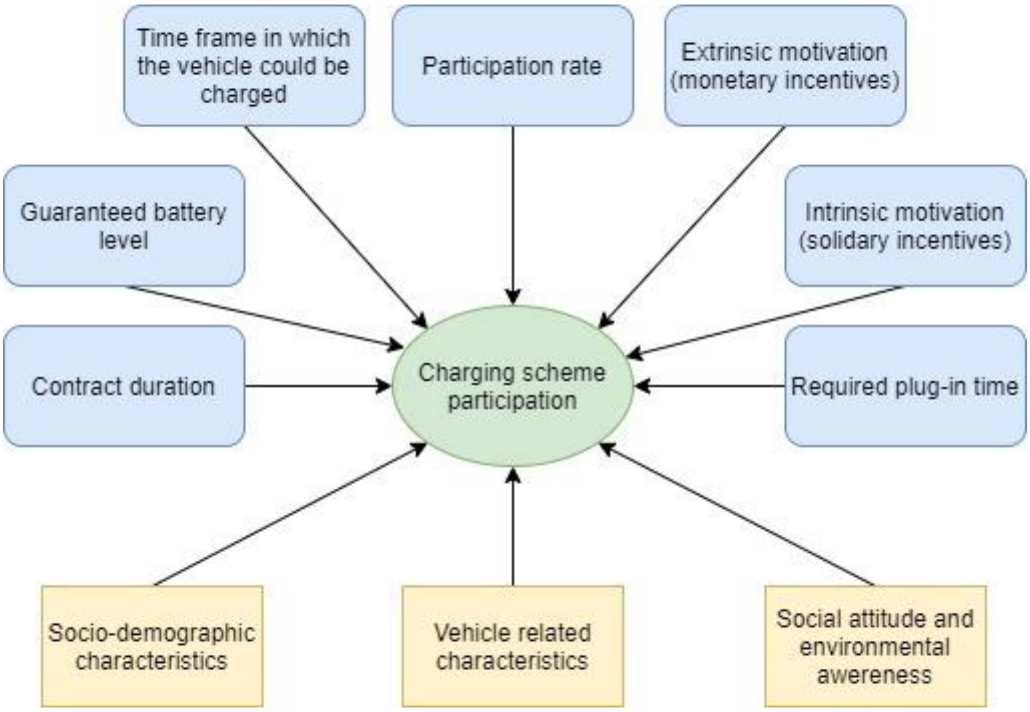

Figure 1 Conceptual model

4. Choice experiment design

After conducting the literature research, it became clear which elements could be included in the survey. By conceptualizing the previous findings, it is possible to arrive at a setup for this research. This chapter starts with a short introduction to the method that will be used. Secondly, the choices made with regard to the experimental design will be discussed. Thirdly, the selection of the characteristics of the EV users that will be included in the survey will be presented. After it is clear how the survey will be composed, the data collection phase and the data analysis phase will be discussed as well.

4.1 Introduction to the discrete choice analysis

As mentioned in section 1.4.2, a discrete choice analysis will be used to find out which factors play a role in the choice of the EV user to participate in a charging scheme. Based on the chosen factors, which are discussed in this chapter, it is possible to set up an experimental design with different choice situations. These choice situations can also be seen as the alternatives that together form the experimental design (Pérez-Troncoso, 2020). However, in this study it is not the case that alternatives will be compared with each other, but the respondents will be asked whether they are willing to participate in a certain alternative.

Furthermore, to prevent the respondent from being presented with a large number of choice situations, it is important to make use of an efficient experimental design. This concerns an experimental design with the aim of maximizing the amount of data obtained from the experiment with a chosen amount of choice situations. A software package that could help with this is Ngene (van Cranenburgh & Collins, 2019). With this software it is possible to indicate what the desired number of choice situations is. When specified in the Ngene syntax, the software will look for the most efficient design.

With the established experimental designs it is subsequently possible to set up a survey that will be issued to the target audience. A similar study conducted by Szep et al. (2023) obtained 786 responses and showed that this was good to perform the analysis. However, it is quite hard to obtain 786 responses during the time available for this research that are also representative for the target audience. The study by Wolbertus & Gerzon (2018) showed that 119 responses were also enough to perform their analysis. Their research is also very similar to this study, however, they only used one survey version for their discrete choice analysis. Given that the plan of this study is to use two survey versions and to compare them with each other, the goal is to get around 150 responses.

After there are enough relevant responses to the survey, the next step is to analyse the collected data. Apollo (a software package in R) can be used to model discrete choice data by estimating choice models (Hess et al., 2022). Based on the combined data of the survey versions, both a binary logit model as well as a mixed logit model will be estimated. A binary logit model can be used to obtain the preference parameters (beta's), these parameters indicate the importance of an attribute (Bernasco & Block, n.d.). The parameter values are estimated by using the maximum likelihood principle. The aim of this principle is to find the set of parameters that make the data the most likely (Wu & Vos, 2018). The parameters found can ultimately be used to say something about the overall effects of the attributes on the choice for a certain charging scheme. In addition, by including a dummy indicator in each attribute weight that takes a value of 1 for one version of the charging scheme and 0 for the other version, it is possible to distinguish between the two versions of the charging scheme and explore whether sensitivities to attributes are specific to a particular version of the charging scheme.

When estimating a binary logit model it is already possible to take into account that we are dealing with panel data. This could be done by looking at the robust standard errors instead of the classical standard errors. The difference is that the robust standard errors take the panel structure of the data into account (Hess & Palma, 2019). This makes an important contribution in making the model more realistic. However, the model can become even more realistic by taking heterogeneity into account. Specifically, this concerns heterogeneity in the effect that an attribute has on the choice to participate in a charging scheme. When this is taken into account, we are dealing with a mixed logit model.

The difference between the parameters of a binary logit model and a mixed logit model is in the fact that the parameters in a mixed logit model are not seen as a single value, but as a distribution. For this reason, two parameters will be estimated per constant (which indicates the predisposition to participate in a charging scheme) and attribute. These two parameters are the mean and the standard deviation of the relevant constant or attribute for a particular charging scheme version (Hess & Palma, 2019). To begin with, the mean says something about the effect of the attribute on the choice regarding charging scheme participation. When there is a significant difference between the estimates for this parameter in the two charging scheme versions, this means that the relevant attribute has a different effect on the choice to participate in a charging scheme in the two charging scheme versions. Furthermore, the standard deviation estimates say something about the heterogeneity in the sample with regard to the effect of a certain attribute. When the value for the standard deviation is significant, this means that there is heterogeneity in the sample and therefore in the effect that a certain attribute has on the choice to participate in a charging scheme. If there is a significant difference in the standard deviation between the two charging scheme versions, this means that there is variation in the degree of heterogeneity. It may then be the case that one charging scheme version has a higher degree of heterogeneity than the other.

Next, with regard to the precise estimation of both logit models, there is an important thing to take into consideration. When different data sources are used for the estimation of discrete choice models, e.g. one data source from Europe and the other from Asia, the variance may differ across them. The same applies for data sources from two differently framed surveys, as is the case in this study. When the variance of unobserved factors differs significantly between the different data sources, it is important to take this into account when performing the analysis. Therefore an extra parameter is added, namely the so-called "scale" parameter. If the scale parameter is significantly different from 1, the variance differs across the two data sources and the coefficients in one of the models must be adjusted to account for this difference in scale (Train, 2012).

Finally, Apollo will not only be used to estimate the parameters for the attributes. In order to answer RQ4 this software package will also be used to estimate the interaction effects between the different factors that characterize the EV users and the participation rate. As mentioned before, by looking for these interaction effects, it is possible to see whether there are other factors besides the attributes that influence the participation rate of an EV user.

4.2 Experimental design

The second section of this chapter is about the experimental design. This involves drawing up the various choice situations that will be presented to the respondents. This section will start with discussing the attributes that will be included in the experimental design. Subsequently, the designs for the incentive-based version and intrinsic-based version will be discussed separately.

4.2.1 Attribute selection

Based on the findings in the literature, this subsection describes the different attributes with the associated attribute levels that were selected for this research. Section 3.2 described six attributes that may be interesting to include in this study. These six attributes are in the order of section 3.2: guaranteed battery level, charging time restriction, required plug-in time, participation rate, contract duration, and monetary compensation. Of these six attributes, four are included in this study.

The choice to include only four of the six attributes is primarily due to the fact that it is important for the research to ensure that the choice situations do not become too complex. By only including four of the six attributes, it can be ensured that the complexity does not become too high. As a result, it was first decided to maintain a fixed contract duration, because this attribute is not specifically interesting for a charging scheme. Secondly, it was also decided to not include a required plug-in time, because the charging speed can vary greatly per type of charging pole. This makes it less realistic to include this attribute in the charging scheme designs. The selected four attributes are discussed below.

To begin with, the first selected attribute is about the guaranteed battery level. Based on the examples from the literature, it has been decided that this study will include different guaranteed battery levels after which the charging station will switch off. In this case, an EV user could, when participating in a charging scheme, indicate the percentage to which level his/her EV should be charged before the charging could stop. Based on the study by Lagomarsino et al. (2022), the attribute levels will have an interval of 25%. In addition, a status quo alternative will also be included to test the overall acceptance of this restriction. Therefore, the attribute levels 50%, 75% and 100% are included in this study.

The second selected attribute is the charging time restriction. A time constraint will be applied in this study based on the charging profiles and peak and off-peak hours as discussed in the report by Refa et al. (2023). The report states that there is a peak load between 5 p.m. and 11 p.m. and also a somewhat smaller peak load between 8 a.m. and 2 p.m. To ensure that the load on the network by the EVs will decrease at this time, the time frames have been set up in such a way that EV users make less use of the electricity network within the peak load period. For this study, two possible time-limiting measures will be examined, namely only being able to charge between 11 p.m. and 5 p.m. (mainly evening restriction) and only being able to charge between 2 p.m. and 8 a.m. (mainly morning restriction). At times outside the time frames, no power will be supplied to the vehicle. In addition to these two attribute levels, this attribute will also include a status quo alternative to test the overall effect of this restriction on the charging scheme participation. Therefore, the attribute level “no restriction” will be included as well.

The third selected attribute is the participation rate of the other EV users in a charging scheme. In order to investigate the effect of the participation rate on the choice three different attribute levels will be used with a large difference between these values. The attribute values that will be used are 10%, 50% and 90%. By using these values it is possible to investigate whether the participation rate is an important determinant in the choice of an EV user or not.

Finally, with regard to the monetary compensation, this study will use a discount per kWh and a discount per typical charging session. First of all, the reason to not include a monthly discount is because a monthly discount will not appeal to potential participants as the monthly costs of EV users can vary widely. Furthermore, by looking at 4 different sources (Statistics Netherlands, 2023; Laadpaal Today, 2023; ANWB, 2023; AutoWeek, 2022) it can be concluded that using a private charging station costs an average of 45 cents per kWh and using a public charging station costs an average of 55 cents per kWh. We can use these numbers to express a financial compensation per kWh in euros. For convenience, the average of these two prices (50 cents) is used to calculate the discounts. This study examines the influence of a 10%, 20% and 30% discount on the willingness to participate in a charging scheme. This equates to a discount of 5 cents, 10 cents and 15 cents. Finally, with regard to the discount per typical charging sessions, the respondents are told that they should imagine owning an EV with a battery capacity of 50 kWh, corresponding to an average range of 300 km (Kempton, 2016). In this case a full charging session will be equivalent to a discount of respectively 2,50 euro, 5 euro and 7,50 euro. However, we assume that a typical charging session will be charging a vehicle from 25% to 75% (50% increase in battery level). Therefore, the attribute levels included for the discount per session will be respectively 1,25 euro, 2,50 euro and 3,75 euro.

4.2.2 Incentive-based design

Now it is clear which attribute values will be used in this study, the next step is to set up the experimental designs. We are talking about experimental designs, since not one but two experimental designs are drawn up in this study. This subsection (4.2.2) will discuss the incentive-based charging scheme designs and subsection 4.2.3 will discuss the intrinsic-based charging scheme designs.

With regard to the selected attributes, this means that the first three attributes that are purely characteristic of a situation in which a charging scheme is used, will be used in both charging scheme versions. However, the fourth attribute, which concerns a monetary compensation, will only be used in the incentive-based charging scheme designs.

So, with regard to the incentive-based design, three attributes that are characteristic of a situation in which a charging scheme is used and one extrinsic incentive attribute are included in this design. Table 1 shows that each of the attributes are subdivided into three attribute levels and shows the necessary additional information for each attribute.

Table 1 Charging scheme attributes incentive-based design

Attribute	Attribute level 1	Attribute level 2	Attribute level 3
Guaranteed battery level	50%	75%	100%
Time frame in which the vehicle could be charged*	Car will only be charged from 11 P.M. to 5 P.M. (18 hours a day)	Car will only be charged from 2 P.M. to 8 A.M. (18 hours a day)	No restriction in charging time
Participation rate**	10%	50%	90%
Discount per kWh*** Discount per typical charging session (e.g. 25%-75%)****	5 cents 1,25 euro	10 cents 2,50 euro	15 cents 3,75 euro

** At times outside the time frames, no power will be supplied to the vehicle.*
*** Rate indicating the percentage of fellow EV users that participate in a charging scheme.*
**** Discount is based on the average kWh price of 50 cents.*
***** Discount when the battery is charged with 50% (e.g. 25% - 75%).*

Using the overview of the attributes in table 1, it was subsequently possible to draw up an experimental design. This involves drawing up the various choice situations. By using the Ngene software it is possible to create an efficient experimental design. This efficient design could subsequently be used to compile choice situations based on the different attribute levels. To ensure that the respondents are not presented with too many questions and enough data can be obtained from the survey, it has been decided to draw up nine choice situations. In addition, nine choice situation has been chosen to obtain attribute levels balance. Attribute level balance means that each attribute level occurs equally often in the experimental design. As mentioned earlier, each of the attributes has three attribute levels. By using nine choice situations, each of the attribute levels can appear three times in the experimental design, see Appendix B for the Ngene code. Table 2 provides an overview of the nine choice situations that will be used in the survey with the incentive-based charging scheme designs.

Table 2 Experimental design for the incentive-based schemes.

Design number	Guaranteed battery level	Time frame in which the vehicle could be charged	Participation rate	Discount per kWh and per typical charging session (e.g. 25%-75%)
1	75%	No restriction	50%	15 cents/3,75 euro
2	100%	11 P.M. to 5 P.M.	10%	5 cents/1,25 euro
3	50%	2 P.M. to 8 A.M.	90%	10 cents/2,50 euro
4	100%	11 P.M. to 5 P.M.	50%	10 cents/2,50 euro
5	75%	2 P.M. to 8 A.M.	90%	15 cents/3,75 euro
6	100%	2 P.M. to 8 A.M.	50%	15 cents/3,75 euro
7	75%	No restriction	10%	10 cents/2,50 euro
8	50%	11 P.M. to 5 P.M.	90%	5 cents/1,25 euro
9	50%	No restriction	10%	5 cents/1,25 euro

Finally, in addition to the choice situations as presented in the experimental design, a short text is also presented above the choice situation in which it is emphasized that participating in a charging scheme benefits the participants. By using this piece of text, an additional distinction is also made between the incentive-based charging scheme designs and the intrinsic-based charging scheme designs. The text displayed above each choice situation in the survey with the incentive-based charging scheme designs is as follows:

"The purpose of the charging schemes is to balance the electricity demand in your neighbourhood. When EV users participate in a charging scheme, they are asked to adjust their charging behaviour and will receive a discount in return."

4.2.3 Intrinsic-based design

The intrinsic-based design differs from the incentive-based design in that this experimental design consists of three attributes instead of four attributes, namely only the attributes that are characteristic of a situation in which a charging scheme is used. Table 3 shows each attribute with the accompanied three attribute levels and the necessary additional information for each attribute.

Table 3 Charging scheme attributes intrinsic-based design

Attribute	Attribute level 1	Attribute level 2	Attribute level 3
Guaranteed battery level	50%	75%	100%
Time frame in which the vehicle could be charged*	Car will only be charged from 11 P.M. to 5 P.M. (18 hours a day)	Car will only be charged from 2 P.M. to 8 A.M. (18 hours a day)	No restriction in charging time
Participation rate**	10%	50%	90%

** At times outside the time frames, no power will be supplied to the vehicle.*
*** Rate indicating the percentage of fellow EV users that participate in a charging scheme.*

Such as with the other experimental design version, table 3 is used to draw up an experimental design based on the different attribute levels. The Ngene software was used again to compile 9 choice situations, since this also ensures in this situation that the respondents are not presented with too many questions, enough data can be obtained from the survey and attribute level balance will be obtained, see Appendix B for the Ngene code. Table 4 provides an overview of the nine choice situations that will be used in the survey with intrinsic-based charging scheme designs.

Table 4 Intrinsically motivated experimental design

Design number	Guaranteed battery level	Time frame in which the vehicle could be charged	Participation rate
1	75%	No restriction	50%
2	100%	11 P.M. to 5 P.M.	10%
3	50%	2 P.M. to 8 A.M.	90%
4	100%	11 P.M. to 5 P.M.	90%
5	75%	2 P.M. to 8 A.M.	50%
6	100%	2 P.M. to 8 A.M.	10%
7	75%	No restriction	10%
8	50%	11 P.M. to 5 P.M.	90%
9	50%	No restriction	50%

Finally, as with the other survey version, the survey with intrinsic-based charging scheme designs also contains a short text above the choice situation. However, in this case it is not emphasized that participation in a charging scheme benefits the participants, but it is emphasized that participation in a charging scheme involves achieving environmental and social benefits. Framing the charging scheme in this way can emphasize the feeling among EV users that they will participate in a social initiative. As mentioned in the previous chapter, when EV users obtain forms of solidarity incentives, this will appeal to their intrinsic motivation and increase their willingness to participate in a charging scheme. The text displayed above each choice situation in the survey with intrinsic-based charging scheme designs is as follows:

"The purpose of the charging schemes is to balance the electricity demand in your neighbourhood. Participation in a charging scheme will contribute to achieving various sustainability goals. In addition, the use of charging schemes will contribute to the prevention of energy shortages in the neighbourhood, despite the increasing demand for electricity."

A clearer illustration of how the charging schemes are operationalized can be found in Appendix C.3. This Appendix shows an example of both an incentive-based and an intrinsic-based charging scheme design.

4.3 Personal, vehicle-related and attitudinal survey questions

In the previous chapter, the findings of a literature research were discussed of which the aim was also to find factors that could characterize the different EV users. As mentioned in the previous chapter, this is a very broad term, as EV users can be distinguished from each other in so many ways. By looking at other similar studies, a selection was made of characteristics that will be investigated on whether these characteristics will influence the choices made by respondents.

To begin with, a selection has been made of socio-demographic characteristics that may be related to the choices made by the respondents. When questions are presented regarding the socio-demographic characteristics of the respondent, it is very important that the respondent cannot be identified on the basis of his/her answer to these questions. As an example, by using an interval of 10 years for the age characteristic it is possible to maintain anonymity. In addition, with regard to the residential location of the respondent, the question is not asked about the residential location, but about the type of residential area, divided into urban area, suburban area and rural area. Table 5 shows an overview of the socio-demographic characteristics with the options given to the respondents.

Table 5 Socio-demographics characteristics

Socio-demographics	**Choice options**
Age (in years)	18-25/26-35/36-45/46-55/56-65/66-75/76+
Gender	Male/Female/Other
Education level	Primary school/High school/ Apprenticeship/Bachelor/Master or higher
Residential area	Urban area/Suburban area/Rural area
House type	Multi-family house/Terraced house/Semi-detached house/Detached house/Other
Work situation	Full-time/Part-time/Irregularly employed/ Student/Retired/Other
Political orientation	Left oriented/Center left oriented/ Center right oriented/Right oriented/No response

Subsequently, based on the findings in the similar studies, a selection was also made of characteristics of EV users that are more specific about the way in which someone uses his/her vehicle. These characteristics were therefore labelled in the previous chapter under the name vehicle-related characteristics. An overview of the vehicle-related characteristics with the corresponding choice options for the respondents is given in table 6.

Table 6 Vehicle-related characteristics

Vehicle-related characteristics	**Choice options**
Vehicle type	Battery electric vehicle/ Plug-in hybrid vehicle
Vehicle property type	Owner of the vehicle/ Lease vehicle (via work)/Other
Experience with EVs (in months)	Less than 3/3-6/6-12/12-36/36+
Private charging station usage	Yes/No
Work charging station usage	Yes/No
Daily commuting distance (in kilometres)	Less than 10/10-30/30-50/50-80/More than 80
Cars in household	1/2/3/More than 3
Charging frequency (per week)	Less than once/1-2 times/3-4 times/5-6 times/ 7+ times

Next, the respondents will be presented with a number of statements. Section 3.3.3 discussed several social and environmental motivations that were used in other studies. Based on these motivations a set of statements have been created. The answers to these statements can be used to examine whether an EV users' social attitude and/or degree of environmental awareness influence the participation rate. By using a 5-point Likert scale, respondents can indicate to what extent they agree with a certain statement. The higher the answer given on the 5-point Likert scale, the higher the degree to which a respondent agrees with a certain statement. Based on the articles mentioned chapter 3, the following environmental related and social related statements have been drawn up:

1. I see global climate change as a threat to humanity.
2. I feel personally responsible for contributing to the fight against global climate change.
3. I think it's important to show that I care about the environment.
4. I am aware of my energy consumption at home.
5. I think it is important to make environmentally conscious purchases/investments.
6. I feel socially connected to my neighbours.
7. I am willing to take action for the good of my neighbours.
8. I think it's important to show that I care about my neighbours.
9. I think it is important to make sure that I won't profit from the social contributions of my neighbours without contributing myself.
10. I think it is important that my neighbours as much as I won't suffer from the grid capacity problems.

In order to be able to test the interaction effect of the answers given by the respondents to these statements and the charging scheme participation, a factor analysis will be used. A factor analysis is a statistical technique that can be used to identify a smaller number of underlying variables for a higher number of observed variables, like the above mentioned statements (PennState, n.d.). These underlying variables are called factors. By performing this analysis, it can be examined whether some of these statements could say something about someone's social attitude or environmental awareness. Depending on which observed variables collectively form a factor, the factors can be labelled. More details about this factor analysis will be provided in the section 4.5.2.

Finally, given that prior to the analysis it is not clear whether a group of statements together could say something about the respondent's social attitude or environmental awareness, some additional questions will be asked. The answers to these questions can say something about someone's relationship to his/her neighbours and indicate whether the respondent makes some environmentally conscious choices. An overview of the questions and the corresponding choice options are shown in table 7.

Table 7 Social and environmental related questions

Questions	Choice options
How many neighbours do you have contact with on a weekly basis?	0/1-2/3-4/5-6/7+ (neighbours)
Do you do a social activity with at least 1 of your neighbours at least every six months?	Yes/No
Have you ever worked with your neighbourhood on an initiative for a better or more sustainable neighbourhood?	Yes/No
Have you (ever) installed solar panels on your roof?	Yes/No
Do you separate plastic from other waste at home?	Yes/No
Imagine that you need to travel 2.5 km to visit a friend on a Saturday and you have the following travel options available. Which one would you choose?	Car (8 mins)/Bicycle (10 mins)/Walk (30 mins)/Bus (15 mins)

The questions are based on examples from the literature mentioned in the previous chapter. By using the data obtained, it would be possible to look for the interaction effect of, for example, an environmentally conscious choice and charging scheme participation.

4.4 Data collection

This section is about the data collection phase. The first sub section will tell about the way in which the survey was distributed and how the respondents were found. Subsequently, the second sub section discusses a number of relevant descriptive statistics.

4.4.1 Survey distribution

After the survey was approved, the data collection phase of this study began. After a period of 3.5 weeks, about 200 responses were obtained of which 130 were considered valid. With regard to approximately 70 invalid responses, the respondents did not complete the survey or answered the screening question with "no". In addition, an opening statement was displayed at the beginning of the survey. This contained important information regarding the survey and the data, see Appendix C.1 for the opening statement.

The respondents were recruited in different ways. First of all, I shared an anonymous link to the survey through my personal social media profiles. In addition, I created a special twitter account for this research with the aim of reaching other organizations. Just like on my personal social media profiles, I also placed a call on this profile aimed at EV users to fill out the survey. After the survey was posted on various social media platforms, I actively started e-mailing various EV-related organizations, researchers, consultants, policy-makers and EV-related social media profiles. Soon I came into contact with, among others, the Dutch association for electric drivers (Vereniging Elektrische Rijders) who created their own post on their Twitter account. In the end, the various posts on the different social media platforms were shared fairly often by various larger profiles, such as the Twitter and LinkedIn profile of Fastned.

However, when people decide to participate in the survey, it is important that these people are representative of the target audience. For this reason, a screening question has been added to the survey. In this screening question, respondents are asked if they have ever had a plug-in hybrid or fully electric vehicle for at least 1 month. If a respondent answered “yes” to this question, the respondent could continue with completing the survey. When a respondent answered “no” to this question, this respondent was referred to the end of the survey and told that he/she is not part of the target audience. A more complete overview of the survey is presented in Appendix C.

4.4.2 Descriptive statistics of the sample

Next, based on the responses obtained, it is possible to compile a number of descriptive statistics. To begin with, Tables 8 and 9 show the participation rate for each of the charging scheme designs. The tables show the experimental designs followed by a percentage that indicates the share of respondents that chose to participate in a charging scheme in the described situation.

Table 8 Charging scheme participation rates per design (incentive-based version)

Design number	Guaranteed battery level	Time frame in which the vehicle could be charged	Participat-ion rate	Discount per kWh and per typical charging session	Percentage of respondents willing to participate in the charging scheme
1	75%	No restriction	50%	15 cents/3,75 euro	79%
2	100%	11 P.M. to 5 P.M.	10%	5 cents/1,25 euro	51%
3	50%	2 P.M. to 8 A.M.	90%	10 cents/2,50 euro	33%
4	100%	11 P.M. to 5 P.M.	50%	10 cents/2,50 euro	70%
5	75%	2 P.M. to 8 A.M.	90%	15 cents/3,75 euro	54%
6	100%	2 P.M. to 8 A.M.	50%	15 cents/3,75 euro	70%
7	75%	No restriction	10%	10 cents/2,50 euro	72%
8	50%	11 P.M. to 5 P.M.	90%	5 cents/1,25 euro	23%
9	50%	No restriction	10%	5 cents/1,25 euro	31%

Table 9 Charging scheme participation rates per design (intrinsic-based version)

Design number	Guaranteed battery level	Time frame in which the vehicle could be charged	Participation rate	Percentage of respondents willing to participate in the charging scheme
1	75%	No restriction	50%	83%
2	100%	11 P.M. to 5 P.M.	10%	65%
3	50%	2 P.M. to 8 A.M.	90%	43%
4	100%	11 P.M. to 5 P.M.	90%	65%
5	75%	2 P.M. to 8 A.M.	50%	62%
6	100%	2 P.M. to 8 A.M.	10%	75%
7	75%	No restriction	10%	81%
8	50%	11 P.M. to 5 P.M.	90%	35%
9	50%	No restriction	50%	42%

Furthermore, to get an overview of the profile of the respondents, table 10 shows a number of the characteristics of the EV users with the corresponding share in the sample. To see whether the respondents are generally representative of the target audience, the overview in table 10 can be compared with the findings from "The national EV and drivers survey 2021" (Duurkoop et al., 2022). In addition, a clearer overview of the statistics shown in table 10 is provided in Appendix D.

Table 10 Profile of the respondents

Characteristic	Results (percentage)
Age in years	18-25 (9.2%); 26-35 (10.0%); 36-45 (30.0%); 46-55 (30.8%); 56-65 (18.5%); 66-75 (1.5%)
Sex	Male (87.7%); Female (11.5%); other (0.8%)
Education level	Primary school (0.8%); High school (3.1%); Apprenticeship (11.5%); Bachelor (50.8%); Master or higher (33.8%)
Living area	Urban area (35.4%); Suburban area (54.6%); Rural area (10%)
House type	Multi-family house (9.2%); Terraced house (48.5%); Semi-detached house (23.8%); Detached house (16.2%); Other (2.3%)
Work situation	Full-time (76.2%); Part-time (11.5%); Irregularly employed (1.5%); Student (3.1%); Retired (3.1%); Other (4.6%)
Political orientation	Left oriented (26.9%); Center left oriented (26.2%); Center right oriented (14.6%); Right oriented (7.7%); No response (24.6%)
Vehicle type	Fully electric vehicle (96.2%); Plug-in hybrid vehicle (3.8%)
Ownership type	Owner of the vehicle (52.3%); Lease vehicle (via work) (42.3%); other (5.4%)
Private charger	Yes (70.8%); No (29.2%)
Solar panels	Yes (70%); No (30%)

To begin with, the study by Duurkoop et al. (2022) showed that an EV driver is on average 54 years old, in most cases male (92%), is often highly educated (approximately 75% Bachelor or higher) and predominantly works full time (65%). These findings are very similar to the findings of this study. It can be seen that the respondents in this survey were also largely male (87.7%), the majority highly educated (84.6% Bachelor or higher) and mainly full-time workers (76.2%). With regard to the average age, it is not possible to measure exactly what the average age would be in this study, because age categories were used. However, the shares of the different categories show that the average age will not differ much from the average age as found in the other study.

In addition, the study by Duurkoop et al. (2022) also asked about the political orientation of the EV users, what type of vehicle they have, what type of ownership applies, whether they have their own charging station and whether they have solar panels. With regard to the political orientation, the study showed that EV drivers mainly vote for center right oriented, center left oriented and left oriented political parties. These political orientations are consistent with the findings of this study. Furthermore, the study by Duurkoop et al. (2022) showed that 93% of the EV users have a fully electric car, a small majority have bought a vehicle (52% buy versus 46% lease), 63% of the EV users have a charging station on their own property and 74% have installed solar panels on their roof. When looking at the findings in table 10, it can be said that these findings correspond to a large extent with the findings from the study by Duurkoop et al. (2022) and that the sample of this study is therefore representative of the target audience.

4.5 Data analysis

The next phase of this research is the analysis phase. As mentioned earlier, the data is analysed by using Apollo (a software package in R). In R both a binary logit model as well as a mixed logit model have been estimated on the combined data of the two charging scheme versions. Based on this, the influences of the attributes on the participation rate of the EV users including the differences between the two charging scheme versions could first be analysed. Secondly, the role of different characteristics of EV users in explaining why EV users would participate in a charging scheme could be analysed as well.

4.5.1 Estimation of the charging scheme characteristics

During the analysis phase, I first worked towards a binary logit model. By using this model it is possible to predict the intention to participate in a charging scheme within a certain situation. A linear additive utility function has been set up for this and has been processed in R. This utility function is designed in such a way that a combined data set of the two charging scheme versions can be used to estimate the binary logit model. Next, the same utility function could also be used to subsequently estimate a mixed logit model. It was decided to also estimate a mixed logit model, because it is interesting for the research to see whether this may result in a better model-fit compared to the binary logit model. The systematic utility specification for both logit models is as follows:

$$V_{S,nt} = \sum_{h=0}^{H} (\beta_h + \delta_h A) \, x_{hnt}$$

The utility function shows that the goal is to predict the intention of EV user *n* to participate in a charging scheme in situation *t*. Furthermore, h represents the different attributes included in the charging scheme designs and the predisposition to participate in a charging scheme. β_h indicates the associated parameter values for the incentive-based charging scheme. Next, the attribute weights are not directly estimated for both charging scheme version, but are estimated for the incentive-based charging scheme version and the difference in attribute weights compared to the intrinsic-based charging scheme version. When doing this, it becomes possible to see whether the parameter values of the constants and attributes differ significantly between the two charging scheme versions In addition to the incentive-based parameter β_h , the difference between the two charging scheme versions is represented by δ_h. To ensure that the difference between the two versions will be estimated correctly, dummy variable A has been added to the utility function. This variable takes the value of 1 for responses from the intrinsic-based survey version and 0 for responses from the incentive-based survey version. However, the attribute "Discount per kWh" was only applicable in the incentive-based survey. Hence, the dummy variables will always take the value of 0 for this attribute and therefore no parameter will be estimated for this attribute based on the difference between the incentive-based and intrinsic-based version.

Furthermore, it is important to note that it is also possible to estimate the attribute weights for the intrinsic-based charging scheme version in combination with the difference parameters. This can be done by equating the dummy variable to 0 (A=0). In this way it is also possible to check whether the parameter weights for the intrinsic-based version are significant. The difference parameters will give the same values in both cases, but only the sign will change.

Next, during the research it was decided to fix the scale parameter at the value 1. The choice for this arose, because estimation issues appeared when the constant, the attributes, the differences in these parameters compared to the intrinsic-based version and the scale parameter were all estimated. Experiments have shown that fixing one of these parameters would solve these estimation issues. Subsequently, model estimations in the binary logit model showed that the scale parameter is significant at a value close to 1, which implies that there is no big difference between the variance of unobserved factors among the different data sources. By fixing the scale parameter, the eigenvalue of the Hessian turned out to be further away from zero, which equates to a model that converges better and delivers a better performance (Hess & Palma, 2019). Further results showing why it is fine to fix the scale parameter to the value 1 are shown in Appendix E.1.

4.5.2 Estimation of the characteristics of EV users

In an earlier phase of this research, various characteristics were sought to distinguish EV users from each other. These different characteristics could play a role in the choices made by EV users with regard to charging scheme participation. To find out whether EV users with certain characteristics would be more (or less) willing to participate in a charging scheme, the interaction effect between certain characteristics of an EV user and the predisposition to participate in a charging scheme will be investigated. This is done by adding a part to the utility function with which these interaction effects can be examined. The extended systematic utility specification is as follows:

$$V_{S,nt} = \sum_{h=0}^{H} (\beta_h + \delta_h A) \, x_{hnt} + \sum_{c=0}^{C} \beta_c \, D_{cn}$$

The utility function above shows that the first part of the utility function remains the same as in the utility function shown in the previous sub section. However, a second part was added to the utility function in which *c* represents the characteristics that an EV user could have, β_c the associated parameter and *D* the category of the characteristic that applies to EV user *n*.

Furthermore, another important difference is that, in contrast to the attributes and constants, no distinction will be made between the two survey versions for the estimation of the parameters of the characteristics. Since we are dealing with a relatively small data set, it is therefore interesting to combine the data to obtain good results. As can also be seen in the utility function, only 1 parameter is therefore estimated per characteristic.

Next, not all previously discussed characteristics have been included in the model. After performing various analyses, it was decided to not include a large number of characteristics in the final model. This choice was made based on the reasoning that it is better for the overview to only include the characteristics that show an interesting or significant interaction effect. In addition, a smaller number of parameters also ensures a higher model stability.

With regard to the variables that were included in the data set for the characteristics, there are some things that should be explained. To begin with, two variables were constructed by using the respondents' answers to the environmental related and social related statements mentioned in section 4.3. The respondents were asked to what extent they agreed with a certain statement (varying from strongly disagree to strongly agree). After the data collection phase was done, it was possible to perform a factor analysis in SPSS.

After the steps of the factor analysis have been completed, two factors emerged that could be labelled as a factor that says something about the environmental awareness of a respondent and a factor that says something about the respondent’s social attitude towards his/her neighbours. The environmental awareness factor is composed out of the 5 environmental related statements, because they together loaded high on this factor. The social attitude factor is composed out of 3 of the 5 social related statements, namely statements 6, 7 and 8 (see section 4.3). The other two statements did not load high on any factor. A table with all the factor loadings is included in Appendix E.3. Subsequently, dummy coding was used to encode these factors as variables for the data set. It was previously stated that the respondents had to answer the questions related to the statements by using a 5-point Likert scale. When the joint score on the statements that are representative of the environmental awareness factor is higher than or equal to 23, the respondent receives the value 1 for the variable “environmental awareness” in the data set. Since the factor social attitude is composed out of three statements, the rule applies that a respondent receives the value 1 for the variable “social attitude” when the joint score is higher than or equal to 13.

Furthermore, it should be mentioned that some of the variables are dummy coded and some are nominal in the data set. The choice for this depends on what was already possible with the data as it was taken over from Qualtrics. For example, to measure the interaction between a certain gender and the predisposition to participate in a charging scheme, it was possible to code it as, for example, “Sex == 2”. In the case of the variable “high educated” it was necessary to code this as a dummy. This is because there were two categories in the survey that fall within this group (“Bachelor” and “Masters or higher”).

All in all, both a binary logit model and a mixed logit model will be estimated and analysed in order to be able to say something about the various factors that play a role in the choice with regard to charging scheme participation. Furthermore, with regard to the mixed logit model, it is also important to mention that 500 Halton draws were used for the random coefficients. It was decided not to use more than 500 draws, because a larger number of draws would still led to the same results. Finally, the entire R scripts that belong to the binary logit model and mixed logit model can be found in Appendix E.2.

4.6 Concluding remarks

This last section will summarize what has been discussed in this chapter and will discuss a number of important choices made. This chapter started with a clear formulation of how the discrete choice method will be applied within this research. It was discussed how the binary and mixed logit models can be distinguished from each other, the intended goal with regard to the survey distribution and what other important things should be taken into account when applying the method, such as the scale parameter.

Subsequently, choices have been made in section 4.2 with regard to the charging scheme designs. First, a selection was made of four attributes. After the selection, it was discussed how these attributes are implemented in the charging scheme designs. Next to the attributes, it was also discussed how the incentive-based designs are distinguished from the intrinsic-based designs. In contrast to the intrinsic-based designs, the incentive-based designs would contain an extra discount attribute. In addition, the incentive-based designs emphasize that participation in a charging scheme is accompanied with financial compensation, while the intrinsic-based designs emphasize that participation contributes to achieving various sustainability goals and the prevention of energy shortages in the neighbourhood.

Furthermore, it was discussed in section 4.3 which characteristics of EV users would be included in this study. Based on the findings discussed in chapter 3, a number of socio-demographic characteristics were first selected with choice options that are arranged in such a way that the respondent remains anonymous. Subsequently, a number of characteristics were selected that can be categorized as vehicle-related characteristics. This concerns, among others, the months of experience that an EV user has with the use of an electric vehicle. Finally, social and environmental related statements and questions were drawn up with which the environmental awareness and social attitude of the respondent could be ascertained.

Next, based on the choices made with regard to the elements that are included in the research, a survey could be drawn up and distributed. Section 4.4 first discusses the way in which the survey distribution was carried out and then discusses relevant descriptive statistics of the sample to test whether the respondents are representative of the target audience. After comparing the profile of the sample within this study with the profile of the EV users as described in the report by Duurkoop et al. (2022), it can be concluded that the sample is representative of the target audience.

Finally, the data analysis phase is discussed in section 4.5. First of all, it was discussed how the influences of the attributes and charging scheme framings on the participation rate can be measured and how this is coded in RStudio. As an example, in order to be able to measure the effect of framing, it was decided to estimate the parameters of one charging scheme version in combination with the difference in attribute weights compared to the other charging scheme version. Secondly, it is explained how the interaction effect between the different characteristics of EV users and the participation rate will be measured. Based on these explanations it is possible to discuss the results in the next chapter.

5. Results

In this chapter the results of the study are discussed. Based on these results, answers can be given to RQ3 and RQ4. First, the influences of the various characteristics of a charging scheme on the participation rate will be discussed. Subsequently, the role of different characteristics of EV users in explaining why EV users would participate in a charging scheme will also be discussed.

5.1 Model estimations

At the end of the previous chapter it became clear how the parameters will be estimated. Eventually, two models were gradually developed that made it possible to examine the role of the selected factors in the choice to participate in a charging scheme. This concerns a binary logit model and a mixed logit model. In this section the results of estimating these models will be presented. In order to obtain a complete overview of the influences of all selected factors, it was decided to include two estimated models for the interpretation.

To begin with, table 11 provides an overview of the estimates that resulted from a binary logit model. First of all, it is important to notice that the table is split into two parts, namely the attributes, including the constants, and the characteristics of the EV users. The reason for this, as mentioned in the previous chapter, is based on the fact that the parameters of the attributes are estimated separately for both versions of the charging scheme, while the interaction parameters of the characteristics are estimated over the whole sample. For this reason it can also be seen in the table that three parameters have been estimated for each attribute (incentive-based, intrinsic-based & difference), with an exception for the discount attribute, and one parameter for the characteristics.

There is also another attribute that is estimated over the entire sample, namely the attribute "added utility evening time restriction" (shown below the dotted line). In addition to this parameter, there is already a parameter that indicates the effect of a charging time restriction in general. Given that there is already a parameter in the model that measures the effect of a charging time restriction in general for both charging scheme versions, the new parameter will show an additional impact to the current charging time restriction parameter. Since this additional parameter measures the additional effect (utility) of an evening time restriction, the general parameter reflects the value of a morning time restriction. Conversely, if the additional effect of a morning time restriction was estimated instead, this general time restriction parameter would reflect the parameter value of an evening time restriction. However, attempts to estimate this additional parameter for both charging scheme versions constantly resulted in an error. For this reason, it was decided to use one parameter that measures the effect of the additional parameter over the entire sample. This makes it possible to examine the additional effect of an evening restriction on the choice to participate in the charging scheme over the entire sample.

Furthermore, despite the fact that only one parameter is estimated for each characteristic of the EV users, it can be seen that there are two columns of numbers per characteristic. This is because both the classical standard errors and the robust standard errors have been included in the table in order to show the significance for both. As mentioned earlier, this study mainly looks at the robust standard errors, because they also take panel effects into account. In concrete terms, the robust standard errors recognize that there are 130 individuals who made 9 choices, instead of 1170 individual choices. However, to get an additional insight into the potential role of a certain characteristic on the choice to participate in a charging scheme, the classical standard errors are included as well.

Next, table 12 provides an overview of the estimates that resulted from the mixed logit model. This table has the same structure as table 11. However, the main difference is that the parameters for the constants and the attributes are not modelled as a single value, but as a distribution. For this reason, instead of a single parameter, both a parameter for the mean and the standard deviation have been estimated. Section 4.1 explained what is meant by the mean and standard deviation.

Finally, when interpreting the estimated parameters, it should be mentioned that most parameters are coded as linear variables. First of all, the parameter “guaranteed battery level” is coded as a linear variable. However, the decrease in percentage can never be higher than 100%. So this parameter indicates the decrease in utility per decrease in guaranteed battery level, but this could never be multiplied by a value higher than 100. The same applies for the participation rate parameter which indicates an increase in utility per extra percentage of fellow charging scheme users. The last linear coded parameter is the discount parameter. However, for all linear coded parameters, it should be noticed that the utility will of course not increase exactly linearly in reality. Secondly, the charging time restriction parameter is not linear coded. This parameter is coded as a dummy variable that takes the value 1 if there is a restriction in the charging time (both morning and evening) and 0 if this is not the case. Finally, also the evening time restriction parameter and most parameters for the characteristics of the EV users are coded as a dummy variable instead of a linear variable. As an example, the parameter value for female will be multiplied by one if the participant is a female and by zero if not. The other parameters for the characteristics of EV users are coded as nominal variables.

*Table 11 Binary logit model in which all parameters are modelled as a single value and the characteristics of the EV users are derived from the entire data set (combined choices of both versions). *, ** & ***, respectively represent significance at 10 %, 5 % and 1 % levels.*

	Incentive-based Robust Est. (SE)	**Intrinsic-based Robust Est. (SE)**	**Difference Robust Est. (SE)**
Predisposition to participate in a charging scheme (asc_CS)	1.384 (1.089)	0.226 (0.521)	-1.158 (0.973)
Guaranteed battery level	-0.071 (0.015)***	-0.036 (0.006)***	0.035 (0.016)**
Charging time restriction (morning)	-2.253 (0.559)***	-0.713 (0.191)***	1.540 (0.629)**
Participation rate	0.027 (0.010)***	0.003 (0.002)	-0.024 (0.010)**
Discount per kWh	-0.063 (0.070)		
Added utility evening time restriction	-0.513 (0.262)**		

	Combined data Est. (SE)	**Combined data Robust Est. (SE)**
Environmental awareness	0.035 (0.158)	0.035 (0.284)
Social attitude	0.752 (0.231)***	0.752 (0.447)*
Female	0.497 (0.217)**	0.497 (0.372)
Living in an urban area	-0.566 (0.144)***	-0.566 (0.267)**
Living in an detached house	0.683 (0.200)***	0.683 (0.371)*
Full time job (more than 36 hours per week)	0.941 (0.163)***	0.941 (0.301)***
Politically left-oriented	0.693 (0.166)***	0.693 (0.326)**
Driving short distances (on average up to 30 km per day)	0.063 (0.162)	0.063 (0.304)
Separate plastic from other waste	0.523 (0.222)**	0.523 (0.309)*
Use bicycle for short distances (2.5 km)	0.176 (0.162)	0.176 (0.310)
Number of choices	1170	
Null-loglikelihood	-810.98	
Final-loglikelihood	-675.96	
Estimated parameters	20	

*Table 12 Mixed logit model in which the constants and attributes are modelled as a distribution and the characteristics of the EV users as a single value derived from the entire data set (combined choices of both versions). *, ** & ***, respectively represent significance at 10 %, 5 % and 1 % levels.*

	Incentive-based Robust Est.		**Intrinsic-based Robust Est.**		**Difference Robust Est.**	
	Mean (SE)	**Std.dev (SE)**	**Mean (SE)**	**Std.dev (SE)**	**Mean (SE)**	**Std.dev (SE)**
Predisposition to participate in a charging scheme (asc_CS)	2.860 (1.497)	0.132 (2.669)	0.343 (0.993)	1.386 (0.569) **	-2.518 (1.656)	1.254 (2.762)
Guaranteed battery level	-0.131 (0.019)***	0.019 (0.029)	-0.058 (0.011)***	0.050 (0.021)**	0.073 (0.027)***	0.031 (0.039)
Charging time restriction (morning)	-4.390 (0.753)***	-0.333 (2.051)	-1.352 (0.380)***	0.302 (0.598)	3.038 (1.050)***	0.635 (2.202)
Participation rate	0.052 (0.013)***	0.011 (0.024)	0.003 (0.002)	-0.007 (0.005)	-0.049 (0.017)***	-0.018 (0.023)
Discount per kWh	-0.013 (0.088)	0.013 (0.023)				
Added utility evening time restriction	-0.993 (0.454)**					

	Combined data Est. (SE)	**Combined data Robust Est. (SE)**
Environmental awareness	-0.122 (0.534)	-0.122 (0.993)
Social attitude	1.594 (0.647)**	1.594 (0.868)*
Female	0.878 (0.607)	0.878 (0.698)
Living in an urban area	-0.804 (0.426)*	-0.804 (0.676)
Living in an detached house	1.629 (0.588)***	1.629 (0.811)**
Full time job (more than 36 hours per week)	1.622 (0.446)***	1.622 (0.519)***
Politically left-oriented	1.574 (0.593)***	1.574 (1.019)
Driving short distances (on average up to 30 km per day)	0.493 (0.452)	0.493 (0.634)
Separate plastic from other waste	0.532 (0.577)	0.532 (0.787)
Use bicycle for short distances (2.5 km)	0.511 (0.494)	0.511 (0.820)
Number of choices	1170	
Null-loglikelihood	-1045.52	
Final-loglikelihood	-543.48	
Estimated parameters	29	

5.2 Influence of the charging scheme designs on participation

This section discusses the influence of various characteristics of a charging scheme on the choice to participate in a charging scheme. These characteristics primarily concern the attributes of a charging scheme, but also the way in which a charging scheme is framed (incentive-based versus intrinsic-based).

5.2.1 Influence of the charging scheme attributes on participation

To begin with, the influences of the attributes on the willingness to participate in a charging scheme will be interpreted by looking at the binary logit model (table 11). The table shows that in both the incentive-based version and the intrinsic-based version the attributes “guaranteed battery level” and “charging time restriction” are significant at the 1% level. This means that it can be stated with great certainty that these two attributes play an important role in the choice of the EV user to participate in a charging scheme. Furthermore, the parameter “participation rate” was found to be significant in the incentive-based version, but not in the intrinsic-based version. This means that the participation rate of the fellow EV users played a role in the choice of EV users in the incentive-based version. Next, the discount parameter was not found to be significant and therefore does not appear to influence the charging scheme participation. With regard to this parameter it is however important to mention that the attribute levels for this attribute were multiplied by 10 in the database to increase the data stability. In order to process this correctly in the results, the estimated parameter value and the standard error for this attribute have been multiplied by 10 in the final results. Finally, the constant was found to be insignificant. As a result, nothing can be said about the general attitude of the EV users towards a charging scheme. Regardless of the values of the attributes, EV users have no preference or dislike for a charging scheme.

Subsequently, as mentioned in the previous section, an evening restriction parameter is added to the utility function as well. By looking at table 11, it could be seen that this parameter takes the value of -0.513 and is significant at the 5% level. When a morning restriction parameter would be added to this model, instead of an evening restriction parameter, it will obtain the same parameter value, but positive (0.513). As mentioned earlier, these parameters function as a kind of addition to the current charging time restriction parameter. In case an evening restriction parameter is estimated separately, the general restriction parameter represents the effect of a morning restriction. By adding the value of the additional evening restriction parameter to the value of the general restriction parameter, the parameter value of a time restriction in the evening can be calculated. In case of the incentive-based version, the parameter value of a morning restriction is equal to -2.253 and that of an evening restriction is equal to -2.253 - 0.513 = -2.766. This makes it clear that an evening restriction has a significantly more negative effect on the choice to participate in a charging scheme than a morning restriction. In short, the data showed that both charging time restrictions have a significant negative effect on the choice to participate in a charging scheme, but the negative effect of a charging time restriction in the evening is greater than that of a charging time restriction in the morning.

Next, when looking at the estimates of the mixed logit model (table 12), it can first be stated that all parameters have the same sign as in the binary logit model. Secondly, there are also no differences in significance for the parameters of both charging scheme versions. Furthermore, with regard to the standard deviations, it can be seen that most of the standard deviations are found to be insignificant. However, significant standard deviations were found for the constant and the attribute “guaranteed battery level” in the intrinsic-based version, meaning that there is a degree of heterogeneity with regard to this constant and attribute. Since only two parameters were significant at the 5% level, it can be concluded that there is no strong degree of heterogeneity in the sample.

Furthermore, by comparing the utility ranges of the different attributes, it is subsequently possible to say something about the difference in effect of the attributes on the willingness to participate in a charging scheme. As mentioned earlier, the parameter values say something about the effect of the attributes. By multiplying the parameter values with the lowest and highest attribute levels of each attribute, it is possible to calculate the utility ranges for each of the attributes. When a parameter value is multiplied by an attribute level, the utility can be calculated for that particular attribute level. Tables 13 & 14 show for each of the attributes what the utility is for the lowest and highest attribute level. By measuring the difference of these two values, it is possible to see the maximum effect of the associated attribute in this study.

The tables show the utility ranges for each of the charging scheme versions resulting from the binary logit model. Before interpreting the results, it is important to mention that only the significant parameters have been included. In addition, it is also important to note that the utility range is calculated for both charging time restrictions. When we then look at the utility ranges, it can be seen that in both versions the attribute "guaranteed battery level" has the greatest effect on the choice to participate in a charging scheme followed by the charging time restriction attributes. The attribute "participation rate" was found to be significant in the incentive-based version, however, this attribute also had a smaller effect on the choice to participate in a charging scheme than the aforementioned attributes.

Table 13 Utility ranges for the attributes in the incentive-based version

Attribute	Lowest utility	Highest utility	Utility range
Guaranteed battery level	50 × -0.071 = -3.550	0 × -0.071 = 0	3.550
Charging time restriction morning	1 × -2.253 = -2.253	0 × -2.253 = 0	2.253
Charging time restriction evening	1 × (-2.253 - 0.513) = -2.766	0 × (-2.253 - 0.513) = 0	2.766
Participation rate	10 × 0.027 = 0.270	90 × 0.027 = 2.430	2.160

Table 14 Utility ranges for the attributes in the intrinsic-based version

Attribute	Lowest utility	Highest utility	Utility range
Guaranteed battery level	50 × -0.036 = -1.800	0 × -0.036 = 0	1.800
Charging time restriction morning	1 × -0.713 = -0.713	0 × -0.713 = 0	0.713
Charging time restriction evening	1 × (-0.713 - 0.513) = -1.226	0 × (-0.713 - 0.513) = 0	1.226

5.2.2 Incentive-based versus intrinsic-based charging scheme designs

The above subsection showed to what extent the attributes influence the choice to participate in a charging scheme. It has been found that the attributes "guaranteed battery level" and "charging time restriction" played a significant role in both charging scheme versions, however, the extent to which these attributes may influence the participation rate could differ between the two versions. When looking at the difference parameters in figures 11 and 12, it can be seen that these parameters are significant at the 5% level in the binary logit model and at the 1% level in the mixed logit model. This indicates that there is a significant difference in effect of the attributes in each of the charging scheme versions. The tables show that the parameter values of the attributes in the intrinsic-based version are smaller than in the incentive-based version. Since the difference was found to be significant, it can be said that the effect of the attributes is significantly less in the intrinsic-based version compared to the incentive-based version.

Next, when comparing the utility ranges for both versions, it can be seen that the values of the utility ranges are significantly smaller for the intrinsic-based version than for the incentive-based version. This substantiates the conclusion that the effect of the attributes on the choice to participate in a charging scheme is considerably higher in the incentive-based version than in the intrinsic-based version. In addition, the descriptive statistics in section 4.4.2 showed that the participation rate was higher in the intrinsic-based version than in the incentive-based version (on average 62% vs 52%). An important difference between these two versions was that the intrinsic-based version specifically stated that participation will contribute to the prevention of environmental problems and the maintenance of the common good, while in the incentive-based version it was emphasized that the EV user would receive a financial compensation. As mentioned earlier, the social benefits as stated in the intrinsic-based version can result in solidarity incentives that appeal to someone's intrinsic motivation. Based on the participation rates, it can be concluded that these social benefits did indeed lead to a higher participation rate.

All in all, given that the participation rate in the intrinsic-based version was higher and the discount attribute was found to be insignificant anyways, it can be concluded that an appeal to someone's solidarity as a form of an intrinsic motivation had a stronger influence on the choice to participate in a charging scheme than the monetary incentives.

5.3 Role of the characteristics of EV users with regard to participation

The next step in the analysis phase was to investigate the role of the characteristics of EV users with regard to charging scheme participation. The lower parts of tables 11 and 12 give an overview of the estimates resulting from this analysis step. As mentioned earlier, the estimates for the characteristics of the EV users are estimated as a single value in both logit models and both the classical and robust standard errors are shown for each of the characteristics.

When looking at the results, it can be concluded that not many characteristics play a significant role in explaining why EV users would participate in a charging scheme. This could partly be due to the fact that the number of respondents is relatively low. For this and possibly also other reasons, it is still interesting to reflect on the characteristics shown in tables 11 and 12.

To begin with, it can be seen that EV users who have a strong connection with their neighbours (social attitude parameter) are significantly more likely to participate in a charging scheme. This was certainly in line with the expectations as it is seems reasonable to think that people who are more willing to do something good for their neighbours would also be more likely to participate in a charging scheme that has positive consequences for their neighbours. This expectation is based on the reasoning that people who experience a higher degree of social connectedness might also be more driven by the social benefits associated with charging scheme participation.

On the other hand, the environmental awareness parameter is not significant. This tells us that EV users with a high degree of environmental awareness are not necessarily more likely to participate in a charging scheme. However, several tests showed that this insignificance is also partly due to the presence of other characteristics. In fact, this variable correlates (albeit slightly) with the variables “social attitude”, “politically left-oriented” and “separate plastic from other waste”. When these three variables are not included in the model, the parameter “environmental awareness” becomes significant with a positive sign at the 10% level.

Furthermore, the tables show that there are two more parameters found to be significant in both logit models when looking at the robust standard errors, namely the parameters “living in a detached house” and “full time job”. It can be concluded from this that the data set shows that EV users who live detached and/or have a full-time job would be more likely to participate in a charging scheme. In addition, when looking at the robust standard errors, a (slightly) significant interaction effect was also found in the binary logit model for the parameters “female”, “living in an urban area”, “politically left-oriented” and “separate plastic from other waste”. In case of the parameter “female”, this concerns significance at the 20% level. Looking at the sign of the parameters, it could be said that women, people with a left-wing political orientation and people that separate plastic from other waste are more likely to participate in a charging scheme and that people living in an urban area are less likely to participate in a charging scheme.

Finally, there are also parameters included in the table that are just interesting to consider, because these were expected to influence the participation rate. These parameters are “driving short distances” and “use bicycle for short distances”. Both parameters show a positive sign, which was also to be expected. A charging scheme is a measure that could possibly create the feeling that the total use of the car will be limited. For people who only drive a small average distance per day or who also prefer to use the bicycle for shorter distances, it can be explained that they would be more likely to participate in a measure that they feel would restrict their car use.

5.4 Concluding remarks

As mentioned in the introduction, this chapter answers RQ3 and RQ4. To begin with, it has become clear how the characteristics of a charging scheme influence the choice of EV users to participate in a charging scheme. First of all, it has become clear that the charging time restrictions and battery level restrictions played an important role in the respondents' choice. However, all attributes played a significantly smaller role in the respondents’ choice in the intrinsic-based survey version than in the incentive-based version. In addition, the willingness to participate in the charging scheme was also found to be significantly higher in the intrinsic-based version. This can be explained by the fact that the intrinsic motivation of the EV users was specifically appealed to by stimulating them with social benefits. This finding is also in line with the findings from the literature regarding the social schemes. It was found that emphasizing the social benefits of a social scheme could increase the influence of these benefits on the willingness to participate. As a result, it might even be the case that these factors will have a greater influence on the participation rate than monetary incentives. With regard to this study, the results showed that monetary incentives do not necessarily lead to a higher participation rate, but that in this case EV users are rather driven by solidarity. Mentioning that participation can contribute to achieving various sustainability goals and the prevention of energy shortages in the neighbourhood was apparently more convincing.

Next, the finding that appealing to someone's solidarity leads to a higher participation rate can also be substantiated by another finding in this study with regard to RQ4. When analysing the interaction effects of the characteristics of EV users with the charging scheme participation rate, it was first of all found that EV users who indicated that they are socially connected to their neighbours and are willing to take action for the good of their neighbours are also more willing to participate in a charging scheme. This shows that an increased degree of social connectedness in the neighbourhood will be accompanied by an increased willingness to participate in a charging scheme.

Finally, with regard to the analysis of the interaction effects between the characteristics of EV users and the charging scheme participation rate, it was found that most characteristics did not play a role in the EV user's choice to participate in a charging scheme. The fact that just a few interaction effects were found can be explained by the fact that the response rate was relatively low. However, it is also not unlikely that there are actually only a few interactive effects, since it was not necessarily expected for most of the selected characteristics that there would be a certain interaction effect.

6. Conclusion, limitations and recommendations

As a result of a growing demand for electricity, we are facing an increased risk of congestion issues in the electricity network. An important cause of this increasing demand is the increasing number of electric vehicle users. A possible solution that could contribute to the prevention of congestion issues is the introduction of charging schemes. In the context of this study, a charging scheme is defined as a contract between an EV user and the charge card provider/electricity supplier stating, among others, at what times an EV user could charge his/her EV. However, to ensure that charging schemes can effectively contribute to solving the grid capacity problems, it is important that many EV users are willing to participate in such schemes. The aim of this study was therefore to examine various factors that could influence the willingness of an EV user to participate in a charging scheme. To find factors that could possibly influence the willingness to participate in a charging scheme, a literature research was carried out. The findings were divided into three categories: the possible motivations of EV users to participate in a charging scheme (both intrinsic and extrinsic motivations), the attributes of a charging scheme (e.g. the charging time restrictions) and the characteristics of EV users which may play a role in the willingness to participate in a charging scheme.

6.1 Conclusion

The literature has shown that in addition to extrinsic incentives, such as a monetary compensation, an individual's intrinsic motivation may also influence the willingness to participate in a charging scheme. This intrinsic motivation could be linked to someone's solidarity. When someone shows a high degree of solidarity, this person would decide to participate in a charging scheme on the basis of solidarity incentives (intangible rewards) that could be obtained as someone has the feeling that he/she is participating in a social initiative. In order to examine the effect of these two types of motivations separately, two versions of a charging scheme have been drawn up, namely an incentive-based version in which a monetary compensation is explicitly communicated and an intrinsic-based version in which social benefits are explicitly communicated. The results showed that the participation rate in the intrinsic-based version was higher and that a monetary compensation does not influence the choice with regard to charging scheme participation. In addition, the influences of all attributes were found to be significantly lower in the intrinsic-based version than in the incentive-based version. These findings show that the solidarity incentives had a stronger influence on the choice to participate in a charging scheme than the monetary incentives. In other words, the social contributions and social recognition associated with charging scheme participation generally weigh more heavily for EV users than a financial compensation as presented in this study.

Subsequently, with regard to the charging scheme attributes, the results showed that a guaranteed battery level restriction at 50% weighs more heavily than a charging time restriction in either the evening or in the morning. In contrary, a guaranteed battery level restriction at 75% weighs less heavily than a charging time restriction in either the evening or in the morning. Furthermore, the attribute with regard to the participation rate of the fellow EV users in the neighbourhood appeared to have less influence on the choice to participate in a charging scheme than the restrictions mentioned above. In addition, this attribute was only found to be significant for the incentive-based version.

Finally, it can be concluded that many of the analysed characteristics of EV users do not play a role in the willingness of an EV user to participate in a charging scheme. However, the analysis did show that people who have a good connection with their neighbours, who live in a detached house and/or work full time, showed a considerably higher willingness to participate in a charging scheme. In addition, despite the fact that the estimated parameters were less significant, the results also showed that women, persons with a left-wing political orientation and persons who separate plastic from other waste have a higher participation rate and people who live in an urban area have a lower participation rate.

6.2 Limitations

All in all, based on the results, I believe that this study has provided some new insights that may be relevant to policy makers. As mentioned earlier, charging schemes have been compiled based on many examples from the literature. However, what made this study especially unique is that a distinction was made between the way in which the charging schemes were presented to the respondents. On the one hand the sacrifices were compensated by using extrinsic incentives and on the other hand an appeal has been made to someone's solidarity as a form of an intrinsic motivation. Despite the fact that the research has shown interesting results, it is also important to be clear about the limitations of this research.

To begin with, this study looked at the stated intentions of EV users and not at the actions in practice. For many EV users, the concept of a charging scheme is still very new and can therefore be difficult to imagine (Abdullah et al., 2011). However, for this reason it was also chosen to use static charging schemes in this study instead of dynamic charging schemes. Static charging schemes are not dependent on external factors and clearly indicate at which fixed moments there will be a charging limitation and what the compensation will be (if applicable). Despite the fact that dynamic charging schemes are more realistic, as they take into account the current grid capacity (Refa, 2023), static charging schemes are easier to imagine for the respondents. Furthermore, it is also not a major limitation for this study that only static charging schemes were included, since it was mainly important to just visualize a limitation in the EV users' charging behaviour. In addition, the findings from this study are also in line with the findings from the literature, namely that someone’s intrinsic motivation can play an equally important (or even more important) role in the choice of an EV user as an extrinsic incentive.

Next, the study is also somewhat limited by the fact that only 130 valid responses were obtained. Although this number is sufficient to perform the necessary analyses, it would always be better if the response rate was higher. An example of a problem caused by the relatively low response rate is that the parameter associated with the attribute "discount per kWh" received a positive sign in some estimations and a negative sign in others. When the response rate will be higher, the probability that the sign of a parameter will differ per estimation will be smaller. However, as described in section 4.4, the sample is representative of the target audience. This can be explained by the fact that the respondents were approached through many different channels on social media.

6.3 Recommendations

To begin with, now that it has become clear that solidarity incentives weigh more heavily than financial incentives in the choice to participate in a charging scheme, it may be interesting for policymakers to respond to this. In the Netherlands, the so-called "Klimaatfonds" (Dutch Climate Fund) has been set up with the aim of reducing greenhouse gas emissions (PBL, 2023). This investment fund is used, among others, to increase the availability of solar energy. However, a significant increase in solar energy could also cause problems in the electricity network if the use of the network is not properly managed. In the Dutch coalition agreement, 35 billion euro has been reserved for the climate fund, of which 4 billion euro for the category 'energy infrastructure'.

As discussed, charging schemes can contribute to the proper management of the use of the electricity network. Since appealing to the EV user's solidarity is an effective means to encourage an EV user to participate in a charging scheme, it is advisable to make use of this. To evoke this intrinsic form of motivation, it is important to educate EV users. In concrete terms, it could be decided to use a small part of the reserved investment capacity to make EV users aware of the fact that a charging scheme has many social benefits. It is especially important that the consequences of grid capacity problems will be presented, because most people cannot imagine this. In addition, small sacrifices can already lead to big results. For this reason it is more important that many EV users make small sacrifices instead of only a few EV users making big sacrifices. All in all, for a higher participation rate it is especially important that it becomes clear to EV users why charging schemes are so important, that no big sacrifices have to be made and that participation is accompanied by many social benefits. The charge card provider and electricity supplier can, among others, play an important role in educating the EV users. For example, the charge card provider and electricity supplier can show via e-mail or in a mobile app what a charging scheme entails and what its social benefits are.

Furthermore, the research also showed that EV users who have a strong connection with their neighbours are more willing to participate in a charging scheme. Policy makers can also use this finding to increase the participation rate. When policymakers aim to increase the social connectivity within the neighbourhoods, this will also lead to a higher effectiveness of solidarity incentives in appealing to the intrinsic motivation of an EV user. In addition to the fact that this can lead to a higher participation rate in the charging schemes, this may also increase the participation rate in other social schemes. As a solution, policymakers could choose to invest more in social activities within certain neighbourhoods. These social activities can lead to a higher degree of social connectedness, which in turn will increase the sense of solidarity in the neighbourhood.

Next, for further research on charging scheme participation, I would recommend to conduct pilots in practice instead of a stated choice experiment. The advantages of pilots are that EV users can immediately see in practice what these charging schemes entail (both static and dynamic) and that the actual willingness to participate in a charging scheme can be measured instead of the stated intention. For these reasons, the first recommendation for follow-up research is to examine the participation rate in different types of (dynamic) charging schemes by using pilots. As an example, both incentive-based and intrinsic-based charging schemes (respectively charging schemes with and without compensation) could be presented in a number of neighbourhoods to examine the participation rate. The second recommendation for follow-up research is to do efforts to increase the social connectedness in a number of neighbourhoods and examine the effect of it on charging scheme participation. The third recommendation for follow-up research is to investigate how EV users will react to incentives other than financial incentives. For example, people could also be compensated with their own private charging station or the provision of faster public charging stations.

Finally, this study also looked at the role of the characteristics of EV users in the choice to participate in a charging scheme. During this study, a number of characteristics that may influence the charging scheme participation have been examined. However, it might be interesting to continue on this in further research. Instead of only looking for the interaction effects between the characteristics of EV users and the participation rate, it could also be researched what kind of charging scheme designs are preferred by a certain group of EV users. Based on this, it would then be possible to form tailored-made policies for specific groups of EV users. The results of this study, including all collected characteristics, could form a basis for this follow-up study.

7. References

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Appendix

Appendix A Consent points

Below the table is shown that was presented to the interviewees. The people interviewed had to agree to all seven points. After the interviewee agreed to all seven points, the consent form had to be submitted with this person's name and signature.

Table 15 Table with consent points

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated XX/XX/XXXX, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: an audio/video recorded interview that will be transcribed as text. The audio/video is not essential to the research and will therefore be destroyed as soon as the information is transcribed.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that taking part in the study also (possibly) involves collecting specific personally identifiable information (PII). - Signed consent forms - Video/recording materials - Email addresses and/or other addresses for digital communication - Names - Information about the participants' workplace and their specific role in the organisation they work for	☐	☐
5. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach. - anonymisation or aggregation - secure data storage/limited access - transcription	☐	☐
6. I understand that personal information collected about me that can identify me, such as my name or e-mail address will not be shared beyond the study team and will be destroyed at the end of the research project.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
7. I agree that my responses, views or other input can be quoted anonymously in research outputs and made publicly available at the end of the study.	☐	☐

Appendix B Ngene codes

Below you can see the Ngene codes used to set up the discrete choice experiments. You can see that the codes are almost completely the same, however, an extra parameter (b4) has been added to the incentive-based version. This parameter represents the extra attribute "discount per kWh" that has been included in this version. Furthermore, not all attributes are coded the same. With regard to the attributes "guaranteed battery level" (b1), "participation rate" (b3) and "discount per kWh" (b4), it is possible to make an assumption about the utility direction of the attribute levels. As an example, it can be assumed that a discount of 15 cents is more preferred than a discount of 5 cents and that a situation in which the vehicle can be charged up to 100% is more popular than a situation in which the vehicle can be charged up to 75%. However, it is not possible to make this assumption for the attribute "charging time restriction" (b2). It is not possible to know in advance with certainty whether a morning restriction is more popular than an evening restriction and vice versa. For this reason, the parameter belonging to this attribute is coded as a non-informative prior. By assigning the prior a very small value (0.001) it is indicated that little to no information is available about which attribute level is preferred over the others.

```
design
;alts = alt,none
;rows = 9
;eff = (mnl,d)
;con
;model:
U(alt) = b1[0.1]*A[0,1,2] + b2[0.001]*B[0,1,2] + b3[0.1]*C[0,1,2] + b4[-0.1]*D[0,1,2]
$
```

Figure 2 Ngene code extrinsic-based design

```
design
;alts = alt,none
;rows = 9
;eff = (mnl,d)
;con
;model:
U(alt) = b1[0.1]*A[0,1,2] + b2[0.001]*B[0,1,2] + b3[0.1]*C[0,1,2]
$
```

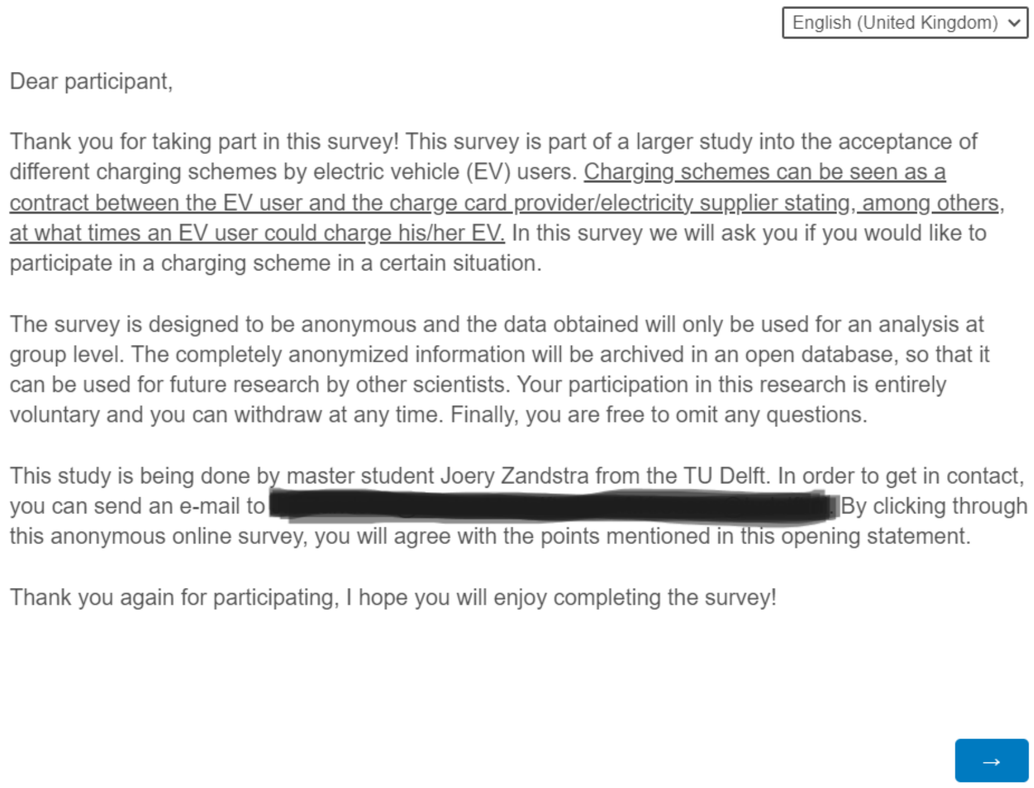
Figure 3 Ngene code intrinsic-based design

Appendix C Survey design

This appendix contains various screenshots of the survey to show how the survey was composed.

Appendix C.1 Opening statement

As soon as people clicked on the anonymous link to participate in the survey, the respondents were first shown an opening statement with information about the project and how the data will be handled, see figure 4.



English (United Kingdom)

Dear participant,

Thank you for taking part in this survey! This survey is part of a larger study into the acceptance of different charging schemes by electric vehicle (EV) users. Charging schemes can be seen as a contract between the EV user and the charge card provider/electricity supplier stating, among others, at what times an EV user could charge his/her EV. In this survey we will ask you if you would like to participate in a charging scheme in a certain situation.

The survey is designed to be anonymous and the data obtained will only be used for an analysis at group level. The completely anonymized information will be archived in an open database, so that it can be used for future research by other scientists. Your participation in this research is entirely voluntary and you can withdraw at any time. Finally, you are free to omit any questions.

This study is being done by master student Joery Zandstra from the TU Delft. In order to get in contact, you can send an e-mail to [redacted] By clicking through this anonymous online survey, you will agree with the points mentioned in this opening statement.

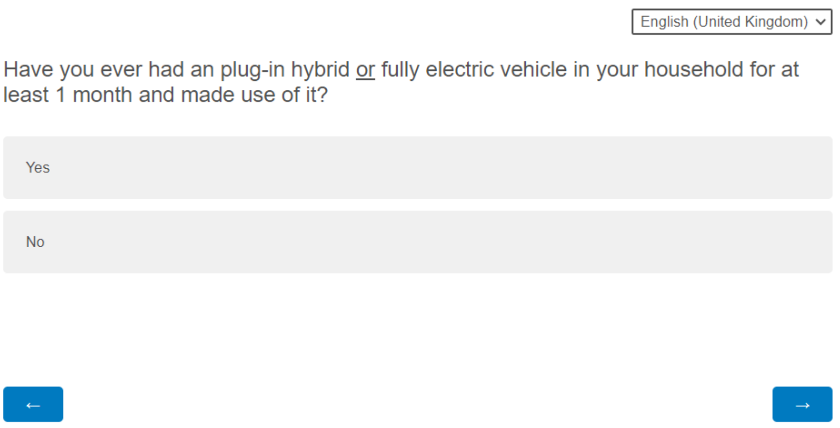
Thank you again for participating, I hope you will enjoy completing the survey!

→

Figure 4 Opening statement

Appendix C.2 Screening question

Subsequently, a screening question is shown. This screening question serves to ensure that the respondents fall within the intended target audience, see figure 5.



English (United Kingdom)

Have you ever had an plug-in hybrid or fully electric vehicle in your household for at least 1 month and made use of it?

Yes

No

← →

Figure 5 Screening question

If a respondent answers the screening question with "yes", the respondent will be redirected to the first question. If a respondent answers the screening with "no", the respondent will be redirected to the end of the survey and will be shown a message indicating that the respondent is not part of the target audience, see figure 6.

NL: Beste deelnemer, u valt buiten de doelgroep en kan daarom niet deelnemen aan dit onderzoek.

EN: Dear participant, you cannot participate in this research, since you are not part of the target audience.

Figure 6 Message if answer to screening question is no

Appendix C.3 Example choice situations

Next, the choice situations will follow. By using a randomizer, the two charging scheme versions will be randomly, but equally, distributed among the respondents. Figure 7 gives an example of an incentive-based choice situation and Figure 8 an intrinsic-based choice situation.

The purpose of the charging schemes is to balance the electricity demand in your neighbourhood. When EV users participate in a charging scheme, they are asked to adjust their charging behaviour and will receive a discount in return.

The question to you is whether you would participate in a charging scheme in the following situation for at least 1 month:

Charging scheme 2/9

- The vehicle can be charged at any time of the day, except for the time frame from **5:00 PM in the afternoon to 11:00 PM in the evening**.
- The vehicle can always be charged to a battery level of **100% (no limitation)**.
- About **10%** of the other EV users in your neighbourhood are already participating in a charging scheme.
- If you participate in this charging scheme, you will receive **a 5 cent discount per kWh used***. Converted, this equals a discount of **1.25 euros per average charging session**.**

*Discount based on an average kWh price of 50 cents.

**Based on charging a vehicle with a range of 300 km from 25% to 75%.

Would you participate in the above charging scheme?

Yes

No

Figure 7 incentive-based example choice situation

The purpose of the charging schemes is to balance the electricity demand in your neighbourhood. Participation in a charging scheme will contribute to achieving various sustainability goals. In addition, the use of charging schemes will contribute to the prevention of energy shortages in the neighbourhood, despite the increasing demand for electricity.

The question to you is whether you would participate in a charging scheme in the following situation for at least 1 month:

Charging scheme 3/9

- The vehicle can be charged at any time of the day, except for the time frame from **8:00 AM in the morning to 2:00 PM in the afternoon**.
- The vehicle can always be charged to a battery level of **50%**. You can expect that charging to 100% is possible on half of the days.
- About **90%** of the other EV users in your neighbourhood are already participating in a charging scheme.

Would you participate in the above charging scheme?

Yes

No

Figure 8 intrinsic-based example choice situation

Appendix C.4 Statements

After the respondent has answered one of the two series of choice situations, the 10 environmental and social related statements will follow, see figure 9.

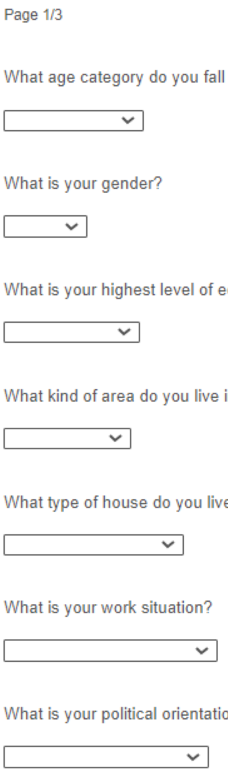
Next, we would like to ask your opinion on the following 10 statements.

	Totally disagree	Disagree	Neutral	Agree	Totally Agree
I see global climate change as a threat to humanity.	○	○	○	○	○
I feel personally responsible for contributing to the fight against global climate change.	○	○	○	○	○
I think it's important to show that I care about the environment.	○	○	○	○	○
I am aware of my energy consumption at home.	○	○	○	○	○
I think it is important to make environmentally conscious purchases/investments.	○	○	○	○	○
I feel socially connected to my neighbours.	○	○	○	○	○
I am willing to take action for the good of my neighbours.	○	○	○	○	○
I think it's important to show that I care about my neighbours.	○	○	○	○	○
I think it is important to make sure that I won't profit from the social contributions of my neighbours without contributing myself.	○	○	○	○	○
I think it is important that my neighbours as much as I won't suffer from the grid capacity problems.	○	○	○	○	○

Figure 9 Environmental and social related statements

Appendix C.5 Characteristics of EV users

Finally, there are three pages of questions that can be used to characterize the respondent. These questions are divided into three categories: socio-demographic characteristics (figure 12), vehicle-related characteristics (figure 10) & additional characteristics (figure 11).



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What age category do you fall into?

What is your gender?

What is your highest level of education achieved?

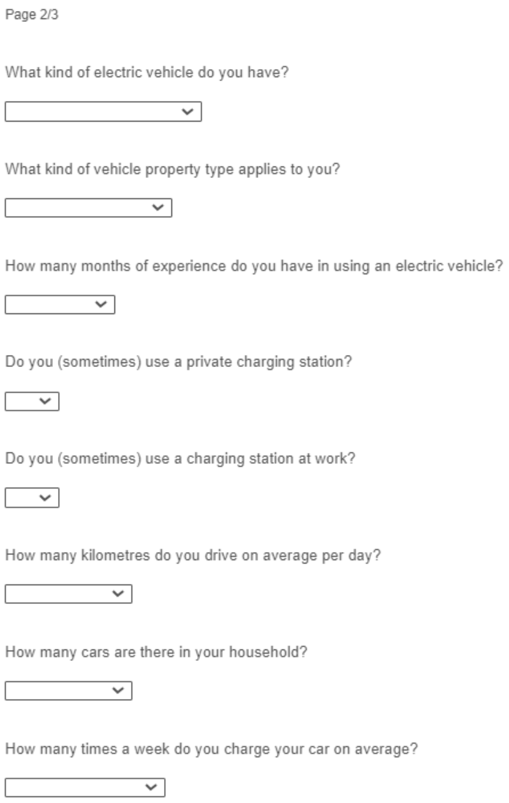
What kind of area do you live in?

What type of house do you live in?

What is your work situation?

What is your political orientation?

Figure 12 Socio-demographic characteristics



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What kind of electric vehicle do you have?

What kind of vehicle property type applies to you?

How many months of experience do you have in using an electric vehicle?

Do you (sometimes) use a private charging station?

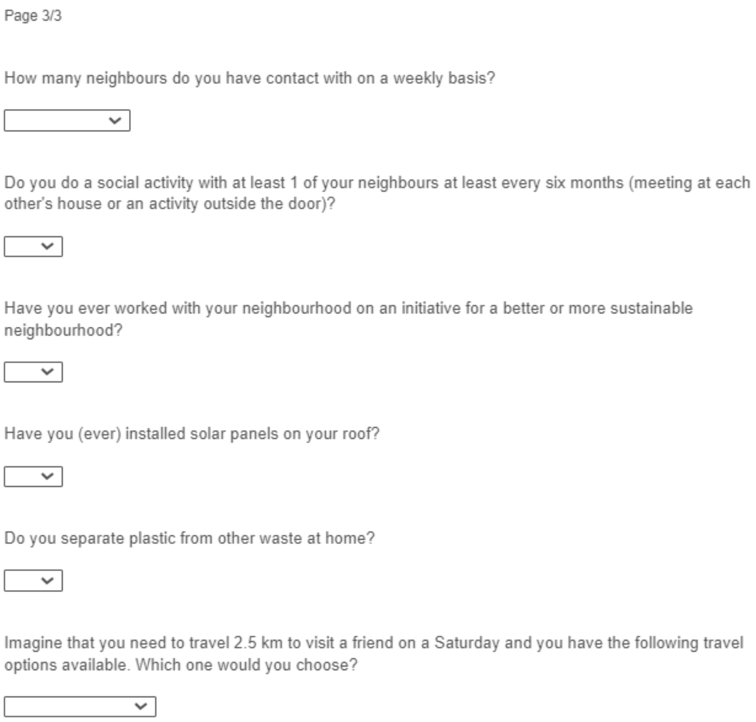
Do you (sometimes) use a charging station at work?

How many kilometres do you drive on average per day?

How many cars are there in your household?

How many times a week do you charge your car on average?

Figure 10 Vehicle-related characteristics



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How many neighbours do you have contact with on a weekly basis?

Do you do a social activity with at least 1 of your neighbours at least every six months (meeting at each other's house or an activity outside the door)?

Have you ever worked with your neighbourhood on an initiative for a better or more sustainable neighbourhood?

Have you (ever) installed solar panels on your roof?

Do you separate plastic from other waste at home?

Imagine that you need to travel 2.5 km to visit a friend on a Saturday and you have the following travel options available. Which one would you choose?

Figure 11 Additional characteristics

Appendix D Bar charts characteristics of EV users

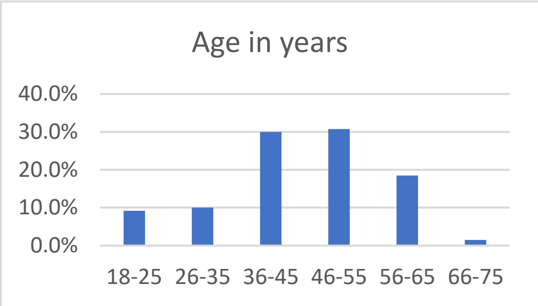

Figure 13 Shares of each age category in the sample

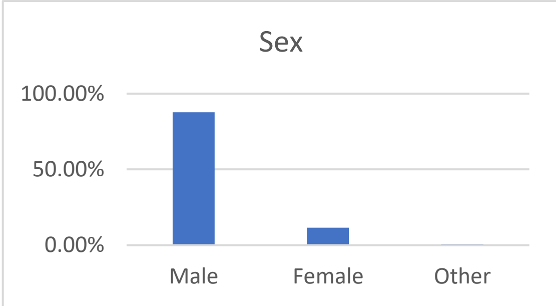

Figure 14 Shares of each sex category in the sample

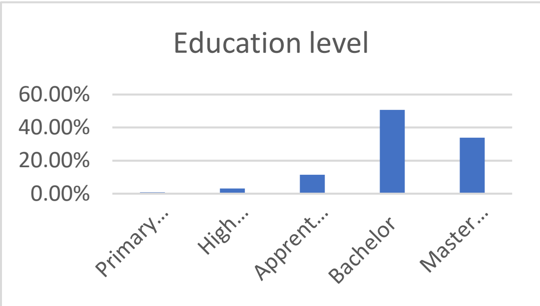

Figure 15 Shares of each education level category in the sample

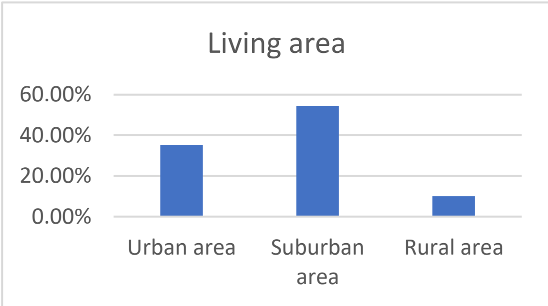

Figure 16 Shares of each living area category in the sample

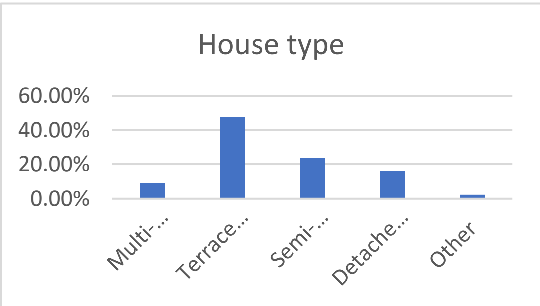

Figure 17 Shares of each house type category in the sample

Figure 18 Shares of each work situation category in the sample

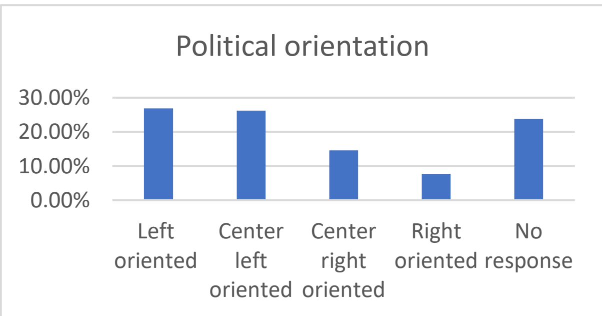

Figure 19 Shares of each political orientation category in the sample

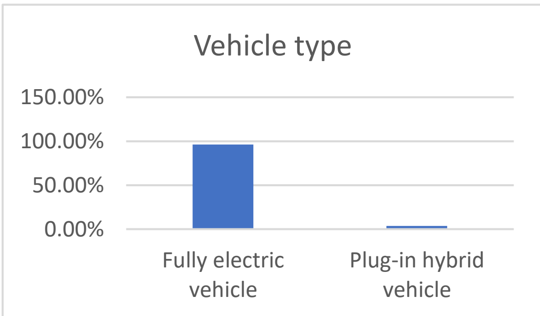

Figure 20 Shares of each vehicle type category in the sample

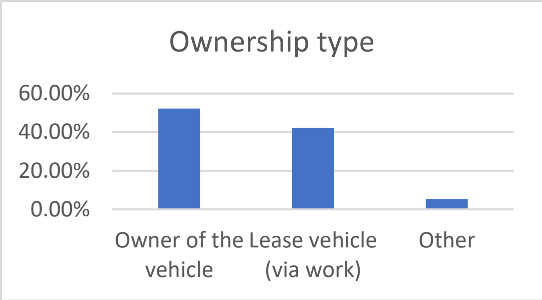

Figure 21 Shares of each ownership type category in the sample

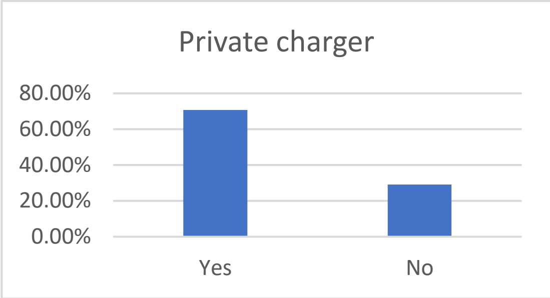

Figure 22 Share of EV users in the sample with a private charger

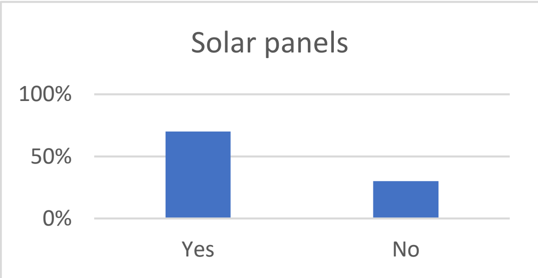

Figure 23 Share of EV users in the sample with solar panels

Appendix E Analysis phase

This appendix contains various tables and figures that are relevant for the analysis phase.

Appendix E.1 Scale parameter

Each of the two figures shown below represent the parameter estimates of an estimated binary logit model in R. An important difference between the two estimations is that the scale parameter is not fixed in the estimation shown in figure 24 and is fixed in the estimation shown in figure 25. On the basis of these figures it is possible to explain why it is fine to fix the scale parameter to the value 1.

As explained earlier, fixing a parameter results in a model that converges better and delivers a better performance. Since it is important for the research that the other attributes are certainly estimated, fixing the scale parameter would be the most obvious choice. Despite the estimation problems, in case of the binary logit model it was possible to estimate the parameter values and the associated robust standard errors when all parameters were taken into account. These estimations are shown in figure 24, which shows that the parameter value of the scale parameter is estimated at 1,068. This number is quite close to the value 1 and for this reason I also looked at how it would affect the estimates of the other parameters if the scale parameter would be fixed at the value 1. When the parameter values (indicated in the green outline) and the p-values (indicated in the red outline) in figure 24 are compared to the same values in figure 25, it can be seen that the differences are minimal. The differences are so minimal that they will not affect the interpretation of the results. For this reason it was decided to fix the scale parameter at the value 1 in both the binary and the mixed logit model.

Estimates:

	Estimate	s.e.	t.rat.(0)	p(1-sided)	Rob.s.e.	Rob.t.rat.(0)	p(1-sided)
Incentive_asc_CS	1.384181	1.040857	1.3298	0.091784	1.089227	1.2708	0.101901
Incentive_version_batterylevel	-0.070696	0.016565	-4.2678	9.869e-06	0.015451	-4.5754	2.376e-06
Incentive_version_timerestriction	-2.253234	0.663356	-3.3967	3.4100e-04	0.559351	-4.0283	2.809e-05
Incentive_version_participationrate	0.026970	0.011890	2.2684	0.011652	0.010096	2.6713	0.003778
Incentive_version_discount	-0.006310	0.007229	-0.8729	0.191361	0.007003	-0.9010	0.183789
Difference_asc_CS	-1.172535	NaN	NaN	NaN	0.972447	-1.2058	0.113956
Difference_batterylevel	0.037057	NaN	NaN	NaN	0.016556	2.2383	0.012600
Difference_timerestriction	1.585243	NaN	NaN	NaN	0.634591	2.4981	0.006244
Difference_participationrate	-0.024193	NaN	NaN	NaN	0.010196	-2.3728	0.008826
scale	1.067604	NaN	NaN	NaN	0.211561	5.0463	2.252e-07
Combineddata_eveningrestriction	-0.512684	0.238598	-2.1487	0.015828	0.261625	-1.9596	0.025020
beta_environment	0.034997	0.158210	0.2212	0.412465	0.284227	0.1231	0.451002
beta_social	0.752493	0.231047	3.2569	5.6321e-04	0.446742	1.6844	0.046052
beta_female	0.497175	0.216725	2.2940	0.010894	0.372013	1.3364	0.090702
beta_urban	-0.566475	0.144229	-3.9276	4.290e-05	0.266779	-2.1234	0.016861
beta_detached	0.682564	0.200171	3.4099	3.2493e-04	0.370988	1.8399	0.032895
beta_fulltime	0.940928	0.163281	5.7626	4.141e-09	0.301431	3.1215	8.9954e-04
beta_left	0.693496	0.165891	4.1804	1.455e-05	0.325584	2.1300	0.016586
beta_shortdistance	0.062984	0.161790	0.3893	0.348528	0.304300	0.2070	0.418012
beta_recycle	0.522531	0.221729	2.3566	0.009221	0.309211	1.6899	0.045525
beta_bicycleshortdist	0.175763	0.161522	1.0882	0.138261	0.309504	0.5679	0.285056

Figure 24 Binary logit model estimates with scale parameter not fixed

Estimates:

	Estimate	s.e.	t.rat.(0)	p(1-sided)	Rob.s.e.	Rob.t.rat.(0)	p(1-sided)
Incentive_asc_CS	1.383746	1.040856	1.3294	0.091853	1.089230	1.2704	0.101973
Incentive_version_batterylevel	-0.070691	0.016565	-4.2675	9.883e-06	0.015451	-4.5751	2.380e-06
Incentive_version_timerestriction	-2.253008	0.663353	-3.3964	3.4140e-04	0.559345	-4.0279	2.813e-05
Incentive_version_participationrate	0.026966	0.011890	2.2681	0.011662	0.010096	2.6709	0.003782
Incentive_version_discount	-0.006308	0.007229	-0.8725	0.191455	0.007003	-0.9007	0.183883
Difference_asc_CS	-1.157868	1.013141	-1.1428	0.126551	0.973186	-1.1898	0.117068
Difference_batterylevel	0.034778	0.016326	2.1302	0.016576	0.015944	2.1813	0.014581
Difference_timerestriction	1.539841	0.724044	2.1267	0.016722	0.629371	2.4466	0.007210
Difference_participationrate	-0.024002	0.011858	-2.0240	0.021483	0.010227	-2.3469	0.009466
scale	1.000000	NA	NA	NA	NA	NA	NA
Combineddata_eveningrestriction	-0.512624	0.238598	-2.1485	0.015837	0.261624	-1.9594	0.025033
beta_environment	0.035004	0.158210	0.2213	0.412448	0.284227	0.1232	0.450991
beta_social	0.752468	0.231046	3.2568	5.6340e-04	0.446740	1.6844	0.046057
beta_female	0.497196	0.216725	2.2941	0.010892	0.372013	1.3365	0.090693
beta_urban	-0.566473	0.144229	-3.9276	4.290e-05	0.266779	-2.1234	0.016861
beta_detached	0.682564	0.200171	3.4099	3.2493e-04	0.370987	1.8399	0.032894
beta_fulltime	0.940942	0.163282	5.7627	4.139e-09	0.301433	3.1216	8.9947e-04
beta_left	0.693495	0.165891	4.1804	1.455e-05	0.325585	2.1300	0.016586
beta_shortdistance	0.062992	0.161790	0.3893	0.348510	0.304301	0.2070	0.418002
beta_recycle	0.522568	0.221730	2.3568	0.009217	0.309214	1.6900	0.045515
beta_bicycleshortdist	0.175782	0.161522	1.0883	0.138235	0.309504	0.5679	0.285036

Figure 25 Binary logit model estimates with scale parameter fixed

Appendix E.2 R scripts

```
### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="BL_test",
  modelDescr ="BL_test_Survey",
  indivID    ="id"
)

#### LOAD DATA
database = read.csv("DATA_Survey_Combined.csv",header=TRUE)

### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(Incentive_asc_CS = 0,
              Incentive_version_batterylevel = 0,
              Incentive_version_timerestriction = 0,
              Incentive_version_participationrate = 0,
              Incentive_version_discount = 0,
              Difference_asc_CS = 0,
              Difference_batterylevel = 0,
              Difference_timerestriction = 0,
              Difference_participationrate = 0,
              scale = 1,
              Combineddata_eveningrestriction = 0, #ADDITIONAL ADJUSTMENT IN UTILITY
              #TO TIMERESTRICTION ATTRIBUTE IF RESTRICTION IS IN THE EVENING
              #Combineddata_morningrestriction = 0  #ADDITIONAL ADJUSTMENT IN UTILITY
              #TO TIMERESTRICTION ATTRIBUTE IF RESTRICTION IS IN THE MORNING
              beta_environment = 0, #IF SUM ANSWER TO STATEMENTS >=23
              beta_social = 0, #IF SUM ANSWERS TO STATEMENTS >= 13
              #beta_young = 0, #UNTIL 45 YEARS OLD
              beta_female = 0, #IF FEMALE
              #beta_highedu = 0, #IF EDUCATION LEVEL 4 OR 5 (BACHERLOR OR HIGHER)
              beta_urban = 0, #IF LIVING IN URBAN AREA
              beta_detached = 0, #IF LIVING IN DETACHED HOUSE
              beta_fulltime = 0, #IF WORKSITUTION IS FULLTIME
              beta_left = 0, # IF POLITICALLY LEFT ORIENTED
              #beta_fullev = 0, #IF THE VEHICLE IS A FULL ELECTRIC VEHICLE
              #beta_carownership = 0, #IF OWNER OF THE VEHICLE
              #beta_yearexp = 0, #IF EXPERIENCE LEVEL IS 4 OR 5 (12 MONTHS+)
              #beta_homecharge = 0, #IF SOMEONE CHARGES AT HOME
              #beta_workcharge = 0, #IF SOMEONE CHARGES AT WORK
              beta_shortdistance = 0, #IF DRIVING LEVEL 1 OR 2 (UP TO 30 KM PER DAY)
              #beta_onecar = 0, #IF ONE CARE IN HOUSEHOLD
              #beta_lowfreqency = 0, #IF CHARGING FREQUENCY LEVEL 1 OR 2 (UP TO 2 TIMES A WEEK)
              #beta_lesscontact = 0, #IF CONTACT LEVEL 1 OR 2 (UP TO 2 NEIGHBOURS A WEEK)
              #beta_activity = 0, #IF ACTIVITY WITH NEIGHBOURS EVERY 6 MONTHS
              #beta_initiative = 0, #IF EVER PARTICIPATED IN NEIGHBOURHOOD INITIATIVE
              #beta_solarpanel = 0, #IF EVER HAD SOLARPANELS
              beta_recycle = 0, #IF SEPERATE PLASTIC FROM OTHER WASTE
              beta_bicycleshortdist = 0) #IF VEHICLE USED FOR SHORT DISTANCES (2.5 KM)

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

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

#### DEFINE MODEL AND LIKELIHOOD FUNCTION

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

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

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

  ### Create alternative specific constants and coefficients using interactions with socio-demographics
  beta_characteristics = beta_environment* high_environmental_awareness + beta_social * high_social_attitude + beta_female * (sex == 2) + beta_urban * (living_area == 1) + beta_detached *
(house_type == 4) + beta_fulltime * (work_situation == 1) + beta_left * (left_oriented == 1) + beta_shortdistance * (driving_distance == 1) + beta_recycle * (recycle == 1) +
beta_bicycleshortdist * (vehicle_choice == 2) #+ beta_young * (age_until45 == 1)  + beta_highedu * (high_education == 1)  + beta_fullev * (vehicle_type == 1) + beta_carownership *
(ownership_type == 1) + beta_yearexp * (oneyear_experience == 1) + beta_homecharge * (home_charging == 1) + beta_workcharge * (work_charging == 1) + beta_onecar * (cars_household == 1) +
beta_lowfreqency * (charging_frequency == 1) +  beta_lesscontact * (neighbour_contact == 1) + beta_activity * (neighbour_activity == 1) + beta_initiative * (neighbour_initiative == 1) +
beta_solarpanel * (solarpanel == 1)
  ### List of utilities: these must use the same names as in mnl_settings, order is irrelevant
  V = list()
    V[['csp']]  = (scale^intrinsic_version) * (Incentive_asc_CS + Difference_asc_CS * intrinsic_version + guaranteed_battery_level2 * (Incentive_version_batterylevel +
Difference_batterylevel * intrinsic_version) + (charging_time_restriction_yes == 1) * (Incentive_version_timerestriction + Difference_timerestriction * intrinsic_version) +
participation_rate * (Incentive_version_participationrate + Difference_participationrate * intrinsic_version)) + discount_scaled * Incentive_version_discount * (intrinsic_version == 0) +
(charging_time_restriction == 0) * Combineddata_eveningrestriction + beta_characteristics
    V[['ncsp']]  = (scale^intrinsic_version)*0

    ### Define settings for MNL model component
    mnl_settings = list(
      alternatives  = c(csp=1, ncsp=0),
      avail         = list(csp=1, ncsp=1),
      choiceVar     = choice,
      V             = V
    )
  ### Compute probabilities using MNL model
  P[['model']] = apollo_mnl(mnl_settings, functionality)

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

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

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

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

apollo_saveOutput(model)
```

Figure 26 R script binary logit model

```
### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="BL_test",
  modelDescr ="BL_test_Survey",
  indivID    ="id",
  mixing = TRUE,
  nCores=6
)

#### LOAD DATA
database = read.csv("DATA_Survey_Combined.csv",header=TRUE)

### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(Mu_Incentive_asc_CS = 0,
              Sigma_Incentive_asc_CS = 1,
              Mu_Incentive_version_batterylevel = 0,
              Sigma_Incentive_version_batterylevel = 1,
              Mu_Incentive_version_timerestriction = 0,
              Sigma_Incentive_version_timerestriction = 1,
              Mu_Incentive_version_participationrate = 0,
              Sigma_Incentive_version_participationrate = 1,
              Mu_Incentive_version_discount = 0,
              Sigma_Incentive_version_discount = 1,
              Mu_Difference_asc_CS = 0,
              Sigma_Difference_asc_CS = 1,
              Mu_Difference_batterylevel = 0,
              Sigma_Difference_batterylevel = 1,
              Mu_Difference_timerestriction = 0,
              Sigma_Difference_timerestriction = 1,
              Mu_Difference_participationrate = 0,
              Sigma_Difference_participationrate = 1,
              scale = 1,
              Combineddata_eveningrestriction = 0, #ADDITIONAL ADJUSTMENT IN UTILITY
              #TO TIMERESTRICTION ATTRIBUTE IF RESTRICTION IS IN THE EVENING
             #Combineddata_morningrestriction = 0  #ADDITIONAL ADJUSTMENT IN UTILITY
             #TO TIMERESTRICTION ATTRIBUTE IF RESTRICTION IS IN THE MORNING
             beta_environment = 0, #IF SUM ANSWER TO STATEMENTS >=23
             beta_social = 0, #IF SUM ANSWERS TO STATEMENTS >= 13
             #beta_young = 0, #UNTIL 45 YEARS OLD
             beta_female = 0, #IF FEMALE
             #beta_highedu = 0, #IF EDUCATION LEVEL 4 OR 5 (BACHERLOR OR HIGHER)
             beta_urban = 0, #IF LIVING IN URBAN AREA
             beta_detached = 0, #IF LIVING IN DETACHED HOUSE
             beta_fulltime = 0, #IF WORKSITUTION IS FULLTIME
             beta_left = 0, # IF POLITICALLY LEFT ORIENTED
             #beta_fullev = 0, #IF THE VEHICLE IS A FULL ELECTRIC VEHICLE
             #beta_carownership = 0, #IF OWNER OF THE VEHICLE
             #beta_yearexp = 0, #IF EXPERIENCE LEVEL IS 4 OR 5 (12 MONTHS+)
             #beta_homecharge = 0, #IF SOMEONE CHARGES AT HOME
             #beta_workcharge = 0, #IF SOMEONE CHARGES AT WORK
             beta_shortdistance = 0, #IF DRIVING LEVEL 1 OR 2 (UP TO 30 KM PER DAY)
             #beta_onecar = 0, #IF ONE CARE IN HOUSEHOLD
             #beta_lowfreqency = 0, #IF CHARGING FREQUENCY LEVEL 1 OR 2 (UP TO 2 TIMES A WEEK)
             #beta_lesscontact = 0, #IF CONTACT LEVEL 1 OR 2 (UP TO 2 NEIGHBOURS A WEEK)
             #beta_activity = 0, #IF ACTIVITY WITH NEIGHBOURS EVERY 6 MONTHS
             #beta_initiative = 0, #IF EVER PARTICIPATED IN NEIGHBOURHOOD INITIATIVE
             #beta_solarpanel = 0, #IF EVER HAD SOLARPANELS
             beta_recycle = 0, #IF SEPERATE PLASTIC FROM OTHER WASTE
             beta_bicycleshortdist = 0) #IF VEHICLE USED FOR SHORT DISTANCES (2.5 KM)

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

### Set parameters for generating draws
apollo_draws = list(
  interDrawsType = "halton",
  interNDraws    = 500,
  interUnifDraws = c(),
  interNormDraws = c("draws"),
  intraDrawsType = "halton",
  intraNDraws    = 0,
  intraUnifDraws = c(),
  intraNormDraws = c()
)
### Create random parameters
apollo_randCoeff = function(apollo_beta, apollo_inputs){
  randcoeff = list()

  randcoeff[["Incentive_asc_CS"]] = Mu_Incentive_asc_CS + Sigma_Incentive_asc_CS * draws
  randcoeff[["Incentive_version_batterylevel"]] = Mu_Incentive_version_batterylevel + Sigma_Incentive_version_batterylevel * draws
  randcoeff[["Incentive_version_timerestriction"]] = Mu_Incentive_version_timerestriction + Sigma_Incentive_version_timerestriction * draws
  randcoeff[["Incentive_version_participationrate"]] = Mu_Incentive_version_participationrate + Sigma_Incentive_version_participationrate * draws
  randcoeff[["Incentive_version_discount"]] = Mu_Incentive_version_discount + Sigma_Incentive_version_discount * draws
  randcoeff[["Difference_asc_CS"]] = Mu_Difference_asc_CS + Sigma_Difference_asc_CS * draws
  randcoeff[["Difference_batterylevel"]] = Mu_Difference_batterylevel + Sigma_Difference_batterylevel * draws
  randcoeff[["Difference_timerestriction"]] = Mu_Difference_timerestriction + Sigma_Difference_timerestriction * draws
  randcoeff[["Difference_participationrate"]] = Mu_Difference_participationrate + Sigma_Difference_participationrate * draws

  return(randcoeff)
}

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

#### DEFINE MODEL AND LIKELIHOOD FUNCTION

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

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

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

  ### Create alternative specific constants and coefficients using interactions with socio-demographics
  beta_characteristics = beta_environment * high_environmental_awareness + beta_social * high_social_attitude + beta_female * (sex == 2) + beta_urban * (living_area == 1) +
 beta_detached * (house_type == 4) + beta_fulltime * (work_situation == 1) + beta_left * (left_oriented == 1) + beta_shortdistance * (driving_distance == 1) +
 beta_recycle * (recycle == 1) + beta_bicycleshortdist * (vehicle_choice == 2)
  #+ beta_young * (age_until45 == 1) + beta_highedu * (high_education == 1) + beta_fullev * (vehicle_type == 1) + beta_carownership * (ownership_type == 1)
  #+ beta_homecharge * (home_charging == 1) + beta_workcharge * (work_charging == 1) + beta_yearexp * (oneyear_experience == 1)
  #+ beta_lowfreqency * (charging_frequency == 1) + beta_onecar * (cars_household == 1)  +  beta_lesscontact * (neighbour_contact == 1)
  #+ beta_activity * (neighbour_activity == 1) + beta_initiative * (neighbour_initiative == 1) + beta_solarpanel * (solarpanel == 1)
```

Script continues on next page

```
  ### List of utilities: these must use the same names as in mnl_settings, order is irrelevant
  V = list()
    V[['csp']]  = (scale^intrinsic_version) * (Incentive_asc_CS + Difference_asc_CS * intrinsic_version + guaranteed_battery_level2 * (Incentive_version_batterylevel +
Difference_batterylevel * intrinsic_version) + (charging_time_restriction_yes == 1) * (Incentive_version_timerestriction + Difference_timerestriction * intrinsic_version) +
participation_rate * (Incentive_version_participationrate + Difference_participationrate * intrinsic_version)) + discount_scaled * Incentive_version_discount * (intrinsic_version == 0) +
(charging_time_restriction == 0) * Combineddata_eveningrestriction + beta_characteristics
    V[['ncsp']]  = (scale^intrinsic_version)*0

    ### Define settings for BL model component
    mnl_settings = list(
      alternatives  = c(csp=1, ncsp=0),
      avail         = list(csp=1, ncsp=1),
      choiceVar     = choice,
      V             = V
    )
  ### Compute probabilities using MNL model
  P[['model']] = apollo_mnl(mnl_settings, functionality)

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

  ### Average across inter-individual draws
  P = apollo_avgInterDraws(P, apollo_inputs, functionality)

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

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

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

apollo_saveOutput(model)
```

Figure 27 R script mixed logit model

Appendix E.3 Factor analysis

This appendix shows the results of the factor analysis. Table 16 first shows that two factors arise based on the 10 statements (also known as indicators). However, the communalities of statement 9 and 10 are under 0.25, which means that these statements are not sufficiently related to the other statements and will therefore be removed in the next iteration.

Table 16 Results of the first iteration of the factor analysis; Extraction Method: Principal Axis Factoring; Rotation Method: Oblimin with Kaiser Normalization.

	Factor 1	Factor 2	Communalities
Statement 5	.799		.465
Statement 2	.794		.631
Statement 3	.685		.509
Statement 1	.627		.322
Statement 4	.585		.672
Statement 6		.865	.637
Statement 7		.818	.670
Statement 8		.747	.688
Statement 9		.444	.222
Statement 10		.398	.232

Table 17 shows the second iteration of the factor analysis. This table shows that all statements have a high loading on 1 of the two factors and that all communalities are above 0.25.

Table 17 Results of the second iteration of the factor analysis; Extraction Method: Principal Axis Factoring; Rotation Method: Oblimin with Kaiser Normalization.

	Factor 1	Factor 2	Communalities
Statement 5	.804		.471
Statement 2	.796		.611
Statement 3	.696		.526
Statement 1	.639		.313
Statement 4	.581		.649
Statement 6		.868	.684
Statement 7		.814	.685
Statement 8		.702	.647

Finally, the factor correlation matrix is also shown below. This matrix shows that the factors correlate somewhat high with each other. This means that we are not dealing with orthogonal factors. As a result, it has been decided to stick to the Direct Oblimin rotation, as shown above.

Table 18 Factor Correlation Matrix

Factor	1	2
1	1.000	.424
2	.424	1.000