Dutch energy consumer preferences for the adoption of sustainable residential heating technologies

Master thesis

R.A. van der Ende

TU Delft

Dutch energy consumer preferences for the adoption of sustainable residential heating technologies

A context-dependent stated choice experiment to measure consumer behaviour within future scenarios of the Dutch energy transition

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in Engineering and Policy Analysis

Faculty of Technology, Policy and Management

By

Ruben van der Ende

Student number: 4382633

To be defended in public on April 20th 2021

Graduation committee

Chairperson	: Dr.ir. E.J.L Chappin	Engineering Systems and Services
First Supervisor	: Dr. E.J.E. Molin	Engineering Systems and Services
Second Supervisor	: Dr. G. de Vries	Multi-Actor Systems

Delft
University of
Technology

Preface

Dear reader,

Hereby, I present my master thesis, which is the final deliverable for completing the master program Engineering and Policy Analysis. For the past few months, I have been reading, analysing, and writing to finalise this thesis to obtain my master degree at Delft University of Technology. During my studies, I always was interested in topics related to sustainability and the built environment, which resulted in researching energy consumer preferences regarding the adoption of sustainable residential heating technologies.

As an expression of my gratitude, all the people who supported me during the research process are thanked. Especially, because completing this process alone was extra challenging during the turbulent times. Therefore, your support meant even more.

First, I want to thank the members of my graduation committee for all the feedback, advice and quick responses to my answers. Your guidance really helped me to find the right focus and to streamline the research process. Emile, I would like to thank you for linking my personal interest to this specific research topic at the Energy Transition Lab. Your knowledge regarding the Dutch energy transition and experience in guiding a master thesis student helped me a lot. Eric, thank you for sharing your extensive knowledge about stated choice modelling. At the start, I was not known with this method but your contributions really helped me to deal with complex parts of the process and improve my thesis. Gerdien, I want to thank you for the fresh perspective that you provided during the meetings. Your expertise as a climate psychologist made it easier for me to empathise with the Dutch energy consumer. Kristel, you were the first person I could turn to for quick answers to my specific questions (also during the late hours before a deadline). You spent a lot of time helping me, which is much appreciated.

Second, I would like to thank the respondents for filling in the survey, providing feedback, and stating interesting insights. The short time you invested in my research is ultimately of great value.

Third, a special thanks to my friends and family for helping me during the process by discussing the topic and providing mental support. You kept me motivated, which encouraged me to achieve the ultimate goal. Lastly, an extra special thanks, to Isabelle and Cynthia for reviewing parts of my thesis and providing useful contributions.

Ruben van der Ende,

Delft, April 2021

Summary

Climate change and global warming are some of the greatest challenges the world is currently facing. This challenge has structural impacts on the natural environment as well as on human well-being. As a response to the concerns regarding climate change, the Netherlands started a renewable energy transition. Nevertheless, the realisation of the Dutch energy transition is far from being achieved. Changes in energy behaviour such as the adoption of energy-efficient technologies will help to achieve the Dutch energy transition goals. Businesses and policymakers in the energy sector can accelerate this process. To do so it is vital for them to know the preferences of the energy consumers.

Stated choice experiments are a useful method to measure choice behaviour and consumer preferences. The method uses experiments with hypothetical choice situations in which the respondents are asked to choose between multiple options. However, it is the question of whether this method is useful for measuring energy consumer preferences. Prior academic research showed that energy consumer behaviour strongly depends on situational and contextual factors. Context-dependent stated choice experiments can serve as a solution because they include a stated choice context related to the choice situations. In this research, the contexts will describe and explain the possible future scenarios of the Dutch energy transition. Therefore, choice behaviour regarding sustainable energy technologies can be measured in a way that it stays valid over time and that it is applicable within future scenarios.

However, this method is not widely applied within the energy domain. Therefore, knowledge is lacking on how the dynamic and uncertain future scenarios of energy transitions can be used as choice context within context-dependent stated choice experiments. To fill this knowledge gap, a context-dependent stated choice experiment accompanied with various future scenarios of the Dutch energy transition is performed in this research. In particular, the experiment measures energy consumer preferences related to the adoption of sustainable heating technologies. The focus of this thesis research is on heating because sustainable heating provision is a significant factor in achieving the Dutch climate goals. All in all, the determination of the energy consumers preferences and the future contexts of the Dutch energy transition within this research is represented by the following research question:

What are the energy consumer preferences regarding the adoption of sustainable residential heating technologies and how are these related to future contexts of the Dutch energy transition?

Methodology

A literature study is performed to find which contexts influence the adoption of sustainable heating alternatives. These contexts are found by analysing contexts that influence the future of energy transitions as well as the Dutch energy transition in particular. The literature shows two main categories of contextual factors that are influential to the future of Dutch residential heating. These two being, social interactions between energy consumers and temporal contexts. These categories are translated into "Penetration rate" and "Urgency of the Dutch energy transition" and serve as context variables for the stated choice experiment. The experiment is executed in the form of an online survey. It measures the preferences of Dutch energy consumers regarding the sustainable heating alternatives (hybrid heat pump, all-electrical heat pump, and district heating) and asks to compare this choice with a currently used heating technology (base alternative). Furthermore, the survey measured user experiences and socio-demographics. Overall, this led to a data set of 95 responses, which is the input of a Multinomial Logit Model (MNL) that estimates the choice behaviour of the respondents. After which, a scenario analysis is performed to explore the choice behaviour of the Dutch energy consumers within various future scenarios.

Results

The research results showed that energy consumers prefer sustainable alternatives over the current situation. These preferences are strengthened within scenarios with a high penetration rate and a high sense of urgency. Next to these context variables, the technology characteristics are most influential for the choice behaviour. Particularly, the costs related to the sustainable heating technologies are important. The higher the costs, the more the energy consumers tend to stick to natural gas-based solutions and vice versa. Looking at the technology types, all-electrical heat pumps are the preferred sustainable heating alternative while district heating is the least favourable. The effects of the socio-demographics showed that none of these variables declare the differences in technology type preferences within the sample. Energy consumers that fit in the age group of 18-35 or 51-65 are most willing to adopt a sustainable heating alternative. While looking at the relevance, the socio-demographics have a bigger influence on the choice behaviour than the context variables, which indicates that personal situations are seen as more important than the overall choice context. Lastly, the scenario analysis results show that the main dilemma that the energy consumers face is choosing whether to go for a sustainable alternative or not. While the exact typing of a sustainable technology is less important. All in all, the scenarios indicate that large-scale sustainable technology adoption can be achieved by improving the technical characteristics of the sustainable alternatives and by increasing the sense of urgency of the Dutch energy transition.

Research limitations

The research is accompanied by a few limitations. The main limitation is the unrepresentativeness of the sample combined with the significant influence of the socio-demographics on the choice behaviour of the energy consumers. Therefore, the findings do not represent the choice behaviour of the Dutch population in full. Particularly, because low educated, lower-income and older persons are under-represented within the sample. The consequence of this limitation is that the findings could be biased or lead to a distorted view. Therefore, the preferences of the sample for sustainable heating technologies are likely to be less present in the Dutch society as a whole.

Policy recommendations

Based on the results, the following recommendations were composed for policymakers that want to stimulate the adoption of sustainable heating technologies: (1) Support the innovation of the sustainable alternatives by entering into a partnership with specialised companies and research groups. This will improve the technology performances and cause cost reductions, which will accelerate technology adoption. (2) Emphasise the sense of urgency of the Dutch energy transition. This can be done by starting a national promotion campaign regarding the consequences of climate change. This strategy optimises the sense of urgency, which increases sustainable technology adoption.

Future research recommendations

Lastly, the following main recommendations for future research are given: (1) Perform an experiment whereby the sample is representative for the Dutch population to make the interpretations directly applicable. This can be achieved by increasing the sample size and by monitoring the sample during the distribution process to approach under-represented people. (2) Implement socio-demographic questions about homeownership to test whether homeowners are more likely to adopt sustainable heating alternatives. These outcomes are especially important for the Dutch government because it determines the efficiency of their strategies to encourage energy consumers to adopt. (3) Apply an incremental approach to test the influential contexts and attributes regarding the adoption of sustainable heating technologies. As it is impossible to test them all together in one experiment, conducting smaller experiments is advised. The significant outcomes could then be merged into one extensive experiment.

Contents

List of Figures

List of Tables

List of abbreviations

Abbreviations	**Meaning**
ASC	Alternative specific constant
DCM	Discrete choice model
LL	Log of likelihood
LRS	Likelihood Ratio Statistic
ML	Mixed Logit
MNL	Multinomial Logit Model
RUM	Random Utility Maximization
RP	Revealed Preference
SP	Stated Preference
TAM	Technology Acceptance Model

1 Introduction

Climate change and global warming are some of the greatest challenges the world is currently facing. The fundamental increase of global warming is the effect of human and industrial activities over the past 200 years and strengthens climate change dramatically (Howard-Grenville, Buckle, Hoskins & George, 2014). This results in severe and potential irreversible disturbances such as threatened ecosystems, sea-level rise, food scarcity and extreme weather conditions (IPCC, 2014). Overall, climate change has structural impacts on the natural environment as well as on human well-being (Parry, Canziani, Palutikhof, Van der Linden & Hanson, 2007).

As a response 195 countries signed the Paris agreement which is a global action plan that deals with the impacts of climate change by limiting global warming below 2.0 °C ("Paris Agreement", n.d.). Furthermore, each of these countries formulated national strategies to tackle climate concerns. For example, the Netherlands stated two national goals regarding climate mitigation. First, based on their national climate agreement, the Dutch government stated the goal of 49% reduction of greenhouse emissions in 2030 ("Klimaatakkoord", 2019). Second, based on their national climate law, they aimed to reduce 95% of greenhouse emissions by 2050 (Scheepers, Faaij & Van den Brink, 2020). Both goals are compared to the greenhouse emissions of 1990 and form an important step for the Dutch energy transition. The first sign of an energy transition within the Dutch energy debate was after the introduction of the National Environmental Policy Plan in 2001. This plan was introduced due to concerns about the scarcity of fossil fuels and the effects of climate change (Bosman, Loorbach, Frantzeskaki & Pistorius, 2014). The plan is based on transition management, which is a governance approach for sustainability (Loorbach, 2007; Rotmans, Kemp & Van Asselt, 2001). The Dutch energy system integrally implemented this approach as the main driver for their energy transition (Kern & Smith, 2008; Loorbach, Van der Brugge & Taanman, 2008).

1.1 Problem description

The realisation of a national energy transition for sustainability is far from being achieved in the Netherlands. Currently, only 8.6% of the Dutch energy consumption is produced by renewable energy sources (CBS, 2020), which indicates that the Netherlands is lagging compared to other European countries (Eurostat, 2021). In general, for the improvement of a sustainable energy transition, a wide range of changes in energy behaviour is needed (Stern, 1999). The quality of the environment heavily depends on human behaviour and the encouragement of pro-environmental behaviour and lifestyles are essential for reducing its environmental impact (Steg & Vlek, 2009; Thøgersen, 2005). The behavioural changes that are needed include the adoption of energy-efficient technologies, investments in the energy efficiency of buildings, and changes in energy use behaviour. (Steg, Perlaviciute & Van der Werff, 2015).

However, to reach behavioural changes, such as the adoption of sustainable energy technologies, the preferences of the consumers need to be known. Innovative sustainable technologies usually lack widespread market penetration, which is caused by the characteristics of the technologies as well as their business cases. Therefore, knowledge regarding consumer preferences is important since it optimises the business cases for marketing strategies of manufacturers as well as promotion policies of governments (Liao, Molin, Timmermans & Van Wee, 2019). Overall, consumer research can help businesses and policymakers to understand energy consumer behaviour. They can use their expertise to increases sustainable technology adoption, which then serves as a solution to environmental policy problems (Stern, 1999).

1.2 Academic knowledge gap

Stated choice experiments are a useful method to measure choice behaviour and consumer preferences. The method uses experiments with hypothetical choice situations in which the respondents choose between multiple alternatives. These are described by attributes in which each option contains different values. The chosen option is seen as the alternative that best matches the preference of the respondent (Causade, de Dios Ortúzar, Rizzi & Hensher, 2005). As advantage, the method has the strength to single out the valuation of particular attributes (Sagebiel, Müller & Rommel, 2014). Furthermore, the method allows designs with much variation in the attributes, which enables the evaluation of preferences for products and services that are not available in the market yet (Train, 2009; Beelaerts van Blokland, 2008). Therefore, stated choice experiments is now an accepted approach for measuring consumer preferences and is applied in various fields such as transport, health economics, and market research (Louviere, Hensher & Swait, 2000).

However, it is the question of whether this method is useful for measuring energy consumer preferences. Prior academic research showed that energy consumer behaviour strongly depends on situational and contextual factors (Black, Stern & Elworth, 1985; Steg et al., 2015; Steg & Vlek, 2009: Stern, 1999; Thøgersen, 2005). The future situations of energy transitions are uncertain and dynamic, which makes it difficult to measure choice behaviour and preferences regarding sustainable energy technologies. The uncertainties in foreseeing future conditions are caused by the dynamics of the transition and result in inaccurate energy forecasts (Utikar & Scott, 2006). Furthermore, the downside of stated choice experiments is that the measured preferences are only valid for the stated hypothetical choice situation within the experiment. When the choice situation changes, the preferences will change as well, which conflicts with the dynamic nature of energy transitions. This complicates the ability to measure choice behaviour regarding sustainable energy technologies in a way that it stays valid over time and that it is applicable within future scenarios.

Context-dependent stated choice experiments could provide a solution for measuring consumer preferences within future scenarios of energy transitions. Context-dependent stated choice experiments are a specific type of stated choice experiments in which the respondents make discrete choices based on the attributes related to the alternatives given a stated context. The contexts are external circumstances or effects that are not directly linked to the alternatives of the choice experiment. Therefore, the contexts are different from the attributes of the alternatives. Altogether the contexts form a scenario that influences the decision-making process (Oppewal & Timmermans, 1991). For example, the weather or trip purpose are contextual factors that may influence decision-making related to transport mode choice (Molin & Timmermans, 2010). In this research, the contexts will describe and explain the possible future scenarios of energy transitions. The outcomes of such experiments can be used to estimate the strength of the effects that attributes and contexts have on preferences for the alternatives. With such insights, businesses and policymakers can respond and anticipate to the effects that attributes and context have on consumer preferences. As mentioned earlier, this could improve business cases and promotion policies that support sustainable technology adoption.

Nevertheless, to the best knowledge of the researcher, this method is not widely applied within the energy domain. Therefore, knowledge is lacking on how the dynamic and uncertain future scenarios of energy transitions can be used as choice context within context-dependent stated choice experiments. To fill this knowledge gap, a context-dependent stated choice experiment related to the adoption of sustainable energy technologies is performed in this research. For convenience, the context-dependent stated choice experiment is called "stated choice experiment" for the rest of this research. The contribution of this research is to apply dynamic future contexts within stated choice experiments related to energy transitions by measuring consumer preferences in various future scenarios. Furthermore, insights regarding the influences of several contexts on preferences related to sustainable energy technologies are gained, which produce preferences that stay valid for different future scenarios. These insights are important since they will determine the preferences of the alternatives and strengthen the level of adoption, which determines the success of energy transitions.

1.3 Research scope: Dutch residential heating alternatives

In this chapter, the focus points of the research are elaborated. First, this research focuses on the Dutch energy transition because of its interesting policy approach. As mentioned in the first paragraphs, the Netherlands started their transition due to climate concerns and it is based on a governance approach for sustainability (Loorbach, 2007; Rotmans et al., 2001). The approach entails innovation and fundamental change that leads to a more sustainable energy system. The approach is focused on transitional change, bottom-up processes and involvement of non-state actors within the process. The Dutch energy transition is seen as the basis of an overall government approach for tackling climate change, which results in similar approaches in other countries (Kemp, 2011).

Second, this research focuses on the preferences for sustainable energy technologies because they facilitate energy transitions by improving energy behaviour and help to achieve energy-related goals (Essletzbichler, 2012). In this research, the adoption of sustainable residential heating technologies is chosen as a focus point of the Dutch energy transition because the Dutch heating regime needs to undergo significant changes in the coming years. Changes are necessary to achieve the EU climate target of 80% reduction in energy consumption of buildings by 2050. However, the Dutch government is even more ambitious by aiming to achieve an energy-neutral building stock at the same time (Olonscheck, 2015). The emphasis on residential heating technologies is based on the fact that residential heating is responsible for 30% of the energy consumption within Europe (Stieß & Dunkelberg, 2013) and 15% within the Netherlands (Klip, 2017). While by adopting sustainable heating alternatives 60 % of the Dutch energy demand can be reduced (KVGN, 2017).

Lastly, this research focuses on sustainable heating technologies that have the most adoption potential to support the Dutch energy transition. Therefore, the focus is on hybrid heat pumps, all-electrical heat pumps and district heating. Hybrid heat pumps are seen as a transition technique for the existing housing stock since these houses first need adequate insulation measures before a more sustainable heating technology is implemented (Heynen, Groot, Vrisekoop, Witkop & Kolenbrander, 2018). The other two technologies are seen as more long term solutions since they include large-scale modifications and have the most potential to become carbon neutral. The implementation of these alternatives is recommended for strategies related to Dutch municipal heating visions (ECW, n.d.; Klip, 2017; NPRES, 2020).

1.4 Research objectives and research questions

The objective of this research is to fill the identified knowledge gap by realising the research contribution. As stated in Chapter 1.2, this implies the application of dynamic future contexts within stated choice experiments related to the Dutch energy transition. The research objective is achieved by performing a stated choice experiment to measure the preferences of Dutch energy consumers for adopting sustainable heating technologies within various future contexts, which produces preferences that stay valid over time. To achieve the research objective, the research contribution is translated into the following main research question:

What are the energy consumer preferences regarding the adoption of sustainable residential heating technologies and how are these related to future contexts of the Dutch energy transition?

To help answering the main research question, the following sub-research questions are formulated:

1. What are the influential contexts that form the future of Dutch residential heating?
    a) Which contexts are influential for energy transitions in general?
    b) Which contexts are influential for the Dutch energy transition?
2. To what extent do Dutch energy consumers prefer the adoption of sustainable residential heating alternatives over non-sustainable heating techniques and how are these preferences related to the stated choice contexts and technology attributes?
3. What is the effect of socio-demographic characteristics on the energy consumer preferences for sustainable residential heating alternatives?

1.5 Relevance of research

The research contribution, as described in Chapter 1.2, is associated with scientific as well as social relevance. First, this research has scientific relevance because context-dependent stated choice experiments are methodologically new to analyse consumer preferences towards energy-related products and services. Therefore, this research contributes to the literature by determining influential contexts related to the energy domain. Furthermore, by performing a context-dependent stated choice experiment, this study provides insights related to the application of Dutch energy transition contexts within choice experiments. These insights will support the production of energy consumer preferences that stay valid and applicable within different future scenarios.

Second, social relevance is present since choice behaviour and preferences related to sustainable heating technologies are measured. As mentioned earlier, consumer preferences can be used to understand energy consumer behaviour, which supports business cases and stimulation policies related to sustainable energy alternatives. This improves sustainable technology adoption and therefore stimulates the implementation of energy transitions.

Lastly, this research is relevant to the Engineering and Policy Analysis master program. It relates to the program, due to the interfaces with several sustainable development goals, which can be seen as grand challenges that are caused by climate change. This research results in insights that improve the validity of stated preferences data which can be used for fitting policies that strengthen decision-making.

1.6 Thesis structure

The remainder of the report is elaborated in multiple chapters and contains the following structure: In Chapter 2, the research approach and corresponding methods are explained. In Chapter 3, a literature review is executed to determine the influential contexts for the adoption of sustainable heating technologies, which serve as input for the experimental design. In Chapter 4, the design of the stated choice experiment and its corresponding survey is constructed. The results are given by providing descriptive statistics in Chapter 5 as well as model estimations in Chapter 6. Furthermore, in Chapter 7, the results are applied in a scenario analysis to explore the choice behaviour of the Dutch energy consumers within various future scenarios of the Dutch energy transition. Based on the results, Chapter 8 states the conclusions and discusses the research outcomes. Lastly, in Chapter 9, the limitations of the research are elaborated upon. Policy recommendations and recommendations for further academic research are given to tackle the limitations.

2 Methodology

This chapter describes the methods that are used to answer the previously stated research questions. Namely, a literature study and discrete choice analysis. In Chapter 2.1, the purpose and application of the literature study are explained. The discrete choice analysis consists of two parts that have their own contribution to the method. First, a stated choice experiment is used for collecting the energy consumer preferences related to the chosen sustainable residential heating alternatives. In Chapter 2.2.1, the theory and steps related to the stated choice experiment are elaborated. Second, as data analysis, a discrete choice model (DCM) is estimated to find the preferences and corresponding trade-offs related to the residential heating alternatives. In Chapter 2.2.2, the theory behind discrete choice modelling is given.

2.1 Literature study

Within this research, a stated choice experiment is performed whereby respondents choose between sustainable residential heating technologies given a stated context. However, to measure the preferences, the relevant contexts related to the adoption of these technologies need to be known. The literature study serves as a qualitative method that reviews the literature to identify the relevant contexts that influence choice behaviour related to the chosen residential heating alternatives. However, as mentioned in Chapter 1.5, stated choice experiments have not been used to analyse consumer preferences within the energy domain. Therefore, an extensive classification of relevant energy contexts is needed to find the contexts related to the adoption of sustainable residential heating alternatives. The classification is formed by reviewing literature that describes contexts that influence the future of energy transitions, Dutch energy transition in particular, and the adoption of sustainable heating technologies.

The review is performed by using the ”snowball method”. This method uses key papers as a starting point and finds further relevant literature by scanning their citations and bibliographies. The relevant literature is found by using Google Scholar and the TU Delft repository as online databases. Further explanation and the outcome of the literature study can be found in Chapter 3.

2.2 Discrete choice analysis

To gain insights into energy consumer preferences related to the sustainable residential heating technologies, discrete choice analysis is used. In prior research, the method is used because it includes disaggregating models. This characteristic means that the method is capable of measuring the choice behaviour of individuals (Ben-Akiva & Bierlaire, 1999). Due to this characteristic, the method is used within this research to analyse energy consumer preferences. First, as data input for the discrete choice analysis, Chapter 2.2.1 describes how state choice experiments are executed as a data-gathering technique. Second, Chapter 2.2.2 explains how energy consumer preferences are analysed by using discrete choice modelling.

2.2.1 Stated choice experiment for data collection

In general, (stated) choice experiments can be used as a data-gathering technique and serve as input for the discrete choice model. Whether the choice experiment is stated or not depends on the data type that is used for the discrete choice analysis. In general, two different types of data can be used within discrete choice models. Namely, revealed preference (RP) data and stated preference (SP) data. The two data types differ mostly in terms of applicability. RP data is collected in surveys whereby individuals make actual choices and therefore reveal preferences in real-world situations. RP data reflects actual choices, but such data is limited to existing or historically existed choice situations. SP data is collected by respondents that make discrete choices in hypothetical choice situations. An advantage that SP data has over RP data is that it allows designs with much variation in the attributes, which enables the evaluation of preferences for products and services that are not available in the market yet (Train, 2003; Beelaerts van Blokland, 2008). However, SP data also has limitations. Namely, SP data could be less valid due to the discrepancy between the hypothetical and real-world behaviour. What the respondents say could be different from what they would do if the hypothetical situation was real, this phenomenon is also known as the hypothetical bias (Train, 2009).

Within this research, energy consumer preferences and their relation with future scenarios of the Dutch energy transition are measured. As stated by Train (2009), RP data is not available within new or future situations. Therefore, the preferences can not be gathered as RP data, which means that SP data is more applicable and will be used within this research. Due to this decision, a stated choice experiment is performed to measure choice behaviour related to sustainable heating technologies within hypothetical choice scenarios. The design of the stated choice experiment is elaborated in Chapter 4. The chosen design is based on the common types of choice experiments and their experimental designs, which are stated in the coming two sections.

Context-dependent- vs stated choice experiment

Within this research, two types of stated choice experiments are distinguished. Namely, stated choice experiments and context-dependent stated choice experiments. The main difference between the two types is the inclusion of contexts variables, which are influential for the decision-making process. Within stated choice experiments, the utility functions contain the main effects caused by the attributes of the alternatives and the interaction effects among attributes (Oppewal & Timmermans, 1991). However, as mentioned in Chapter 1.2 and Chapter 2.2.1, hypothetical choice situations are given to gather SP data. Therefore, the respondents need to be informed of the contexts since they describe the circumstances of the choice situation (Molin, 2019e). Within a DCM, the context variables are included as interaction effects that may affect constants and parameters. If the interaction coefficient is significant, then the parameter that has an interaction with the context variable is significantly affected by the context variable. Mostly, contexts variables are categorical and therefore effect coded. This results in an estimated main constant that includes the derived utility across all contexts (Molin & Timmermans, 2010).

Experimental design types

Within this section, several types of experimental designs are explained and one is chosen as the method to construct the choice sets. The first decision to choose a design type is whether a full factorial or fractional factorial design is applied. A design is full factorial if all possible combinations of all selected attribute levels are constructed. The advantage of this design is its simplicity and the ability to estimate all main and all interaction effects. However, the main disadvantage is that the design results in too many choice set combinations. The total amount of alternatives is given by L^N, whereby L is the number of levels and N is the number of attributes (Molin, 2019a). Given the attributes and levels, as can be seen in Chapter 4.1.2, the use of a full factorial design would result in $3^5 = 243$ choice sets that are proposed to the respondent to conduct the stated choice experiment. Therefore, a full factorial design is not suitable for this experiment, which results in the application of a fractional factorial design. This type of design is a fraction of a full factorial design and therefore, reduces the number of choice sets. The fractions can be calculated with the software package Ngene, which is elaborated and applied in Chapter 4.1.3 and Appendix A.

The two most common types of fractional factorial designs are orthogonal fractional factorial designs and efficient designs. A design is orthogonal when there is attribute level balance and when all parameters are independently estimable (Choicemetrics, 2018). Orthogonal designs are characterised by zero correlation between attributes, which results in low standard errors and reliable parameters. Furthermore, it ensures attribute level balance, which means that all attribute levels are observed an equal number of times. The disadvantage of orthogonal designs is the possible occurrence of dominant alternatives, which would result in no revelations regarding information about trade-offs. Therefore, dominant choice sets should be removed. However, this reduces the efficiency of designs by introducing correlations (Molin, 2019c). Therefore, efficient designs can be used. These designs minimize the standard errors of parameters, which helps to avoid dominant alternatives, could increase the reliability of parameters and may reduce the number of choice sets. Efficient designs are based on prior information related to the parameters, which should be obtained via a pilot study or via existing parameter values from comparable literature (Molin, 2019c). However, pilot studies are too time-consuming for this thesis project. Furthermore, context-dependent stated choice experiments related to the adoption of sustainable heating technologies do not exist yet. This hinders the ability to gather reliable prior information, which results in biased parameters. Therefore, an orthogonal fractional factorial design is used within this research.

Online survey for data-gathering

As mentioned at the beginning of this chapter, SP data is collected by using a stated choice experiment that serves as input for the discrete choice analysis. This data-gathering technique is translated into an online survey, which contains the stated choice experiment, questions about the user experience related to the experiment, and socio-demographic questions. Each of the three parts serves a different goal. First, the stated choice experiment contains the choice sets to measure the energy consumer preferences related to the sustainable residential heating alternatives. Second, the questions about the experience of the respondents are held to test the validity of the results and to improve the research method related to applications in the energy domain. Third, the socio-demographic questions are used to test whether the sample is representative of the Dutch population and to test whether there is coherence between the preferences and socio-demographic characteristics. Lastly, the selection, characteristics and design of these four aspects of the online survey are elaborated in Chapter 4 and analysed in Chapter 5 and Chapter 6.

2.2.2 Discrete choice modelling for data analysis

Discrete choice modelling is used to analyse the data collected by the stated choice experiment. This method contains DCMs that are able to estimate the choice behaviour of individuals. The features of DCMs are based upon a framework that entails a set of four general assumptions (Ben-Akiva & Bierlaire, 1999). First, the model is disaggregated, which means that there is an individual *decision-maker* who shows his preferences by making a choice or making a decision. Within this research, the decision-makers are the energy consumers. Second, the decision-maker can choose from a choice set, which is formed by several *available alternatives*. According to Train (2009), the choice set needs to include three specific characteristics. Namely, a choice set should contain all possible alternatives (*exhaustive*) whereby the alternatives are *mutually exclusive* and *finite*. This means that only one alternative can be chosen and that the available alternative can be counted by the researcher. Within this study, the choice of a sustainable residential heating alternative is an example of a choice from a discrete choice set. Third, each alternative is characterised by its *attributes*, which influence the choice of the decision-maker. Fourth, a *decision rule* defines the process that a decision-maker uses to evaluate and choose an alternative. Most DCMs follow the concept of random utility maximisation, this concept is explained in the next section.

Random Utility Maximization Theory

As mentioned before, DCMs are commonly based on the assumption that each alternative is captured by a utility value whereby the decision-maker selects the alternative with the highest utility. In other words, utility-maximizing behaviour occurs. Models that follow this assumption are based on the Random Utility Maximization (RUM) theory and are called RUM models. RUM models can be explained in the following way (Ben-Akiva & Bierlaire, 1999; Train, 2009). A decision-maker (n) is choosing between two alternatives (i,j). Per alternative, the decision-maker is receiving some level of utility (U_n) and the decision-maker chooses the alternative with the higher utility. Equation 2.1 is showing the situation when alternative i is chosen within this model.

$$U_{ni} > U_{nj} \quad \forall j \neq i \quad (2.1)$$

However, the utility is known for the decision-maker, but not for the researcher. The researcher only observes the decisions related to the alternatives and attributes as stated in the choice set, which causes incomplete information. Therefore, uncertainty is included in the model as well. According to Manski (1977), four types of uncertainty can occur. Namely, unobserved alternative attributes, unobserved individual characteristics, measurement errors, and proxy / instrumental variables. To capture the uncertainty, the total utility consists of an observed factor *systematic utility* and an unobserved *error term*, which is seen as a random term. Equation 2.2 is stating the utility function for alternative j with the systematic utility (V_j) and unobserved error term (ε_j).

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (2.2)$$

The systematic utility of alternative j is calculated by the sum of multiplying the weight parameter of attribute m (β_m) with its attribute level (X_{jm}). This is described in Equation 2.3. Thereafter, the total utility of alternative j (U_j) is calculated by the summation of the observed utility and the error term related to all the attributes as stated in Equation 2.4 (Chorus, 2019).

$$V_j = \sum_m \beta_m X_{jm} \quad (2.3)$$

$$U_{jn} = \sum_m \beta_m X_{jm} + \varepsilon_{nj} \quad (2.4)$$

Lastly, an alternative specific constant (ASC) could be implemented in the utility function. The ASC includes the average utility of an alternative generated by all factors that are not included in the model. The ASC is the utility when all attribute values of an alternative are set to zero. As only the differences between utilities are relevant, the base alternative has an ASC of zero (Ben-Akiva & Bierlaire; Molin, 2019b). The ASC can only be estimated with labelled alternatives or when unlabeled alternatives are compared with a base alternative. When ASCs are present, the utility function is like Equation 2.5.

$$U_{jn} = ASC + \sum_m \beta_m X_{jm} + \varepsilon_{nj} \quad (2.5)$$

Multinomial Logit Model

The difference in assumptions related to the random part of utility has created several DCMs based on specifications of the unobserved factors The easiest and widely used DCM is the Multinomial Logit Model (MNL). The model is popular since the choice probabilities are in a closed form and easy to interpret (Train, 2009). The MNL is based on the assumption that the error terms are assigned independent and uncorrelated over alternatives (Independent and Identically Distributed (IID assumption)), but have an identical variance for all alternatives. The assumption provides convenience related to the choice probability which is also an advantage of the model. However, the model also has limitations. MNL models are not capable of capturing correlations within alternatives that have similarities, which are known as nesting effects. Nevertheless, the MNL model is used within this study as DCM for data analysis, due to its simplicity, wide use, and closed-form choice probabilities. All in all, the model formulates the probability (P) an alternative (i) is chosen given a choice set of alternatives (J) with j alternatives. Equation 2.6 is showing the probability function of the MNL model.

$$P(i) = \frac{exp(V_i)}{\sum_{j=1}^{J} exp(V_j)} \quad (2.6)$$

Model performance

When a MNL model is estimated, the model performance (also known as the goodness of fit) can be measured by testing whether the MNL model fits the data. The estimated parameters are based on the Maximum Likelihood-principle, which means that a set of parameters are found that make the data most likely. However, the likelihood of estimates can become very small (nearly zero), no matter the size of the data set. Therefore, the log of likelihood (LL) is used. This results in a very large and negative number that indicates the model performance. The closer the LL is to zero, the better the model performs and the more accurate the estimates are (Chorus, 2019). To calculate the goodness of fit, the LL can be used in two different ways.

The first way to use the LL to assess a model's fit is by calculating McFadden's rho-squared (ρ^2). The rho-squared is calculated by including the log-likelihood function of the model with the estimated parameters (LL_β) and the log-likelihood function of the null model (LL_0) (Equation 2.7). The null-model is a model whereby all parameters/ betas are zero. The value of ρ^2 determines a percentage of initial uncertainty as explained by the model (Chorus, 2019).

$$\rho^2 = 1 - \frac{LL_\beta}{LL_0} \quad (2.7)$$

The second way to gain an indication about the model performance is to compare the model fit between two separate models. This can be done via the likelihood ratio test. The test is executed by calculating the Likelihood Ratio Statistic (LRS), which is done by multiplying the differences of the LL's of the models with minus two (as stated in Equation 2.8). After the LRS value is known, the difference in degrees of freedom needs to be known. This can be done by measuring the difference in parameters between the two models. The degrees of freedom are looked up in a chi-square table (they indicate the rows) and the threshold value can be seen for the preferred significance level. If the LRS is bigger than the threshold value, then model B is fitting the data better than model A. However, this test can only be executed for nested models. This is the case when one model is a subset of the other (which has more estimable parameters) (Chorus, 2019).

$$LRS = -2 * (LL_A - LL_B) \quad (2.8)$$

3 Literature review

In this chapter, an extensive literature review is held to find the contextual factors that are influential for the adoption of sustainable residential heating technologies. Therefore, the literature review consists of influential contexts related to energy transitions in general (Chapter 3.1.1), the Dutch energy transition in particular (Chapter 3.1.2), and the adoption of sustainable heating technologies (Chapter 3.1.3). All in all, the conclusions from the literature review are stated in Chapter 3.2 and will answer the following research sub-questions:

What are the influential contexts that form the future of Dutch residential heating?

a) Which contexts are influential for energy transitions in general?

b) Which contexts are influential for the Dutch energy transition?

3.1 Determination of influential contexts

In this chapter, the influential contexts for the adoption of the chosen heating alternatives are determined. However, to facilitate this determination the definition of the nature of a context is selected. This definition explains what is seen as a context within this research and what is not. As mentioned in Chapter 1.2, contexts are seen as external effects that together define the setting that influences the decision-making process (Oppewal & Timmermans, 1991). This view regarding contexts is also supported by Thomadsen et al. (2018), who stated that ”Contexts are factors that have the potential to shift the choice outcome by altering the process by which the decision is made”. In other words, within this research, the contexts will describe the future scenarios of the Dutch energy transition. These scenarios describe the stated choice situations and potentially influence the choice behaviour of the respondents.

The influential contexts for this research are gained by reviewing literature regarding three levels of energy transitions. Namely, contextual factors that influence energy transitions in general, the Dutch energy transition, and the adoption of sustainable heating alternatives within the Netherlands. The determination is performed step-by-step, whereby the scope narrows per level. Furthermore, from Chapter 3.1.1 onwards, the influential contexts are illustrated as *italic text*. The last step includes choosing the specific choice contexts for the stated choice experiment of this research. These contexts include and summarise influential factors for the future of Dutch residential heating.

3.1.1 Influential contexts for energy transitions

In this chapter, the influential contexts for the realisation of an energy transition are illustrated. The determination of these contexts is important because it defines general factors that influence the global energy future as well as specific cases, such as the Dutch energy transition. The contexts are gained by reviewing literature regarding situational and contextual variables that are general and applicable on a global scale including climate change, geopolitics, and sustainable consumer behaviour.

Climate change and future energy resources

Climate change concerns and the *depletion of fossil fuels* started a transformation of energy systems on a global scale. To avoid risks for the natural environment and humans, a shift from fossil fuels to a more sustainable pathway is needed (Creutzig et al., 2014; Kemp, 2011). Luckily, such shifts to low-carbon economies by entering new climate regimes have been emphasised internationally. Many countries stated the ambitions of mitigation climate change risks, which is proved by their involvement within the Kyoto protocol and Paris agreement (Chung & Kim, 2018). Overall, *climate change concerns* and the *depletion of fossil fuels* started the energy transitions of most nations, including their ambitious policies to achieve their climate goals by adopting a more sustainable energy regime (Kammermann & Dermont, 2018). Nevertheless, some *energy system values* such as low-cost energy and securing energy supply are important formal rules which can be challenging for the practicalities of the sustainable energy transitions (Parkhill, Demski, Butler, Spence & Pidgeon, 2013). Therefore, the challenge for the global energy systems is to find the right balance between their three main values: sustainability, security and affordability (Bosman et al., 2014).

Geopolitics

Scholten & Bosman (2016) stated that *geopolitics* can behave as implications for renewable energy systems and therefore serve as an important contextual factor for successful implementation of energy transitions. The causes of these implications are mainly geographical and technical characteristics of renewable energy systems. For example, the potential of renewable energy sources and the raw materials that are needed for sustainable technologies are not equally distributed around the world. Such characteristics result in geopolitical implications such as a fundamental change in power relations between producer and consumer countries, constraints of energy markets due to the size of electricity grids, and unbalanced energy prices due to fluctuations of renewable energy generation. Furthermore, Vakulchuk, Overland & Scholten (2020) reviewed the literature regarding the geopolitics of renewable energy and stated that renewable energy is likely to worsen geopolitical tensions regarding important raw materials and cybersecurity, which is influential for the outcomes of sustainable energy transitions.

Influential contexts on sustainable energy behaviour

Environmental quality depends on human behaviour patterns and underlying factors that are responsible for these behaviour patterns. As mentioned before, consumer behaviour is based on individual and contextual factors. Prior academic research confirms this for sustainable energy behaviour as well. With the detection of these contextual factors, policymakers could design interventions to improve environmental behaviour by removing the barriers of change which should solve environmental policy problems (Steg & Vlek, 2009; Stern, 1999). Several studies have focused on the empowerment and encouragement of environmental behaviour and lifestyles by analysing the underlying contextual factors that influence consumer behaviour. An elaboration of the influential contexts follows in the coming paragraphs.

First, Stern (2000) developed a conceptual framework that describes the causes of environmental behaviour. He stated that contextual forces form one of the major types of causes behind environmental behaviour. Including forces such as *interpersonal influences* (persuasion by others), *community expectations*, and various aspects of social, economic, and political context such as *oil prices*, *interest rates of financial markets*,*sensitivity of government to public pressure*.

Second, Testa, Cosic & Iraldo (2016) also stated that contextual factors are influential for energy behaviour by supporting pro-environmental attitudes. They expanded Stern's (2000) framework by emphasising the importance of another contextual factor. In particular, gaining *public support* by using information provision. They stated that the openness of society and the attitudes towards information sources strongly shaped environmental behaviour. Furthermore, trustworthy information has the ability to influence social norms and personal attitudes. For example, Darnall, Ponting & Vazquez-Brust (2012) found that consumers who have greater trust in information provided by governments, environmental NGOs, and friends are more likely to rely on eco-labels in their product purchases.

Third, Thøgersen (2005) stated in his research that consumers in the rich parts of the world often lack a sustainable lifestyle which is caused by constraints and limitations in the personal and external domain. He said that consumer policies can activate consumers for changing their lifestyles since these policies can tackle the contextual barriers. Within his article, he focused on *cultural meanings and norms* as an influential class of contextual constraints. Thøgersen stated that the way consumers see the world, also known as cultural lenses (Triandis, 1994), is determining choice behaviour. Furthermore, *Social values* play an important role within a culture since they define the rules in force and set a comparable standard that influences the behaviour of individuals (Larimer, Turner, Mallet & Geisner, 2004). The standard of comparison is also known as a descriptive norm (Cialdini, Reno, & Kallgren, 1990) which influences behaviour by encouraging that good outcomes are achievable (Wiener & Doescher, 1991) and by setting perceptions of social approval regarding certain behaviour (Neighbors, Larimer & Lewis, 2004). *Social values* are hard to change since they are intertwined with human behaviour. This is also the case for radical change to sustainable lifestyles because people are too used to unsustainable consumption practices, such as eating meat and owning big houses (Thøgersen, 2005).

Furthermore, the possible directions in which contextual factors can steer behaviour will be elaborated by using the research of Steg & Vlek (2009). They stated three directions in which contextual factors can steer. First, they can directly influence behaviour. For example, COVID-19 policies prohibit certain behaviour such as meeting in large groups. Second, the relationship between contextual factors and behaviour can be influenced by individual factors such as attitudes and norms. Third, contextual factors influence the relationship between individual factors and behaviour and vice versa. The strength of the contextual factors determines the effects of individual factors on behaviour, as mentioned by Stern (1999) as well. The stronger the presence and effects of contextual factors, the weaker the influence of individual factors on environmental behaviour.

All in all, the articles showed the following influential contextual factors which are essential for realising energy transitions in general: *climate change concerns*, *depletion of fossil fuels*, *energy system values*, *geopolitics*, *interpersonal influences*, *community expectations*, *oil prices*, *interest rates of financial markets*,*sensitivity of government to public pressure*, *public support*, *cultural meanings and norms*, and *social values*. However, it is the question whether these factors are also applicable for the Dutch energy transition. This will be investigated in the next sub chapter.

3.1.2 Influential contexts for the Dutch energy transition

In this chapter, the influential contexts for the Dutch energy transition will be elaborated. The overarching context of the Dutch energy transition is the general situation as stated in the introduction. However, an in-depth analysis regarding the influential contexts for the future of the Dutch energy transition is performed. By reviewing governmental and corporate future visions and strategies regarding the Dutch energy transition, the influential contexts that determine the outcomes of the transition within the Netherlands are found. The usefulness of these documents for reviewing the influential contexts lies in their extensive scenario descriptions. The scenarios descriptions are stating the possible outcomes of the Dutch energy transition, but more important the contextual influences on these outcomes. Therefore, an overview of all the influential contexts will be gained by focusing on the scenario descriptions within the future visions and strategies.

TNO's scenario description

The first document that is reviewed is TNO's scenario description for climate-neutral energy systems within the Netherlands (Scheepers, et al., 2020). Within their research, they composed two scenarios named ADAPT & TRANSFORM. The scenarios illustrate the systematical changes of the Dutch energy system that are needed for achieving the international goals of the Paris agreement as well as the national climate agreement goals. The time span of the proposed changes is between 2030 and 2050. Their analysis shows that the goal of greenhouse gas reduction can be achieved in both scenarios. Furthermore, the costs of the proposed energy system of both scenarios are lower compared to an energy system that is not climate neutral. Therefore, at first sight, the scenarios look the same. However, the scenarios are highly different regarding how the goals are achieved. The main difference is the degree *motivation of civilians and businesses* within the scenarios. Within the ADAPT scenario, the Netherlands builds on their current economic strengths and opts for maintaining their current lifestyle, but with the reduction of greenhouse gases in mind. However, within the TRANSFORM scenario, the Netherlands is willing to change its energy behaviour and switches to a sustainable economy that is less energy-intensive by using innovative energy technologies.

Before the execution of the scenario analysis, the input variables that define the contexts of the scenarios need to be known and quantified. They included variables which they assumed to be constant over time, such as *population growth*, *economic growth*, *energy demand* and *fossil fuel prices*. While other contextual factors are assumed to change over time and are different between the scenarios, such as *intrinsic motivation of civilians and businesses*, *public support*, *energy supply*, *government interference*, and *international cooperation*.

After performing the scenario analysis several predictions were made. First, appropriate energy policies can have a great influence on the energy transition. Innovation and implementation policies regarding sustainable energy technologies increase the level of innovation. This will result in accelerated cost reduction of such technologies and decrease the overall costs of the Dutch energy system. Furthermore, the availability of sustainable energy technologies can be supported by appropriate stimulation policies, participation processes and clear permit conditions. A high level of availability is desired because it minimises energy system costs. Second, even in case of difficulties regarding energy system changes or less positive *public support* regarding certain technologies, a climate-neutral energy system is feasible in both scenarios. Third, further investigation is needed to obtain technology development and to facilitate future implementation. Lastly, they included *geopolitics* and the *Europeanisation* as contextual factors since foreign developments and climate policies will influence the Dutch energy transition heavily. Verbong & Geels (2007) appointed the European influences as well and stated it as an extra dimension for the ongoing transition because the Dutch energy system is merging with the European electricity system.

Dutch regional energy strategies

The second source of future energy scenarios contains Dutch regional energy strategies. As an elaboration of the Paris agreement, the Dutch government composed their national climate agreement. This agreement is part of the Dutch climate policy and defined the national goal of halving the greenhouse gas emissions by 2030 compared to 1990 ("Klimaatakkoord", 2019). One of the appointments is the regional integration of national policies and goals. Each of the 30 Dutch energy regions has to define their energy strategy in which they illustrate their own energy choices. The regional energy strategy is applied by a collaboration of municipalities, water authorities, provinces, and network operators to achieve sustainable generation, storage, and energy savings which all need to be distributed and spatially fit within the region.

The contextual factors that influence the energy future of the regions are diverse since every region is different. However, some general contextual factors are mentioned in several strategies (Energieregio Rotterdam Den Haag, 2020; Schilling, Naber, & Schepers, 2019; Stuurgroep Energieregio Noord-Holland Zuid, 2020) and therefore are important for the future of the Dutch energy transition. The strategic choices of the regions are based on their *geographical and demographic characteristics*. Some examples of such characteristics are population density, present sector types, and surface distribution (urban area, agricultural, infrastructure, inland waterways, etc.). Furthermore, communication strategies are seen as important for creating *cooperation*, *participation*, *knowledge sharing*. Especially, *participation* is emphasised since it entails financial involvement as well as process involvement. These communication aspects are essential because they facilitate achieving regional energy strategies by influencing the *public support* regarding sustainable energy technologies.

All in all, the future visions, scenario descriptions, and regional energy strategies clearly showed the following contextual factors which are influential for the Dutch energy transition: *motivation of civilians and businesses*, *population growth*, *economic growth*, *energy demand*, *fossil fuel prices*, *public support*, *energy supply*, *government interference*, *international cooperation*, *Europeanisation*, *geographical and demographic characteristics*, *cooperation*, *participation*, and *knowledge sharing*. There is even some overlap of factors between the studies, which emphasises their importance. However, the focus of this research is especially on the future of Dutch residential heating. Therefore, it is tested whether these contexts are also influential for this specific part of the Dutch energy transition. All the influential contextual factors will be elaborated within the next section.

3.1.3 Influential contexts for residential heating

The previous sections stated the contextual factors that are influential for energy transitions and the Dutch energy transition in particular. In this chapter, the influential contextual factors for sustainable heating technologies will be elaborated. These contexts are obtained by reviewing future visions, scenario descriptions and academic literature regarding the future of Dutch residential heating. Altogether, they form the underlying factors that influence the future adoption of residential heating technologies. From these factors, two contextual factors are chosen as contexts for the design of the stated choice experiment. These two contexts are extensively described in terms of their linkage with the other determined contexts and (for implementation purposes) context levels are assigned.

Social influences

Despite the ambitious goals of the Dutch energy transition, TNO's scenario description for climate-neutral energy systems (Scheepers, et al., 2020) shows that there are enough cost-efficient alternatives to reduce the natural gas consumption in both scenarios by one third. They predicted that natural gas use in the built environment is replaced by residual heat from industries, heat pumps, electricity, hydrogen, and biomass. Electrification of heat supplies and the residual heat of industries is essential for making the built environment natural gas free since they could reduce natural gas use by approximately 30% and 50%. The importance of heat supply via regional residual heat and heat transfer via networks is also emphasised by the scenario description of The Hague's heat transition (Naber & Schepers, 2017).

However, the increasing use of residual heat from industries will burden the heat network. Furthermore, expanding and realising new heat networks can be difficult in practice, due to technical complications and social objections. The lack of *public support* could be caused by negative views regarding renewable heating alternatives, which is stated in academic research about public values in the UK. Electrical heating systems that should replace natural gas heating systems within houses were seen as "expensive, not controllable, non-responsive, and ineffective" (Butler, Parkhill & Pidgeon, 2013), while gas alternatives were judged as more favourable, effective, and reliable (Parkhill et al., 2013). According to the research from CE Delft (Rooijers & Kruit, 2018), the lack of *public support* within the Netherlands is mainly caused by the fact that energy consumers prefer natural gas heating since it is on average 1.000 euros cheaper per year per dwelling compared to climate-neutral heating alternatives.

The findings of these studies, as well as previously mentioned documents, emphasise the importance of the contextual factors that are related to interpersonal social interactions within the Dutch society. As stated before, the way society looks at certain sustainable alternatives is important for *public support* and is influenced by *social values*, *cultural meanings and norms*, and *motivations* regarding sustainable residential heating technologies. These factors will be transformed into a context from the perspective of an individual consumer, in order to use it within the context design of the stated choice experiment. Therefore, the *penetration rate* is implemented as the context within this research. This effect includes interpersonal interaction because the adoption of sustainable energy technologies by the individual consumer is stimulated by the adoption of others (Van de Kaa & de Vries, 2015). The social pressure related to the penetration rate will tend the individual consumer to adopt the same product, which increases the overall amount of usage (Leibenstein, 1950). Within this research, the penetration rate is linked to the experiences of others that have comparable housing conditions such as energy label and geographic location since these experiences are a better frame of reference for technology adoption. Therefore, this context is translated to the percentage of adoption by people that have comparable housing and housing characteristics. The levels of these contexts are based on the current residential penetration rate of the alternatives and the proposed rates to achieve the Dutch energy transition goals. Currently, approximately 120,000 all-electrical heat pumps are implemented and 400,000 houses are connected to district heating. This results in penetration rates of 1,5% and 5,1% (Boeters, 2020; CBS Statline, 2020). However, by 2030, the expected numbers are aimed at 1,200,000 all-electrical heat pumps as well as district heating connections, which results in a penetration rate of 15% (Boeters, 2020; Heynen et al., 2018). All in all, the context levels are set at 15% and 85%, which describes the expected numbers of 2030 and a hypothetical situation in 2050.

Urgency of the Dutch energy transition

After analysing the literature, it can be concluded that the influence of time or temporal contexts are a recurring theme for the future of sustainable residential heating technologies. This category of contexts is influential for the future of heating on several levels. First, on a global level due to climate change and its corresponding consequences. For example, the time is ticking for some small islands states due to sea level rises caused by global warming (Lewis, 1990). Furthermore, the Paris agreement is a global action plan with a temporal context, due to its corresponding deadlines related to climate mitigation and the *climate change concerns*. Second, on a European level, because of the transformation of global plans to the implementation of European climate targets and the *Europeanisation* related to the energy transitions of its federal states. Third, on the Dutch national level. As stated in the introduction, the Netherlands started their national energy transition based on the threats related to the scarcity of fossil fuels and the effects of climate change (Bosman et al., 2014). Furthermore, the Dutch government came up with the national climate agreement and corresponding regional energy strategies. All of these national climate goals and climate policies are related to the (national) *climate change concerns* and contain the same deadlines as the global and European action plans. Altogether, they form the temporal perspective context for the Dutch energy transition. An example related to the future of residential heating is the national plan related to gas production in Groningen. The Dutch government aims to release 1.5 million households from the natural gas network and become natural gas-free by 2030. According to Scheepers, et al. (2020), the accelerated termination of Groningen gas production gave the Dutch energy transition an extra impulse towards a natural gas-free energy system. Overall, the termination worked as a deadline which changed the perception of time and boosted the transition.

As with the case of the social contexts, the temporal contextual factors are transformed into one context that is used within the stated choice experiment and contains the perspective of an individual consumer. Therefore, the temporal factors are represented by the contexts of *urgency of the Dutch energy transition.* The urgency is mainly influenced by the global and national consequences of climate change and contains the degree to which the implementation of an energy transition is needed. The context affects individual energy consumer behaviour via the degree of *government interference.* It can be assumed that the *government interference* increases when the urgency of an energy transition is increasing. As a response, the government tries to steer the energy consumers towards sustainable alternatives by stimulating or restricting energy policies. Especially, when the deadlines of their national energy plans are approaching. Overall, in case of a high sense of urgency, more national energy plans are realised and sustainable values are integrated within energy consumer behaviour. Lastly, the context levels are quantified as the years that the Dutch government aims to get rid of the usage of natural gas. Therefore, the levels are the years 2030 and 2050, which are based on the current timeline of the Dutch energy transition. Whereby is assumed that 2030 contains a high urgency and 2050 a low urgency.

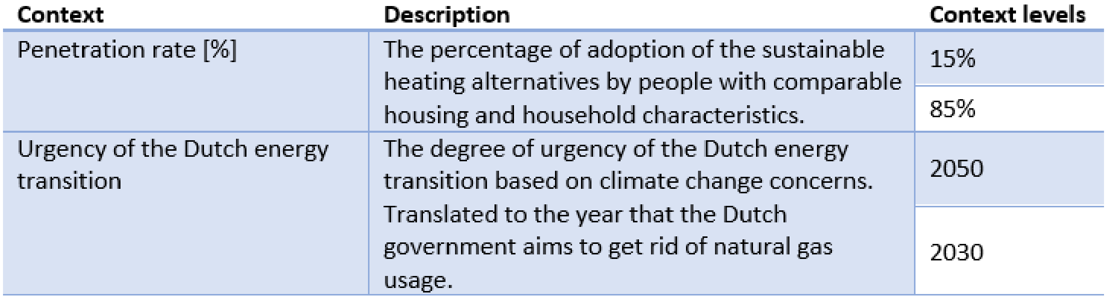
3.2 Conclusion

As stated at the beginning of this chapter, the purpose of the literature review is to find the influential contextual factors for the adoption of sustainable residential heating alternatives. These factors are obtained by performing an extensive literature review regarding the influential contexts of energy transitions in general and the Dutch energy transition in particular. However, before the literature study is executed, the definition of a context is given. This definition facilitates the determination of contexts by explaining whether a characteristic is seen as an influential context or not. Within this research, contexts are stated as external effects that define the setting of the decision-making process and have the potential to alter this process. The contexts define the choice situations of the stated choice experiment and will describe the future scenarios of the Dutch energy transition.

After executing, the outcome of the review results in several influential contexts, which can be clustered into multiple categories, such as social, political, economic, energy/climate, socio-demographic, and temporal contexts. Altogether, an overview of the influential contexts can be seen in Table 2. The overview illustrates the answers to all three research sub-questions that are stated at the beginning of this chapter. However, an important side note is that Table 2 should be seen as a summary or overview of the literature study and not as a leading classification or framework regarding influential contexts within the energy domain. The table describes the contexts that are found during the literature study and roughly place them in contexts categories. However, there are likely more important contexts, which are not found within this research. Furthermore, does the overview not indicate the relations between the contexts. For example, *climate change concerns* is classified as an energy context. However, this contexts is related to a temporal context as well due to the threats and deadlines regarding the consequences of climate change, which is not visible in the overview.

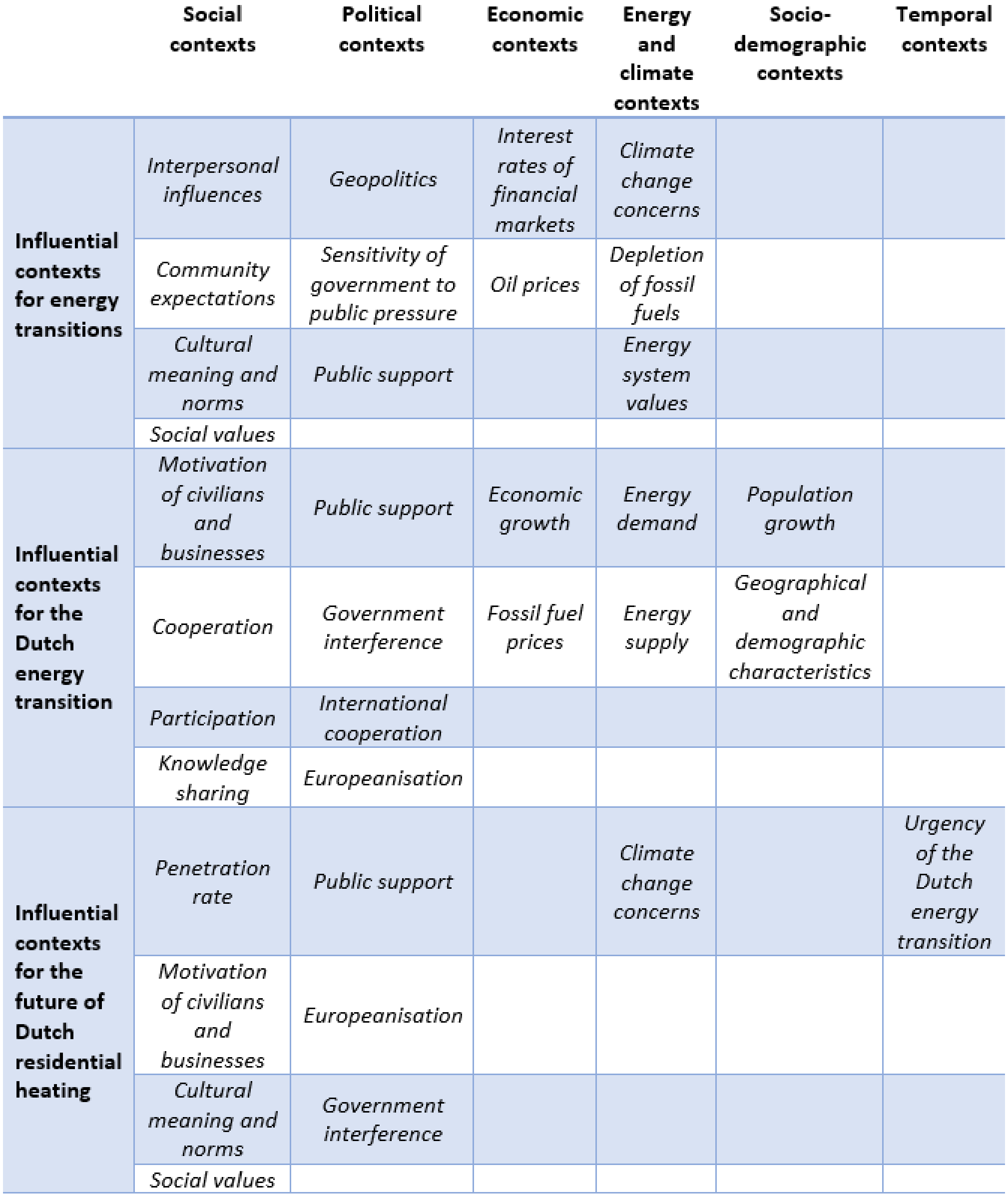
All in all, the influential contexts related to the future of residential heating that are found in the literature study are emphasising the importance of social interactions and temporal aspects. The contexts found within the literature review are translated into the contexts of *penetration rate* and *urgency of the Dutch energy transition*. These two contexts describe and summarise the other contexts of the literature study and are applied as choice contexts in the stated choice experiment. Lastly, an overview of the descriptions and levels of these two contexts can be seen in Table 1.

Table 1: Description of contexts within the stated choice experiment design



Context	**Description**	**Context levels**
Penetration rate [%]	The percentage of adoption of the sustainable heating alternatives by people with comparable housing and household characteristics.	15%
		85%
Urgency of the Dutch energy transition	The degree of urgency of the Dutch energy transition based on climate change concerns. Translated to the year that the Dutch government aims to get rid of natural gas usage.	2050
		2030

Table 2: Overview of influential contexts within literature review



	Social contexts	**Political contexts**	**Economic contexts**	**Energy and climate contexts**	**Socio-demographic contexts**	**Temporal contexts**
Influential contexts for energy transitions	*Interpersonal influences*	*Geopolitics*	*Interest rates of financial markets*	*Climate change concerns*		
	Community expectations	*Sensitivity of government to public pressure*	*Oil prices*	*Depletion of fossil fuels*		
	Cultural meaning and norms	*Public support*		*Energy system values*		
	Social values					
Influential contexts for the Dutch energy transition	*Motivation of civilians and businesses*	*Public support*	*Economic growth*	*Energy demand*	*Population growth*	
	Cooperation	*Government interference*	*Fossil fuel prices*	*Energy supply*	*Geographical and demographic characteristics*	
	Participation	*International cooperation*				
	Knowledge sharing	*Europeanisation*				
Influential contexts for the future of Dutch residential heating	*Penetration rate*	*Public support*		*Climate change concerns*		*Urgency of the Dutch energy transition*
	Motivation of civilians and businesses	*Europeanisation*				
	Cultural meaning and norms	*Government interference*				
	Social values					

4 Stated choice experiment design

As stated in the methodology, the stated choice experiment is the first part of the discrete choice analysis and serves as a data-gathering technique. The experiment is used to obtain the SP data related to the adoption of the sustainable heating alternatives. To compile the stated choice experiment and its corresponding choice sets, an experimental design has to be formed. The experimental design is based on the chosen sustainable heating alternatives, their attributes, attribute levels, and related contexts. All of these aspects are stated in Chapter 4.1. After the experimental design is formed, the stated choice experiment is translated into an online survey. The online survey is the application to collect the data by using the program Qualtrics. The structure and the content of the survey are stated in section 4.2.

4.1 Experimental design

As mentioned before, the experimental design is used to form the stated choice experiment and is based on the alternatives, attributes, attribute levels, and related contexts. The following chapters describe the creation and content of these components. First, in Chapter 4.1.1, the selected heating alternatives are explained via a brief technology description. Second, in Chapter 4.1.2, the relevant attributes and the corresponding attribute levels related to the technologies are selected and described. Third, the construction process of the experimental design is described in Chapter 4.1.3. The experimental design is formed by two steps. The first part is the regular choice experiment that consists of alternatives within choice sets including related attributes and attribute levels. The second part includes the context profiles with their corresponding context variables and context descriptions. Altogether, the experimental design is formed by combining both parts, which means nesting the choice sets under the context descriptions (Molin & Timmermans, 2010).

4.1.1 Selected residential heating alternatives

As stated in Chapter 1.3, the focus of this research is on hybrid heat pumps, all-electrical heat pumps and district heating as future sustainable residential heating technologies. Therefore, a brief technology description is given in the following sections, which serves as an introduction and background knowledge of these technologies.

All-electrical heat pump

An all-electrical heat pump is a sustainable heating alternative that is applicable for individual households. It uses energy from geothermal heat or the outside air. With the help of electricity, the energy is transformed into usable energy for heating a dwelling and its tap water. All-electrical heat pumps are highly efficient since they make use of renewable energy and only use a limited amount of electricity. On average all-electrical heat pumps have an efficiency rate of 350% - 450% (CE Delft, 2020a). However, the efficiency is dependent on the difference between the temperature of the heat source and the required temperature for heating the dwelling. Therefore, proper isolation is needed for optimal usage, namely a minimum of energy label B (ECW, 2020a). Lastly, all-electrical heat pumps operate entirely on electricity, which reduces gas usage to zero. However, electricity usage is increasing significantly, which means that the electricity grid must be strengthened in case of large-scale deployment.

Hybrid heat pump

A hybrid heat pump combines an all-electrical heat pump with a high-efficiency boiler, which results in an energy mix of electricity and natural gas. This heating technology is also implemented in individual households for heating the dwelling and its tap water. On average, the all-electrical heat pump provides about half of the heat demand. However, the efficiency between the all-electrical heat pump and the high-efficiency boiler is quite different. Therefore, the total efficiency depends on the share of the heat demand that is generated by the all-electrical heat pump and by the high-efficiency boiler. The high-efficiency boiler must assist when the heat generation of the all-electrical heat pump is not sufficient, which happens around one-fifth of the time. For example, during a cold winter or when a lot of warm tap water is needed (CE Delft, 2020c). By still using natural gas, the hybrid heat pumps are less sustainable than all-electrical alternatives. However, as mentioned in Chapter 1.3, this technique is seen as a transition technique for the existing housing stock since these houses first need adequate insulation measures before a more sustainable heating technology is implemented (Heynen et al., 2018).

District heating

District heating is a sustainable heating alternative whereby a collective of households is heated by using a large-scale heat source, which is transferred via a heat network. The most common heat source is the residual heat from industries (Scheepers, Faaij & Van den Brink, 2020). In general, there are three types of district heating based on the temperature of the heat network. High-temperature (75°C or higher), middle-temperature (55-75°C) and low-temperature (30-55°C) heat networks. Low-temperature heat networks have less heat loss and can be connected to more heat sources than other alternatives (NPRES, 2020). However, middle- and low-temperature heat networks need additional technologies, such as collective heat pumps, to increase the temperatures for sufficient space heating and hot water supply (CE Delft, 2020b; ECW, 2020b). High-temperature district heating is also more applicable. No extra insulating measures or large installations are needed and even dwellings with a minimum of energy label D can use it (CE Delft, 2020b; ECW, 2020b). Therefore, this research and its stated choice experiment focuses only on high-temperature heat networks as a sustainable heating alternative.

The biggest drawback is the difficult implementation of heat networks. Regarding infrastructure, complete neighbourhoods have to switch from the gas to a heat network and the electricity grid must be strengthened since the alternative is all-electrical (ECW, 2020b). Lastly, the average efficiency of heat networks is different per case since it depends on a lot of site-specific factors, such as the temperature of the heat network and the heat loss during transport (CE Delft, 2020b).

Heading technologies currently used

The fourth category of heating technology that is part of the experimental design contains the heating techniques that are currently used. This category includes all the heating technologies that are currently used by Dutch households and connected with the Dutch natural gas network, such as central heating- and high-efficiency boilers. Still, 91% of the Dutch households are heated with the use of such boilers (Van den Eerenbeemt, 2020). These boilers are heating water by burning gas. Thereafter, this heated water is pumped through pipes and transported to radiators, which deliver the heat for the dwelling.

This heating technology category will be included within the choice sets and serves as a base alternative for the respondents. The respondents still need to choose between the sustainable alternatives. However, they can use the characteristics of their current heating technology to compare the situations and to make a considered choice. The specific characteristics and their values are implemented as attributes and attribute levels within the choice sets. These components are presented in the next paragraph.

4.1.2 Selection of attributes and attribute levels

In this section, the selection of attributes and attribute levels is explained. Furthermore, the definition of the attributes and the distribution of their values is given. The selection of the attributes and their levels is based on reviewing prior literature regarding choice experiments that describe the influential factors for the adoption of sustainable heating alternatives.

In this research, the alternatives are presented as unlabelled alternatives whereby the three sustainable heating technologies are illustrated by an attribute regarding technology type. Presenting the alternatives as unlabelled means that the alternatives consist of the same attributes and attribute levels. Therefore, the attributes are based on characteristics of all three techniques and implemented with levels based on the total range of values. The usage of unlabeled alternatives is generally preferred since it results in a smaller number of choice sets (Molin, 2019b). Regarding the attribute levels, each attribute consists of three levels, which allows testing for linearity. Furthermore, the levels are chosen within a wide range and equidistance is preserved to increase validity, reliability, and to assure orthogonality (Molin, 2019a). All in all, an overview of all the attributes and attribute levels of the sustainable alternatives can be seen in Table 3 and the attributes are described below.

- First, the *investment costs* are included as attribute in several (stated) choice experiments regarding adopting sustainable heating alternatives and seen as influential for choice behaviour (Gu, Yang, Feng & Timmermans, 2019; Malla & Ruokamo, 2019; Rouvinen & Matero, 2013; Ruokamo, 2016). The attribute includes all the costs related to the purchase and installation of the heating device. The levels of the attribute are *€5000, €10.000, €15.000* (CE Delft, 2020a; CE Delft, 2020b; CE Delft, 2020c; Gu et al., 2019; Malla et al., 2019; Rouvinen et al., 2013; Ruokamo, 2016).

- Second, the *operating costs* are stated within several studies (Malla et al., 2019; Rouvinen et al., 2013; Ruokamo, 2016). This attribute includes annual electricity consumption, maintenance, and repair costs. The levels of the attribute are *€500, €1500, €2500* (CE Delft, 2020a; CE Delft, 2020b; CE Delft, 2020c; Malla et al., 2019; Rouvinen et al., 2013; Ruokamo, 2016).

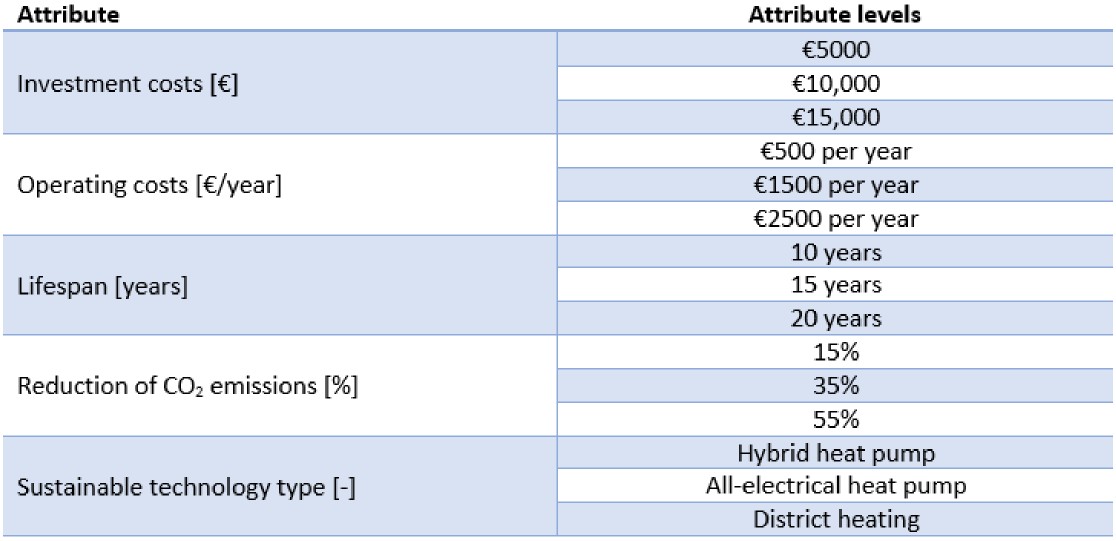
- Third, the *lifespan* is seen as an influential attribute in the form of a technological performance characteristic. Within this research, the focus is on the lifespan of the technologies that are implemented within a dwelling. The lifespan of energy infrastructure at the neighbourhood level is not taken into account. The attribute levels are *10, 15, 20 years* (CE Delft, 2020a; CE Delft, 2020b; CE Delft, 2020c).

- Fourth, the environmental friendliness of the heating alternatives is seen as an important characteristic related to the technologies (Malla et al., 2019; Rouvinen et al., 2013; Ruokamo, 2016). This aspect is translated to the *reduction of* CO_2 *emissions* by comparing the sustainable alternatives with the current natural gas heating system. In case of a dwelling with four persons, energy label C and a living space of 120 m^2 , the average gas consumption is 2076 m^3 , which is responsible for 3737 kg CO_2 emissions per year (Bosch, 2011; De Brauw, n.d.). However, these emissions can be reduced by adopting sustainable heating alternatives since all-electrical heat pumps are responsible for 3220 kg CO_2 emissions per year (CE Delft, 2020a), hybrid heat pumps for 3370 kg CO_2 emissions (CE Delft 2020c), and district heating for 66.1 GJ heat, which is 1771 kg CO_2 emissions (CE Delft, 2020b). By calculating the percentage change of all three techniques, the levels are stated as a reduction of *15, 35, 55 %* CO_2 emissions.

- Fifth, the attribute *Technology type* is implemented to subdividing the three sustainable heating technologies over the choice sets. This distinguishes the preferences between the technologies, which is used for model estimation later on. Therefore, the levels are *hybrid heat pumps, all-electrical heat pumps, district heating.*

- Lastly, as mentioned in Chapter 4.1.1, currently used heating technologies are included within the choice sets and serve as base alternative of the respondents. Therefore, these technologies are also characterised by the previously mentioned attributes. The attribute levels are based on literature related to high-efficiency boilers. Therefore the following attribute levels are assumed: *investment costs* of around *€1500 - €3000*, *operating costs* of *€1450 per year*, a *lifespan* of *15 years*, and a *reduction of 0%* CO_2 *emissions* (because it is the base alternative)(CE Delft, 2020d).

Table 3: Attributes and attribute levels of the experimental design



Attribute	Attribute levels
Investment costs [€]	€5000
	€10,000
	€15,000
Operating costs [€/year]	€500 per year
	€1500 per year
	€2500 per year
Lifespan [years]	10 years
	15 years
	20 years
Reduction of CO_2 emissions [%]	15%
	35%
	55%
Sustainable technology type [-]	Hybrid heat pump
	All-electrical heat pump
	District heating

4.1.3 Construction of experimental design

In this section, the construction process of the experimental design is given. The experimental design is formed by performing three steps. The first step is to form the choice sets of the choice experiment, which consists of the alternatives and their corresponding attributes and attribute levels. The second step is to form the context profiles, which represents scenarios that are based on combinations of the context variables. The last step includes constructing the experimental design by combining the choice sets with the context profiles. This is done by nesting the choice sets under the context profiles (Molin & Timmermans, 2010). The construction process of these three steps is stated in the coming sections.

Choice set formation

The forming process of the choice sets is held by mixing the attribute levels and assigning the combinations of attribute levels to choice sets. This step is performed by using the software Ngene. Ngene is capable of the generation of designs for stated choice experiments. Regarding the design generation, some characteristics were especially important. First, as mentioned in Chapter 2.2.1, an orthogonal fractional factorial design is used within this research. This type of design ensures attribute level balance and results in uncorrelated attributes. Second, the heating technologies within this research are presented as unlabeled alternatives, as stated in Chapter 4.1.2. Therefore, the construction of alternatives and choice sets will take place sequentially. With sequential construction, the alternatives are constructed and then randomly placed into the choice sets. This results in uncorrelated attributes within the alternatives, but attributes can be correlated between the alternatives. However, this is not problematic since the parameters can still be estimated (Molin, 2019b). All in all, Ngene formed an orthogonal fractional factorial design of twelve choice sets. The choice set design and further explanation about the construction in Ngene are elaborated in Appendix A.

Context profile formation

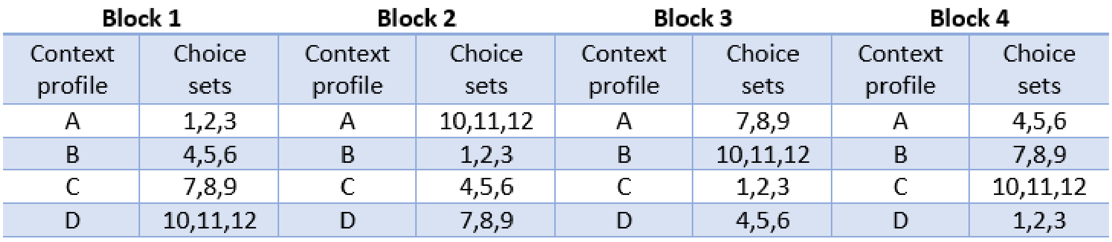
The second step includes forming the context profiles, which means combining the context variables into profiles that serve as scenarios. The scenarios will transform the choice sets into more realistic choice situations. Compiling the profiles can be done manually, because there are only two contexts with each two context levels, as stated in Table 1. This results in a full factorial design of four context profiles. Each of the four profiles describes a hypothetical scenario based on the contexts. The following profiles will be included within the stated choice experiment:

- Profile A: This scenario includes a **low penetration rate (15%)** and a **low urgency** related to the Dutch energy transition, causing that the Netherlands will get rid of natural gas in **2050**.
- Profile B: This scenario includes a **low penetration rate (15%)** and a **high urgency** related to the Dutch energy transition, causing that the Netherlands will get rid of natural gas in **2030**.
- Profile C: This scenario includes a **high penetration rate (85%)** and a **high urgency** related to the Dutch energy transition, causing that the Netherlands will get rid of natural gas in **2030**.
- Profile D: This scenario includes a **high penetration rate (85%)** and a **low urgency** related to the Dutch energy transition, causing that the Netherlands will get rid of natural gas in **2050**.

Constructing nested-choice sets

The last step for the construction of the experimental design is performed by nesting the choice sets under the context profiles. This will result in nested context-choice sets. As stated by Molin & Timmermans (2010), the total amount of context-choice sets is calculated by multiplying the number of choice sets by the number of context profiles. In regard to this research, this would result in $12 * 4 = 48$ context-choice sets. However, this results in too many choices to answer for a respondent and it would make the average response time of the survey too long. Therefore, the context-choice sets are divided into four blocks of each twelve choice sets. This means that there are four versions of the survey. By using a blocking scheme, each block contains the same choice sets. However, the order of the choice sets is different between the blocks. The blocking scheme ensures attribute level balance. This results in not orthogonal blocks, but an orthogonal design in total. Altogether, the final design of the context-choice sets is implemented in the four blocks and can be seen in Table 4.

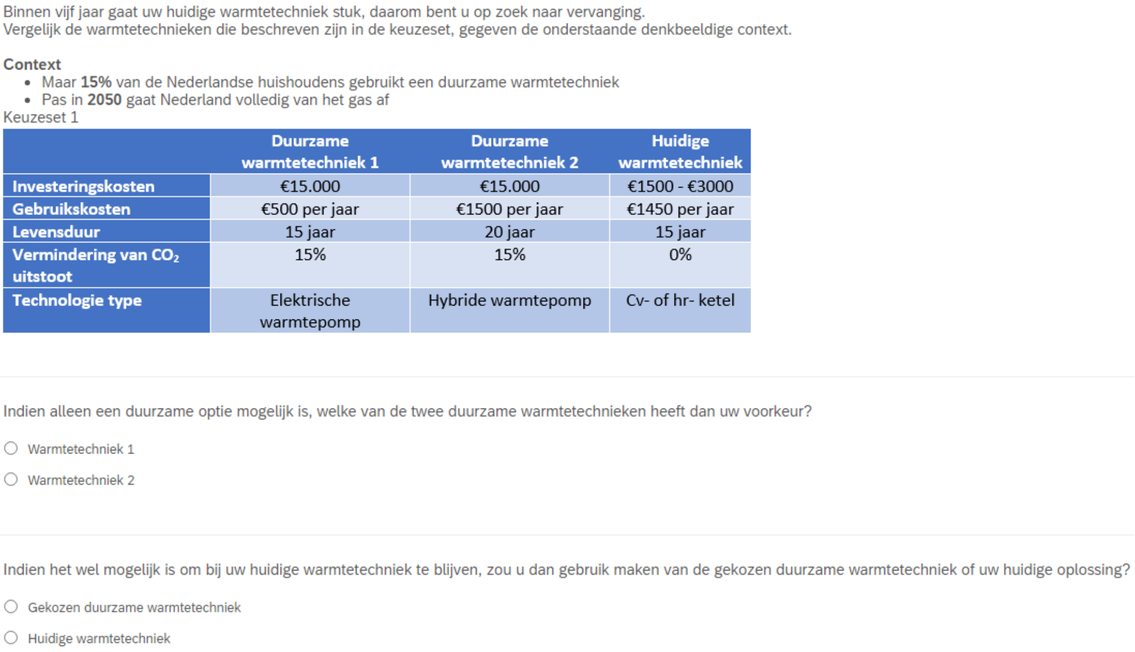
Table 4: Nested choice set design



Block 1		**Block 2**		**Block 3**		**Block 4**	
Context profile	Choice sets	Context profile	Choice sets	Context profile	Choice sets	Context profile	Choice sets
A	1,2,3	A	10,11,12	A	7,8,9	A	4,5,6
B	4,5,6	B	1,2,3	B	10,11,12	B	7,8,9
C	7,8,9	C	4,5,6	C	1,2,3	C	10,11,12
D	10,11,12	D	7,8,9	D	4,5,6	D	1,2,3

Choice task

As mentioned in Chapter 4.1.1, a base alternative is included in the choice sets and serves as a reference point for the respondents. Furthermore, it shows whether the respondent prefers the chosen sustainable technology or their currently used alternative. The respondents are first asked what their preference is regarding the sustainable heating technologies before the base alternative is included as an option. The advantage of this approach is that in case of a large part of the sample chooses the base alternative, the choice data of the sustainable heating technologies still provides insights related to the trade-offs between the attributes. The context-choice sets and their two corresponding questions together form a choice task. As an example, one of the 48 choice tasks is given in Figure 1.



Binnen vijf jaar gaat uw huidige warmtetechniek stuk, daarom bent u op zoek naar vervanging.
Vergelijk de warmtetechnieken die beschreven zijn in de keuzeset, gegeven de onderstaande denkbeeldige context.

Context

- Maar **15%** van de Nederlandse huishoudens gebruikt een duurzame warmtetechniek
- Pas in **2050** gaat Nederland volledig van het gas af

Keuzeset 1

	Duurzame warmtetechniek 1	**Duurzame warmtetechniek 2**	**Huidige warmtetechniek**
Investeringskosten	€15.000	€15.000	€1500 - €3000
Gebruikskosten	€500 per jaar	€1500 per jaar	€1450 per jaar
Levensduur	15 jaar	20 jaar	15 jaar
Vermindering van CO_2 uitstoot	15%	15%	0%
Technologie type	Elektrische warmtepomp	Hybride warmtepomp	Cv- of hr- ketel

Indien alleen een duurzame optie mogelijk is, welke van de twee duurzame warmtetechnieken heeft dan uw voorkeur?

○ Warmtetechniek 1

○ Warmtetechniek 2

Indien het wel mogelijk is om bij uw huidige warmtetechniek te blijven, zou u dan gebruik maken van de gekozen duurzame warmtetechniek of uw huidige oplossing?

○ Gekozen duurzame warmtetechniek

○ Huidige warmtetechniek

Figure 1: Choice task example

4.1.4 Choice modelling

Utility functions are composed and used to model the choices of the respondents. As mentioned in Chapter 2.2.2, these functions are following the RUM theory whereby the systematic utility of an alternative is based on the parameters of the attributes and the attribute levels. As illustrated in Figure 1, each choice task consists of two questions. The first question is the choice between two sustainable heating technologies whereby their characteristics are stated in the choice set. The alternatives are unlabelled and therefore generic parameters are used. The second question is the choice between the currently used alternative of the respondent (base alternative) and the chosen sustainable technology of question 1. The base alternative is presented in the choice tasks as a reference point of the current situation and has a utility function that is interpreted as an ASC with a fixed value of 0. Therefore, a constant is added to the utility functions of the sustainable alternatives, which expresses the difference in utility between the presented sustainable alternatives and the basic alternative. This constant is not alternative specific, but present in the utility functions of both the alternatives. Furthermore the constant represents the average utility that is generated by all factors that are not included in the model. All in all, the utility functions of both alternatives are the same in terms of present variables. The systematic utility function of the alternatives can be seen in Equation 4.1.

$$U_i = C_{SHA} + \beta_{IC} * IC + \beta_{OC} * OC + \beta_{LS} * LS + \beta_{RE} * RE + \beta_{ST} * ST \quad (4.1)$$

Meaning of the components:

- U_i = Utility of alternative i
- C_{SHA} = constant for both the Sustainable Heating Alternatives (SHA)
- β_{IC} = parameter for the variable *Investment costs* (IC)
- β_{OC} = parameter for the variable *Operating costs* (OC)
- β_{LS} = parameter for the variable *Lifespan* (LS)
- β_{RE} = parameter for the variable *Reduction of* CO_2 *emissions* (RE)
- β_{ST} = parameter for the variable *Sustainable technology type* (ST)

4.2 Survey design

The stated choice experiment is translated into an online survey, which serves as a method for data-gathering. The survey is formed by using the software Qualtrics. This chapter elaborates on all the components of the survey design, except the already stated choice tasks. First, Chapter 4.2.1, describes briefly the content en structure of the survey. Second, Chapter 4.2.2, mentions the questions related to how the respondents experienced the experiment, which helps to test the validity of the results and to improve the research method related to applications within the energy domain. Third, Chapter 4.2.3, contains the socio-demographic components that are questioned within the survey to test the representativeness of the data and to interpret the results. Fourth, within Chapter 4.2.4, the design process of the survey is elaborated by explaining the points of improvement that are gained by testing the survey. Lastly, in Chapter 4.2.5, the distribution strategy of the survey is explained.

4.2.1 Structure of the survey

The structure of the survey is briefly described below and is based on the components as previously mentioned. The full version of the survey can be seen in Appendix B.

General introduction
First, the survey starts with a general and personal introduction whereby the respondents are thanked for their participation. Furthermore, the topic and the purpose of my research is briefly explained and linked to the EPA master program. To inform the respondents, the average survey duration and the process of data

processing (related to privacy) is given. Lastly, at the bottom of the introduction, the contact details are mentioned in the case of questions from the respondents.

Introduction and explanation of stated choice experiment
Second, the survey introduces the stated choice experiment by stating the components of the survey. The alternatives, attributes, attribute levels and contexts are explained. Furthermore, an example choice set is illustrated to prepare the respondents for the rest of the survey.

Stated choice experiment
Third, the respondents are asked to choose between the two sustainable residential heating alternatives given the attributes, attribute levels, and stated context. Each of the respondents fills in 12 choice situations whereby the attribute levels and contexts differ. Furthermore, per choice situation, the respondent chooses between their chosen sustainable heating technology and the base alternative.

User experience questions
Fourth, directly after the stated choice experiment, statements regarding the experience of the respondents related to the choice experiment are given. The respondents state whether they approve of the statements by using a five-point Likert scale. The insights from these statements should improve the validity of their answers and the application of the method for future cases. The user experience questions are illustrated in section 4.2.2.

Socio-demographic questions
Sixth, questions related to socio-demographics are asked to gain knowledge regarding the characteristics of the sample. These outcomes are gathered to test the representativeness related to the Dutch population. Further elaboration is given in section 4.2.3.

Ending and acknowledgement
Lastly, the ending of the survey is given by again thanking the respondents for their participation. Furthermore, a text box and the contact details are implemented to send feedback or general remarks.

4.2.2 User experience

Directly after the stated choice experiment, the respondents give their thoughts by answering some statements. These statements are related to the respondent's opinions regarding the textual explanations within the experiment, the layout and presentation of the choice sets, the clarity and realism of the stated contexts, their empathy in the context, and whether important components were missing. The feedback gained from these question should increase the validity of the data by confirming that the choices related to the hypothetical situations are comparable with real-world situations. Within the survey, the respondents answer the statements via a five-point Likert scale (strongly disagree, disagree, neutral, agree, strongly agree). All in all, the user experience is gained by answering the following five statements:

- I experienced the explanations of the choice experiment as clear.

- I experienced the layout and way of presenting of the choice experiment as clear.
- I have experienced the described contexts as clear.
- I experienced the contexts and the context values (that formed the hypothetical scenarios) as realistic.
- Certain aspects influenced my choice behaviour, that were not included in this experiment.

4.2.3 Socio-demographics

As described in Chapter 4.2.1, the last questions of the survey are socio-demographic questions. The questions show insights related to the sample. However, none of the questions are directly linked to an individual. Furthermore, every socio-demographic question will include a 'do not answer' option to secure privacy. The socio-demographics that are implemented within the survey are gender, age (year of birth), educational attainment, professional status, yearly (gross) household income, and household size. The options of each socio-demographic question are based on Dutch population statistics, which are obtained by using online databases such as CBS Statline.

4.2.4 Testing the survey

Before the final survey is distributed, the provisional version of the survey is tested by friends and family. The testing phase has the purpose to improve the survey by gaining feedback related to comprehensibility, total duration, and textual adjustments. The group of respondents that filled in the pilot was diverse in terms of the socio-demographics to check whether the survey is understandable to most people. All in all, the following enhancements were implemented:

- Improvement of overall readability by using less jargon
- Improvement of the clarity of the questions by simplifying language use
- Shortened and more concise introduction and other explanations
- Adding the base alternative within the choice sets, including their attribute levels
- Reducing the statements related to sustainable attitudes (from 15 to 12)
- Adding an indication of the total average survey duration
- Grammatical improvements
- Changing the formulation of the contexts to improve the emphasis of the diverse values
- Omission of possible attribute levels within the attribute explanation
- Adding more categories to the household income question to improve the capability to test for representativeness

4.2.5 Survey distribution

The survey was distributed via social media within my own network. First, the survey was shared among friends and family. Second, a LinkedIn message was composed and distributed with business relations. However, other people shared the message as well, which resulted in a bigger and more mixed sample because 1500 different people viewed the post. Lastly, to further increase and mix the sample, the survey was distributed outside of my network. This is done by sharing the survey within public Facebook- and LinkedIn groups that are related to sustainability and renewable energy. The LinkedIn- as well as the Facebook messages can be seen in Appendix C.

All in all, the distribution strategy had the main focus of increasing the sample size. However, it is questionable whether this strategy results in a representative sample. Despite sharing the survey by others,the respondents that originate from my own network likely contain the same socio-demographic characteristics. Furthermore, the public social media groups were selected because these groups would contain people that were more likely to respond, but these respondents might be biased towards using sustainable heating alternatives. Within Chapter 5, the representativeness of the sample is tested based on the sample- and population distributions. The test determines the influence of the representativeness of the sample regarding the interpretation of the results.

5 Descriptive statistics

This chapter is describing the descriptive statistics of the sample based on the choice data that is gained by distributing the survey. First, in Chapter 5.1, the Qualtrics data is prepared for the data analysis and coming model estimations, which includes data cleaning and variable coding. Second, in Chapter 5.2, the characteristics of the sample are given by analysing the sample distributions related to the socio-demographics and the experiences of the choice experiment. Third, in Chapter 5.3, the representativeness of the sample is stated. This is measured by comparing the sample distributions of the socio-demographics with population data via chi-square tests. Furthermore, the effect of the results of these tests related to their influence on the interpretation of the model estimations is given as well. Fourth, in Chapter 5.4, the descriptive statistics of the choice experiments is elaborated by stating the choice distributions of the alternatives across the choice tasks and context scenarios. Lastly, in Chapter 5.5, a summary of the descriptive statistic findings is given and their impacts on the interpretation of the model estimations are concluded.

5.1 Data preparation

The data was gathered by conducting the Qualtrics survey. The data-gathering process started on 15 January and ended on 12 February 2021. In total 207 persons opened the survey of which 95 respondents completely filled it in. This results in a dropout rate of 54% which is quite high. Possible reasons for this result can be that the respondents experienced the survey as complex or lengthy. Furthermore, the survey is only promoted and conducted online due to Covid-19 circumstances, which could result in less participation compared to face-to-face promoting. Within the survey, it was mandatory to answer each question related to the choice experiment, which results in a total of 1140 observations (each respondent answered twelve choice sets). The distribution of the respondents per block can be seen in Figure 2. The average response time was approximately 16 minutes and 29 seconds. However, the gathered data needs to be cleaned and transformed before it can serve as input for the descriptive statistics analysis and model estimations. In Chapter 5.1.1, the data cleaning and transformation steps are elaborated. In Chapter 5.1.2, variable coding is applied for the model estimation and interpretation.

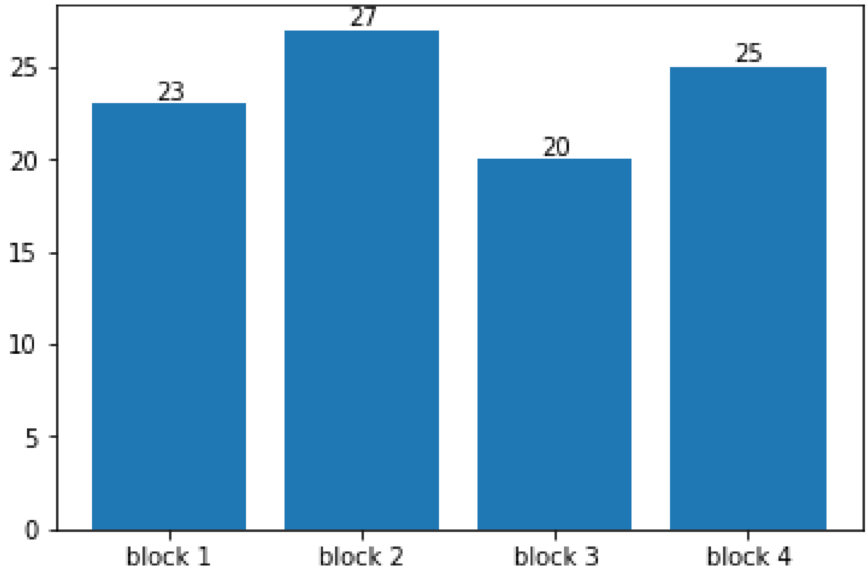


Figure 2: Respondents per block

5.1.1 Data cleaning

As mentioned in Chapter 2.2.1, Qualtrics is used to compose the survey and for data collection. However, the data that was exported from Qualtrics was not directly usable for data analysis and model estimation. Namely, the data contained the answers as text and was not in a usable format (every response was put into one row). Therefore, the following data cleaning steps were made: (1) removing unnecessary data, (2) creating different versions of the survey according to blocking scheme, (3) reconstructing data format for model estimation, (4) applying variable coding, and (5) providing solutions for missing values within the data. In Appendix D, the data cleaning steps are explained in detail.

5.1.2 Variable coding

As mentioned earlier, the data that is gathered from the survey will be used to estimate DCMs. These models show the preferences related to the sustainable heating alternatives, which are based on their utility. The utility of an alternative is calculated within a utility function, which is based on parameters and values related to its corresponding attributes. In case of numeric variables, the parameters of these attributes measure the influence on utility when the value of that attribute changes. With categorical variables, the influences on utility are measured by moving through the categorical levels of that attribute. However, it is not possible to determine a parameter for an individual level due to linear dependency (Daly, Dekker & Hess, 2016). Therefore, effect coding is used for the categorical variables.

With effect coding, $L - 1$ variables are created per variable, whereby L indicates the number of categories of that variable. It includes a coding scheme for the variables, whereby the level is set to 1 when the category is present and 0 when it is not. Per categorical variable, there is also a reference point. This is the reference category and is always coded as -1. This category has a utility that is based on the negative sum of the other estimated parameters of the categories (Beck & Gyrd-Hansen, 2005). Therefore, the sum and the average of the utility contributions is always zero. For consistency, effect coding is used for all categorical attributes, socio-demographics, and contexts. Originally, the *penetration rate* context is a numerical context variable since its levels are based on percentages. However, this variable is effect coded as well, because it is then consistent in terms of measuring scale with the other context variable. This makes it possible to directly compare the parameters of the contexts in terms of utility impact. An overview of the effect coded variables can be seen in Table 5.

Table 5: Overview of effect coded variables

Variable	**Level**	**Effect coding**		
	Attributes of choice alternatives			
Sustainable technology type	Hybrid heat pump	1	0	
	All-electrical heat pump	0	1	
	District heating	-1	-1	
	Socio-demographic variables			
Gender	Male	1		
	Female	-1		
Age	18-35 years	1	0	0
	36- 50 years	0	1	0
	51- 65 years	0	0	1
	65+ years	-1	-1	-1
Educational attainment	Lower-level education	1	0	
	Middle-level education	0	1	
	Higher-level education	-1	-1	
Professional status	Working	1	0	
	Not working	0	1	
	Student	-1	-1	
Yearly (gross) household income	Below average	1	0	
	Average	0	1	
	Above average	-1	-1	
Household size	One person households	1		
	More person households	-1		
	Context variables			
Urgency of Dutch energy transition	2050	1		
	2030	-1		
Penetration rate	15%	1		
	85%	-1		

5.2 Characteristics of the sample

Within the survey, several questions were included to measure the characteristics of the sample. The sample is defined by its socio-demographics (Chapter 5.2.1), and experiences related to the choice experiment (Chapter 5.2.2). Each of the following sections provides the sample- and (if possible) Dutch population distributions. The differences between these distributions can be used for the interpretation of the model estimations later on. The Dutch population distributions are based on data collected from CBS Statline.

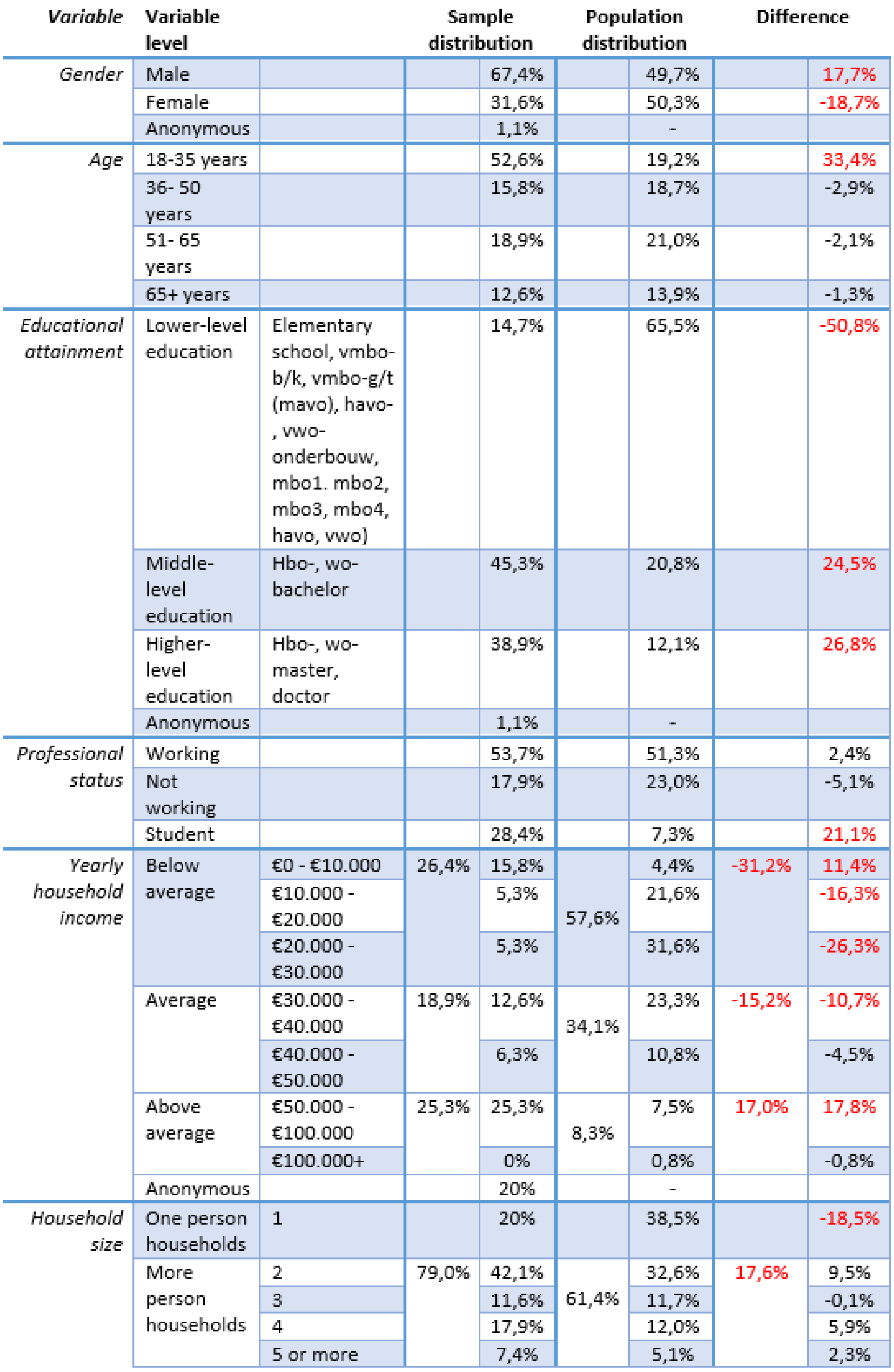
5.2.1 Social-demographic characteristics

Figure 6 is providing an overview of the sample distributions compared to the Dutch population distribution with regard to the socio-demographics. All the red numbers illustrate a percentage difference between the sample and the population that is bigger than 10%. Furthermore, Appendix E.1 contains plots that show the sample distributions of the socio-demographics. While looking at the data, the following outcomes can be perceived:

- In terms of gender, males are over-represented within the sample (67.4%), while the genders are evenly distributed within the Dutch population.
- Considering the age groups, most of the respondents are between 18 and 35 years old (52.6%). Therefore, this age group is over-represented compared to the population. The other ages groups are slightly under-represented.
- While looking at the distribution of educational attainment, the biggest deviation between the sample and the population can be seen. Respondents that followed lower-level education are strongly under-represented within the sample, which results in a difference of 50.8% compared to the population. Logically, the result is that the other education categories are over-represented.
- Mostly respondents with a job filled in the survey (53.7%). Furthermore, students are overrepresented while the respondents without a job were slightly missing within the sample.
- In terms of yearly household income, the sample consists of enormous fluctuation between the categories. The below average and average income groups are both under-represented. However, the lowest income group is over-represented. This fact goes hand in hand with the number of students that filled in the survey. Furthermore, according to the missing values, this was the most inappropriate question of the survey since 20.0% of the respondents wanted to keep their income anonymous.
- Lastly, most of the respondents live in a household with more than one person (79.0%). Therefore, one-person households are strongly under-represented. This effect could also be caused by the large presence of students within the sample. It is not common to live on your own as a student since that would result in high rental prices per person.

All in all, the are quite some differences between the distribution of the sample compared to the population. However, the consequences of these differences for the interpretation of the data and the model estimations have yet to be seen. Therefore, in Chapter 5.3, the difference in distributions of the socio-demographics are statistically checked with chi-square tests. These tests will statistically check whether the sample data can represent the population and what the consequences for the interpretations are.

Table 6: Overview of sample- and Dutch population distributions

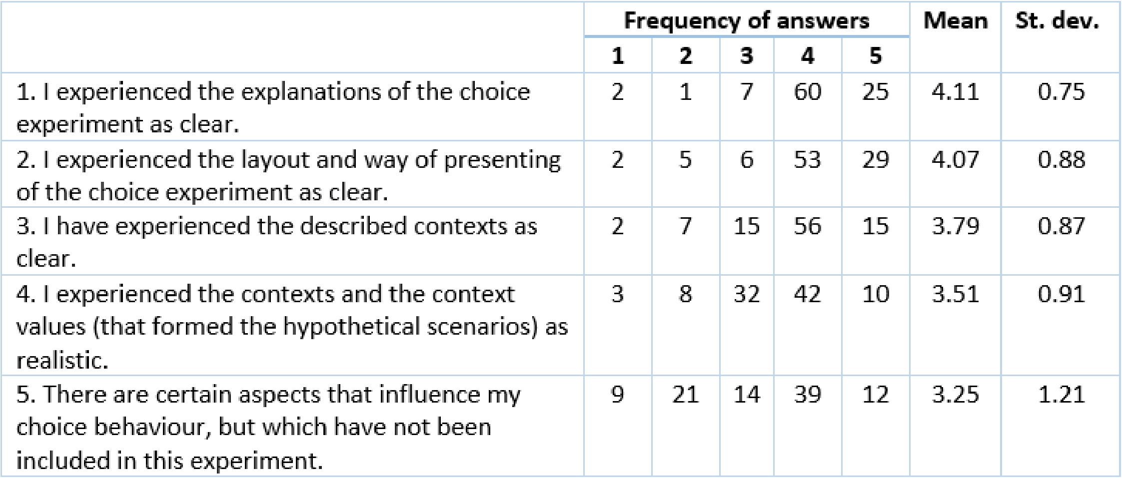


Variable	**Variable level**		**Sample distribution**		**Population distribution**		**Difference**	
Gender	Male			67,4%		49,7%		17,7%
	Female			31,6%		50,3%		-18,7%
	Anonymous			1,1%		-		
Age	18-35 years			52,6%		19,2%		33,4%
	36- 50 years			15,8%		18,7%		-2,9%
	51- 65 years			18,9%		21,0%		-2,1%
	65+ years			12,6%		13,9%		-1,3%
Educational attainment	Lower-level education	Elementary school, vmbo-b/k, vmbo-g/t (mavo), havo-, vwo-onderbouw, mbo1. mbo2, mbo3, mbo4, havo, vwo)		14,7%		65,5%		-50,8%
	Middle-level education	Hbo-, wo-bachelor		45,3%		20,8%		24,5%
	Higher-level education	Hbo-, wo-master, doctor		38,9%		12,1%		26,8%
	Anonymous			1,1%		-		
Professional status	Working			53,7%		51,3%		2,4%
	Not working			17,9%		23,0%		-5,1%
	Student			28,4%		7,3%		21,1%
Yearly household income	Below average	€0 - €10.000	26,4%	15,8%	57,6%	4,4%	-31,2%	11,4%
		€10.000 - €20.000		5,3%		21,6%		-16,3%
		€20.000 - €30.000		5,3%		31,6%		-26,3%
	Average	€30.000 - €40.000	18,9%	12,6%	34,1%	23,3%	-15,2%	-10,7%
		€40.000 - €50.000		6,3%		10,8%		-4,5%
	Above average	€50.000 - €100.000	25,3%	25,3%	8,3%	7,5%	17,0%	17,8%
		€100.000+		0%		0,8%		-0,8%
	Anonymous			20%		-		
Household size	One person households	1		20%		38,5%		-18,5%
	More person households	2	79,0%	42,1%	61,4%	32,6%	17,6%	9,5%
		3		11,6%		11,7%		-0,1%
		4		17,9%		12,0%		5,9%
		5 or more		7,4%		5,1%		2,3%

5.2.2 User experiences

The last characteristic that describes the sample is the user experiences. By asking five statements, thoughts related to the clarity and comprehensiveness of the choice experiment by respondents can be measured. The user experience statements are answered via the same 5-point Likert scale as the previous statements. Table 7, is illustrating the distributions of the answers related to the statements. Luckily, most of the respondents experienced the choice experiment as clear in terms of explanation and presentation. Furthermore, the contexts are mostly seen as clear and realistic, but less than the overall choice experiment. Unfortunately, the respondents slightly agree with the fact that important aspects such as contexts or attributes are missing within the experiment. However, this statement has the highest standard deviation, which implies that there is no strong consensus within the sample regarding this statement. Lastly, at the end of the survey, the respondents could give their general remarks. Most of them explained their opinions and mentioned some improvements and recommendations for future studies. These remarks are taken into account within Chapter 8 and Chapter 9.

Table 7: Experience data



	Frequency of answers					Mean	St. dev.
	1	2	3	4	5		
1. I experienced the explanations of the choice experiment as clear.	2	1	7	60	25	4.11	0.75
2. I experienced the layout and way of presenting of the choice experiment as clear.	2	5	6	53	29	4.07	0.88
3. I have experienced the described contexts as clear.	2	7	15	56	15	3.79	0.87
4. I experienced the contexts and the context values (that formed the hypothetical scenarios) as realistic.	3	8	32	42	10	3.51	0.91
5. There are certain aspects that influence my choice behaviour, but which have not been included in this experiment.	9	21	14	39	12	3.25	1.21

5.3 Representativeness of the sample

As mentioned in section 5.2.1, it is important for the interpretation of the model estimations to test whether the sample is representative of the Dutch population. Therefore, the distributions of the socio-demographics are compared with the population distributions. The outcomes from Table 6 showed already some insights regarding the differences between the distributions. However, the representativeness is also statistically tested. This is executed by performing a chi-square test since all of the socio-demographic variables are categorical.

For each socio-demographic. a separate chi-square test is performed. Each test contains a H0 and H1 hypothesis. The H0 test states that the sample is statistically independent, which means that the sample differs from the population. The H1 states the opposite, namely that the sample is statistically dependent and therefore representative for the population. According to the calculations in appendix D, all the socio-demographics have a p-value that is smaller than 0.05. This results in significant chi-square tests that imply the acceptance of the H0 hypotheses. Therefore, the sample can not be seen as representative of the population. The used data and calculation process of the chi-square test are further elaborated in Appendix E.2.

Nevertheless, it is still possible to estimate the DCMs with an unrepresentative sample, but the fact that the sample is not representative of the population has consequences for the interpretations of the estimated results within Chapter 6. The interpretation of the results should be stated carefully because the choice behaviour of the sample can not be directly translated to choice behaviour within the population. However, the representativeness of the sample is calculated by looking at the socio-demographics as a whole while some categories of socio-demographics are representative of the population. For example, as Table 6 indicates, the age groups of 36-50, 51-65, and 65+ are representative, which means that the influence of these specific age groups on the influence of the respondents can be translated to the population. Lastly, the influence of an unrepresentative sample on the interpretation of the results also depends on the relation between the socio-demographics and the choice behaviour of the respondents. For example, an unrepresentative sample can still lead to representative results when the socio-demographics are not influential for the preferences of the respondents. The relationship between the socio-demographics and the choice behaviour of the respondents is estimated within the models of Chapter 6.

5.4 Descriptive statistics of choice experiment

The last part of the descriptive statistics analysis is related to the choices that are made within the choice experiment. Each respondent answered twelve choice tasks whereby the context and the sequence of the choice sets differed across the version (that are caused by blocking). First, the respondents choose between the two sustainable heating alternatives and then between that chosen technology and the base alternative. Within the data file, each choice task is illustrated by a row that contains information about which choice set and contexts were present. Furthermore, their answers related to the questions are given by stating the choice with and without the base alternative. The descriptive analysis of the data resulted in several plots regarding the choices of the respondents.

First, Figure 3 illustrates the choice distribution between the three sustainable heating alternatives across the choice sets. Within the data file, every choice set has a unique ID. Therefore, it was possible to track the choices within each choice task, despite the different versions of the survey. Each choice set only contains two bars because the respondents only had to choose between two sustainable alternatives. Only choice set four is an exception because within that choice situation the respondents had to choose between two all-electrical heat pumps. Therefore, this alternative is always chosen within choice set four as can be seen in Figure 3.

Unfortunately, it can be seen that per choice situations there was a strong preference for one of the sustainable alternatives. This could be caused by a dominant alternative within a choice set. An alternative can be seen as dominant when it scores better than the other alternative over all the attributes and therefore becomes most preferred. Therefore, such choice data shows limited information regarding the trade-offs that a respondent makes, which could result in biased parameter estimations. However, pure dominance can not be achieved since the alternatives within a choice set differ in terms of the technology type attribute. Therefore, the dominant choices of the respondents can also be influenced by their preferences related to a technology type.

The preference towards a certain technology type can be seen by the overall percentages of the technologies. The most popular technologies are the hybrid- and all-electrical heat pump. These technologies are chosen in 39% and 40% of the observations while district heating is only chosen 21% of the time. Nevertheless, the exact influence of the sustainable technology type attribute on the choice behaviour of the respondents has yet to be tested within the model estimations. Therefore, the choice tasks that contain choice sets with dominant alternatives are still included within the data set.

Second, in Figure 4, the base alternative is included in the choice distribution across the choice task. This result in two possible options per choice set plus the base alternative that is added. Together they form the choice tasks. Luckily, by adding the base alternative less dominance between the alternatives occur. Overall, the respondents are especially doubting between choosing a heat pump or keeping their current heating technology. The base alternative is chosen 29% of the time, the hybrid heat pump 27%, the all-electrical heat pump 28%, and district heating within 16% of the observations.

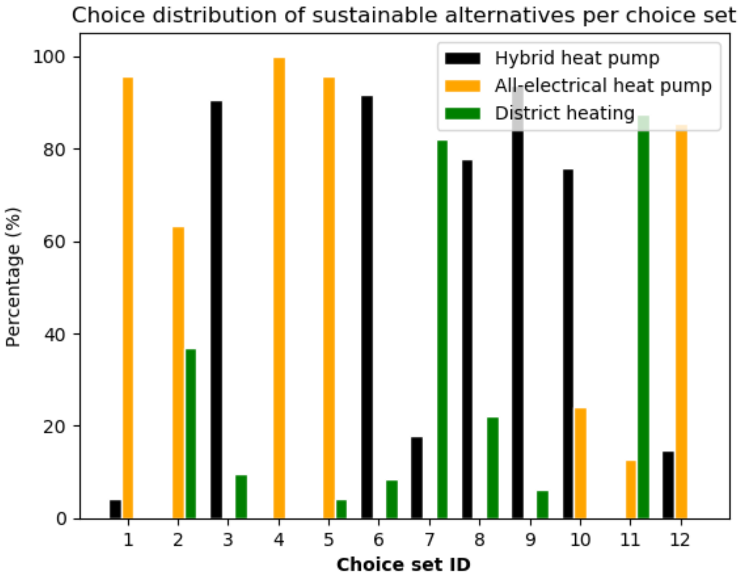


Figure 3: Distribution of the choices per choice task

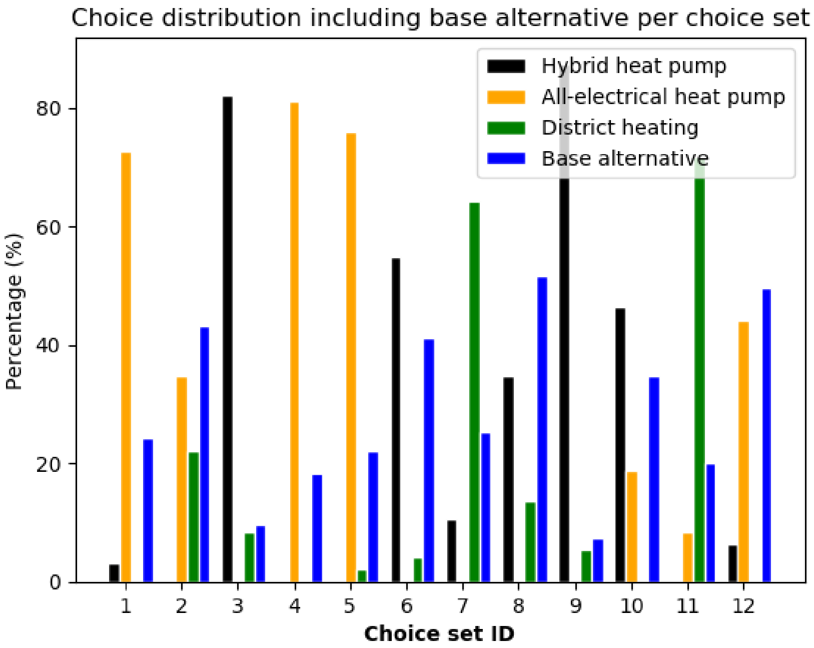


Figure 4: Distribution of the choices per choice task (with base alternative)

Third, Figure 5 shows the choice distribution between the three sustainable residential heating alternatives within the four scenarios. The scenarios are based on the contexts profiles as stated in Chapter 4.1.3. Scenarios A includes a low penetration rate (15%) and low urgency (2050), scenario B includes a low penetration rate (15%) and high urgency (2030), scenario C implies a high penetration rate (85%) and high urgency (2030), and scenario D implies a high penetration rate (85%) and low urgency (2050). The preference towards heat pumps as a future heating alternative in comparison with district heating can be seen in this figure as well. The heat pumps are preferred within each scenario. However, in scenario C this effect decreases and district heating becomes more popular. This effect seems mainly caused by the change in penetration rate since district heating is more preferred in scenario C and D compared to A and B. The popularity of district heating is barely changing between scenario A and B, which could imply that the urgency of the Dutch energy transition is not influencing this technology. Fourth, in Figure 6, the base alternative is added and clearly changes the choice distribution. In scenario A, the base alternative is preferred, because this scenario most closely resembles the current situation. In scenario D, the base alternative is most popular as well, but with a slight decrease due to the increase in the penetration rate. However, the base alternative is the least preferred in the scenarios with a high urgency of the Dutch energy transition (scenario B and C). This is caused by the faster downscaling of natural gas usage, which increases the popularity of the sustainable heating alternatives.

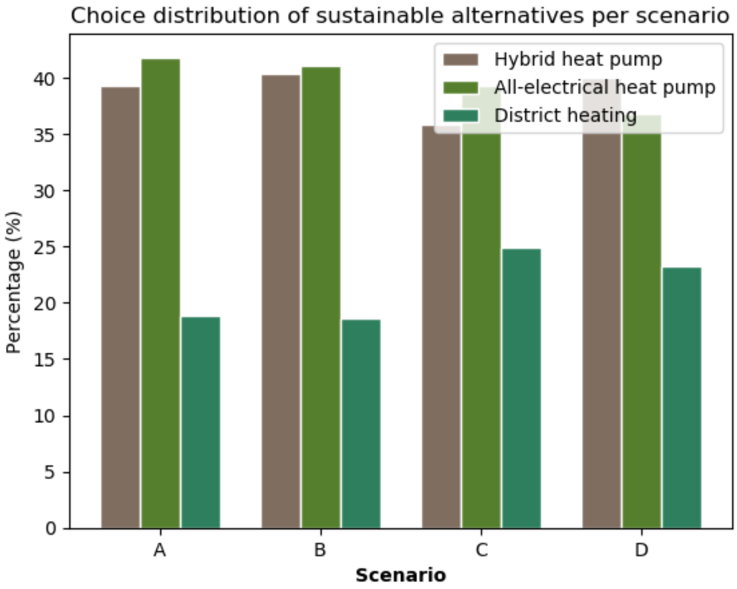


Figure 5: Distribution of the choices per context scenario

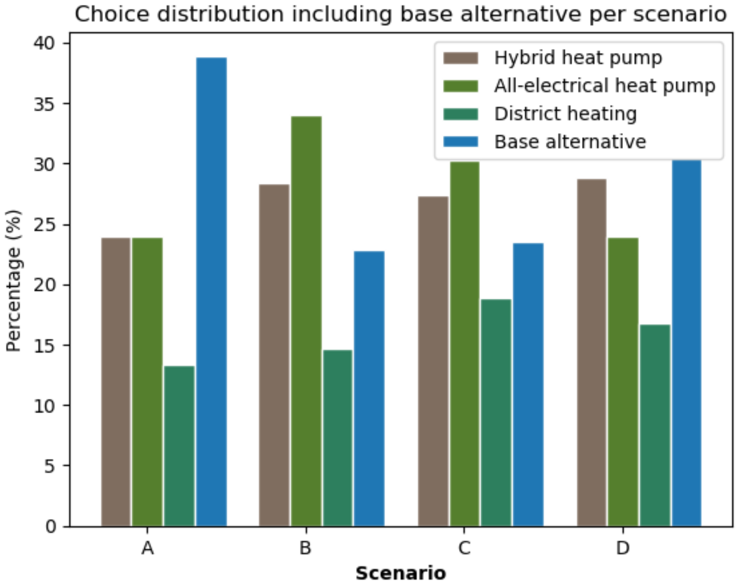


Figure 6: Distribution of the choices per context scenario (with base alternative)

5.5 Conclusion

After four weeks of survey distribution, the total amount of responses became 207 of which 95 respondents finished the survey completely. The Qualtrics data was prepared for the data analysis by cleaning the data and transforming the data set into the right format. Furthermore, variable coding is executed as data preparation for the model estimations of Chapter 6. After composing the data file, the representativeness of the sample is measured, which resulted in the fact that the sample is not representative of the Dutch population. It is still possible to estimate the DCMs. However, the unrepresentativeness must be taken into account with the interpretations of the model estimation results because the choice behaviour of the sample can not be directly translated to choice behaviour within the population.

Furthermore, the characteristics of the sample are given by analysing the socio-demographics and the experiences related to the choice experiment. This showed significant differences between the sample and the population. Thereafter, it became clear that most of the respondents embrace environmental attitudes and overall experienced the survey as clear and realistic. Lastly, the descriptive statistics of the choice experiment are stated by analysing the choice distributions across the choice tasks and context scenarios. This analysis showed the occurrence of dominant alternatives when the base alternative is not included. However, by including the base alternative, the choice distributions are more balanced and fluctuating across the context scenarios.

All in all, the tables and figures of this chapter that are related to the descriptive statistics of the sample and the choice experiment result in interesting choice distributions. However, the precise relations between the choices and model variables (attributes, contexts, and socio-demographics) still have to be estimated. Furthermore, the influence of the unrepresentative sample on the interpretation of the results should be tested by determining the relation between the socio-demographics and the choice behaviour of the respondents. Therefore, the possible explanations for the determined statistics are based on different estimated DCMs and are elaborated in Chapter 6.

6 Discrete choice model estimations

To test the influence of the variables on the choice behaviour of the energy consumers, different MNL models are estimated. All the models are estimated within R by using the Apollo package, which contains a set of tools to support the estimation and application of choice models (Hess & Palma, 2019). First, a **Basic MNL model**, which only contains the attributes, is estimated. This model purely measures the influence of the characteristics of the sustainable heating alternatives on the respondent's choice behaviour. The estimations and interpretations of the model parameters are given in Chapter 6.1. Second, the purpose of this research is to measure Dutch energy consumer preferences on adopting sustainable heating technologies. Therefore, the goodness-of-fit of the basic model is optimised to obtain a DCM that estimates the energy consumer preferences and the influences of the variables on these preferences the best. The optimisation process is formed by adding the (1) contexts variables and (2) socio-demographics. These variables are implemented one by one. Whether they are removed from the model is based on the strength and the significance of the estimated parameters. All together, the variables that have remained conduct the **Final MNL model**. This model has the highest goodness-of-fit and therefore fits the choice behaviour of the respondents the best. Lastly, the optimisation process is held in Chapter 6.2 and the interpretations of the estimated parameters of the final model are stated in Chapter 6.3.

6.1 Basic MNL model

The first model that is estimated is a basic MNL model. This model is seen as basic because it only considers the main effects of the technical characteristics (i.e. the attributes) and the influence of all factors that are not included in the model (i.e. the constant of the alternatives). Therefore, the attributes and the constant are the only variables for which a parameter is estimated within this model. The utility functions of the alternatives within the basic model are based on the utility function and corresponding explanation of Chapter 4.1.4. However, there is a slight difference between these utility functions, due to the execution of effect coding for categorical variables (see Table 5). Therefore, the attribute "Sustainable technology type" is split into two effect coded variables because it consists of three attribute levels. For each effect coded variable, separate parameters will be estimated. Overall, the utility functions of the three alternatives within this model can be seen in Equation 6.1, 6.2, and 6.3. The attributes abbreviations in these equations are the same as in Chapter 4.1.4. Namely, *Investment costs* (IC), *Operating costs* (OC), *Lifespan* (LS), *Reduction of* CO_2 *emissions* (RE), and *Sustainable technology type* (ST)

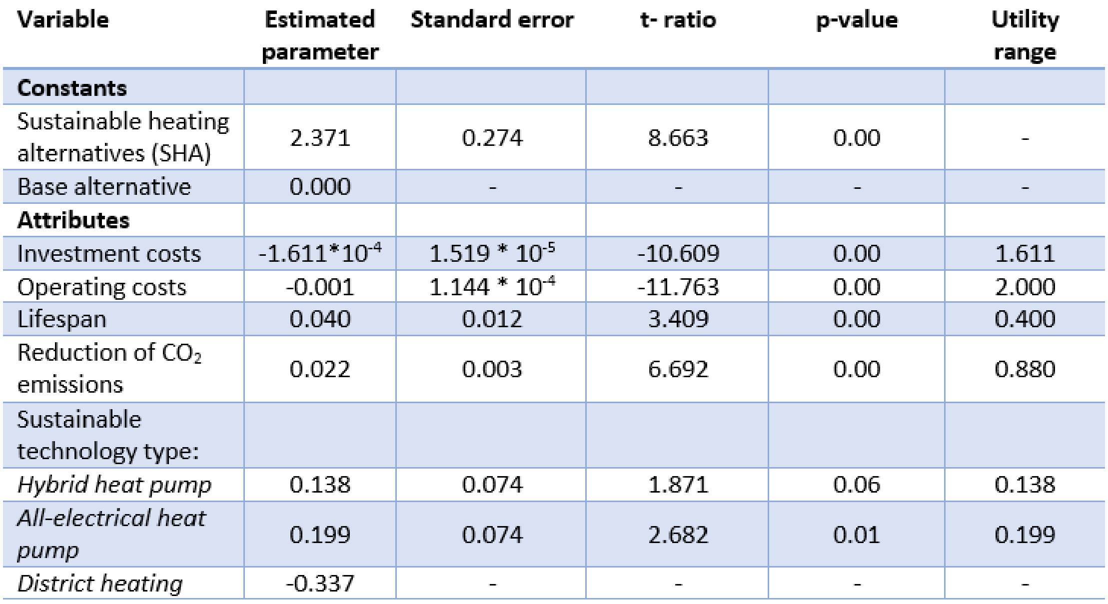
$$\begin{aligned}U_{alt1} = C_{SHA} + \beta_{IC} * IC_{alt1} + \beta_{OC} * OC_{alt1} + \beta_{LS} * LS_{alt1} + \beta_{RE} * RE_{alt1} \\ + \beta_{ST1} * ST1_{alt1} + \beta_{ST2} * ST2_{alt1}\end{aligned} \tag{6.1}$$

$$U_{alt2} = C_{SHA} + \beta_{IC} * IC_{alt2} + \beta_{OC} * OC_{alt2} + \beta_{LS} * LS_{alt2} + \beta_{RE} * RE_{alt2} + \beta_{ST1} * ST1_{alt2} + \beta_{ST2} * ST2_{alt2} \tag{6.2}$$

$$U_{base} = 0 \tag{6.3}$$

The basic model is estimated by composing and executing the R syntax as stated in Appendix F.1. The estimation resulted in a model with an adjusted ρ^2 of 0.247, which indicates that 24.7% of the initial uncertainty can be explained by (the attributes of) the basic model. Furthermore, the goodness of fit is also illustrated by the LRS of the basic model. As mentioned in Chapter 2.2.2, the LRS of the basic model is calculated by comparing its final log-likelihood with that of the null model. The outcomes show that the increase of model fit by the basic model is significant at the 99% significance level (LRS= 632.586, df= 7) because the LRS is bigger than the chi-square value (threshold value for that particular df). Therefore, the basic model fits the data better than the null model. All in all, the estimated parameters of the constant and the attributes are illustrated in Table 8. The interpretation of the estimates is elaborated in Chapter 6.1.2.

Table 8: Estimates of basic MNL model



Variable	Estimated parameter	Standard error	t- ratio	p-value	Utility range
Constants					
Sustainable heating alternatives (SHA)	2.371	0.274	8.663	0.00	-
Base alternative	0.000	-	-	-	-
Attributes					
Investment costs	$-1.611*10^{-4}$	$1.519 * 10^{-5}$	-10.609	0.00	1.611
Operating costs	-0.001	$1.144 * 10^{-4}$	-11.763	0.00	2.000
Lifespan	0.040	0.012	3.409	0.00	0.400
Reduction of CO_2 emissions	0.022	0.003	6.692	0.00	0.880
Sustainable technology type:					
Hybrid heat pump	0.138	0.074	1.871	0.06	0.138
All-electrical heat pump	0.199	0.074	2.682	0.01	0.199
District heating	-0.337	-	-	-	-

6.1.1 Explanation of estimation output

Before the interpretations of the estimated parameters of the basic model are elaborated upon, an explanation regarding the estimation output is given. The explanation shows the meaning of the estimation results and includes the concepts of estimated parameters, utility ranges and p-values.

Constant of sustainable heating technologies

As stated in Equation 6.1 and 6.2, the utility functions of each of the two alternatives, from which the respondents can choose within a choice task, consist of the same constant. This constant is related to all three sustainable heating technologies. The estimated value of the constant shows the utility contribution of these technologies when all variables in the model are set as zero. For convenience, this alternative is called the zero-alternative. In other words, the constant represents the utility of all factors that are related to sustainable heating but not included in the model. For example, attributes that are not assigned to the alternatives such as *ease of use* or *size of technology*, could be important for the installation within households and therefore decision-making of the respondents. Lastly, the constant is also showing the difference between the zero-alternative and the currently used technology. This means that the higher the constant, the more the respondents prefer sustainable alternatives over their currently used technology.

Utility contributions of parameters

The estimated parameters show the utility contributions of the model variables. Regarding the attributes, the parameter shows the utility contribution when the attribute level increases with one unit (if the rest of the utility function is kept constant). The sign of the parameters is showing whether the utility increases or decreases. For example, the estimate of 0.040 related to lifespan indicates that the total utility of a sustainable heating alternative will increase with 0.040 utils for each year that the lifespan increases.

However, this only applies to continuous variables. The interpretation of the effect coded variables is different. With effect coding, the sum of the utility contributions is zero, which means that the average utility contribution is zero as well. The utility contribution per category of an attribute indicates the difference from the average utility contribution of that attribute (which is zero). The utility contribution per category can be calculated by multiplying the estimated parameter with the effect coded attribute level of that particular attribute category (if the rest of the utility function is kept constant) (Molin, 2019d). For example, hybrid heat pumps have an attribute level of 1 for the first variable and 0 for the second variable, which means that the total utility of an alternative is valued ($0.138 * 1 + 0.199 * 0 = 0.138$) utils higher when that alternative is a hybrid heat pump and compared to the average utility of the technology type attribute. This example shows that the first parameter is related and therefore showing the utility contribution of the first category and the second parameter of the second category and so on. Only the reference category has no estimated parameter within the model, but this parameter is calculated by taking the negative sum of the other categorical parameters.

Trustworthiness of estimations

Per estimated parameter, it is tested whether that estimation is representative for the choice behaviour of the sample. When this is the case, the estimated parameter is called significant. To check the significance, two hypotheses (H0 and H1) are formulated. H0 claims that there is no relation between the estimates and the preferences of the sample, while H1 does claim a relation. The p-value results from the model estimates (via the t-ratio) and can be seen as the evidence related to H0. The smaller the p-value, the stronger the evidence that H0 should be rejected. Currently in science, it is common to apply the 95% confidence interval, which is associated with a confidence level of 95% . The confidence level includes the probability that the interval contains the true value of the parameter, which means that an estimated parameter is only seen as significant when it has a p-value that is lower than 0.05 (5%). However, Amrhein, Greenland & McShane (2019) stated that this threshold of 0.05 should be followed less strictly within statistical research because it leads to misconceptions and overstated claims. For example, an estimated parameter with a p-value of 0.06 is seen as non-significant while 94% of the interval contains the parameter in case of re-estimation. In other words, 94% of the confidence interval includes a reliable parameter that is translatable to the sample. Therefore, in this study, the p-values are interpreted more continuous and without a strict threshold. The choice to keep a variable within the model will be based on the continuous p-value scale as well as the strength of the estimated effects of the variables. This last aspect is explained in the next section.

Strength of estimated effects

For each variable (or variable category if effect coded), a utility range is calculated. This characteristic is showing the influence and strength that each variable has on the total utility. The range is given by multiplying the parameters by their minimum and maximum levels. For effect coded variables this means the difference between the levels 0 and 1 or -1 and 1. Overall, the wider the range of a variable, the more influence that variable has on the total utility of an alternative and therefore on the choice behaviour of the respondents. Lastly, to improve the interpretation of the strengths, the utility ranges are translated to the relative importance of the estimated effects. This characteristic shows the percentage of influence that each effect has on the total utility. It is calculated by dividing each utility range by the sum of all the ranges.

6.1.2 Interpretation of estimated parameters

While looking at the output of the basic model in Table 8, several conclusions can be drawn. These conclusions are regarding the estimated constant as well as the estimated parameters of the attributes.

Interpretation of estimated constant

First, the estimated constant of the sustainable heating alternatives has a value of 2.371. This means that the respondents have a positive association with sustainable heating alternatives, which is caused by all factors that are not included. The height of the constant is showing that the unobserved factors are quite influential for the preferences of the respondents because the value is even higher than the utility range of the most influential attribute. Lastly, the basic MNL model only includes attributes, which means that all context variables are part of the unobserved factors as well. Therefore, the estimated parameters of this model can be seen as the average values for all context variables.

Interpretation of attribute influences

Regarding the estimated attribute parameters, four outcomes are highlighted. First, there are no unexpected parameter signs. More costs are decreasing the total utility and the other attributes are seen as additions to the total utility of an alternative. Second, the utility ranges are showing that *Investment costs* and *Operational costs* have the most influence on the total utility. The effect coded categories of *Sustainable technology type* have the lowest importance, which indicates that the characteristics of an alternative are more important than the technology type itself. Third, the estimated parameter values of the sustainable technology types show that the respondents prefer heat pump alternatives since district heating is declining the total utility. This conclusion is in line with the descriptive choice statistics of Chapter 5.

Lastly, the significance of all the estimated parameters is checked. As mentioned earlier, the threshold related to the 95% confidence interval will not be strictly implemented within this research. The first effect coded category of *Sustainable technology type* is a perfect example for this approach. The parameter has a p-value that is slightly higher than 0.05 and would normally be seen as insignificant. However, this would be a misconception because 93.39% of the interval contains the parameter in case of re-estimation. So this parameter is seen as significant as well. Concluding, all the attribute variables influence the choices between the sustainable heating alternatives. Therefore, they are included in the following models as well.

6.2 Optimising the model performance

As mentioned in the introduction of this chapter, the basic MNL model is optimised in terms of the goodness-of-fit to produce a model that estimates the energy consumer preferences and the influences of the variables on these preferences the best. The first step of this process is applied by adding the context variables that were implemented within the experiment (see Table 1). These contexts are effect coded as illustrated by Table 5. The influence of the contexts can not be estimated as main effects within the utility functions of the model. However, they could be included as interaction effects related to constants and attribute parameters (Molin, 2019e). Therefore, such interactions are applied in the optimisation process. The interactions with the constant will indicate the direct effect of the contexts on the utility of the sustainable heating alternatives, while the interactions with the attributes show whether the effects of the attributes on the preferences change among the different contexts. Within this research, several interaction effects of the contexts are assumed to influence the preferences of the respondents. Per interaction effect, a statistical hypothesis test is conducted. The H0 hypothesis states that there is no relationship between the variables of the interaction effect. The hypothesis is rejected if the estimated parameters are statistically significant, which indicates that there is a relationship. Within the optimisation process, the following interaction effects of the contexts are assumed and estimated:

- Interaction effect of *Urgency of the Dutch energy transition* and *Penetration rate* on the *constant*: The literature review findings showed that the context variables are influential for future sustainable heating adoption. Therefore, these two interaction effects are implemented and indicate the influence of the context variables on the preferences for the sustainable alternatives as a whole. The hypothesis of this effect is that *Urgency of the Dutch energy transition* as well as *Penetration rate* positively influence the choices for sustainable heating.

- Interaction effect of *Urgency of the Dutch energy transition* on *Penetration rate*: This effect represents the interactions between the context variables. The hypothesis is that the context variables positively influence each other. For example, high urgency could shift the public opinion towards believing in sustainable values, which could increase the penetration rate.

- Interaction effect of *Penetration rate* on *Sustainable technology type*: This effect indicates the effect of the penetration rate on the parameter of the technology type attribute. In other words, it tests whether the respondents prefer certain technologies based on the penetration rate. The hypothesis is that penetration rate influences the importance of the technology typing, due to the accompanying social pressure that steers the individual consumer to adopt the same product (Leibenstein, 1950).

- Interaction effect of *Urgency of the Dutch energy transition* on *Sustainable technology type*: This interaction indicates the effect of urgency due to climate change concerns on the preferences towards certain sustainable heating technologies. The hypothesis is that the urgency influences the technology type preferences. Namely, the higher the urgency, the more the energy consumers prefer the most sustainable alternatives.

- Interaction effect of *Urgency of the Dutch energy transition* on *Investment costs*: The last interaction represents the effect of urgency on the importance of the investment costs attribute related to the choice behaviour of the energy consumers. Also, this interaction has the hypothesis that urgency positively influences investment costs. So the higher the urgency, the lower the costs matter for sustainable technology adoption.

For convenience, the addition of the contexts resulted in a new model that is called MNL model B. The estimation results in a model with an adjusted ρ^2 of 0.256, which is a slight increase compared to the basic model. The small increase of ρ^2 can also be seen in the LRS of model B. While comparing the goodness of fit of model B with the basic model, it can be concluded that the increase is significant at the 99% significance level (LRS= 17.173, df= 6). Therefore, model B does fit the data better than the basic model. This means that a model is formed that produces more accurate estimates regarding the preferences of the respondents by adding the contexts to the model. Lastly, regarding the significance of the parameters, while looking less strict at the threshold of 0.05 most of the interaction effects are included within the next models. However, the interaction effect of the context variable *Urgency of the Dutch energy transition* with the attribute *Investment costs* and the effect of *Penetration rate* with the *Sustainable technology type* attribute had such high p-values (both around 0.8) that they were seen as non-significant. Therefore, these interactions effects are not translatable to the preferences of the respondents and not included in the coming model iterations. The interpretation of this result is held in the interpretation of the final model.

The second step of the optimisation process is made by adding the socio-demographic variables that were questioned in the survey. The socio-demographics are also effect coded (Table 5 and implemented as main effects as well as interactions effects with the technology attributes. Therefore, the direct influence of the socio-demographics on sustainable heating preferences as well as their influence on the effects of the attributes can be estimated. Within the survey, the socio-demographic questions are the only questions whereby the respondents could answer with “I do not know/ I do not want to answer”. Therefore, the socio-demographics are the only variables that contain missing values in the data set. The missing values can not be implemented within the model estimation, which means that a subset of the data is created that do not contain observations with missing values. Unfortunately, the socio-demographic *Yearly household income* had that many missing values that this variable could not be included in the model estimations. All in all, the following interaction effects of the socio-demographics are assumed and estimated:

- Interaction effect of *Educational attainment* on *Sustainable technology type*: This interaction effect is based on literature that describes the effect of education level on sustainable technology adoption. As stated by (Dharshing, 2017), a higher socioeconomic status, which is determined by education level, leads to more sustainable technology adoption. Furthermore, education can cause environmental awareness, which further strengthens technology adoption (Braun, 2010). This interaction indicates the effect of education levels on the preferences towards certain sustainable heating technologies. Based on the literature, the hypothesis is that education level influences the technology type preferences. Namely, the more educated an energy consumer is, the more it prefers the most sustainable alternative.

- Interaction effect of *Age* on *Sustainable technology type*: This interaction indicates the effect of age groups on the preferences of the sustainable heating technologies. This interaction effect is based on literature that describes the effect of age on sustainable technology adoption. First, Michelsen & Madlener (2012) found within their research that the age of the homeowner is relevant for the preferences for adopting innovative heating systems. Furthermore, their research indicates that older homeowners prefer oil-fired techniques, while younger homeowners are more open towards sustainable solutions. They stated that these differences could be caused by the difference in risk aversion. Second, Chen & Sintov (2016) also found that younger respondents had more intentions to adopt energy management technologies than older people. Therefore, based on the literature, the hypothesis is that age influences the technology type preferences. Namely, that the respondents of the youngest age group are more likely to choose the most sustainable alternative.

After implementing the socio-demographics, the resulting model showed that none of the estimated interaction effects with the attributes were significant. Therefore, these variables are removed from the model. The interpretation of this result is held in the interpretation of the final model. The variables that have remained compose the final model, which is further elaborated and interpreted in the next chapter.

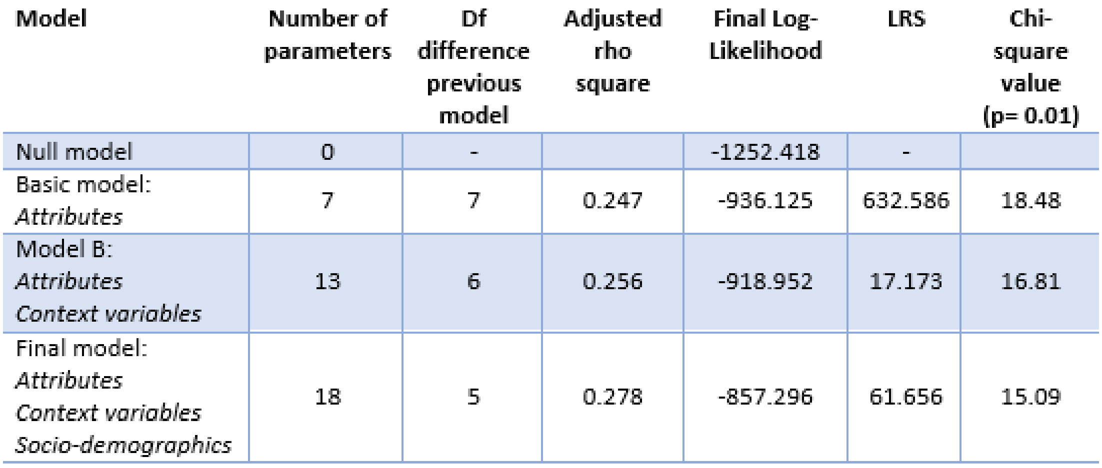
6.3 Final MNL model

The final model is estimated by composing and executing the R syntax as stated in Appendix F.2. The utility functions of the three alternatives within this model are presented in Equation 6.4, 6.5. The equation for the second alternative (that is presented in each choice set) is the same as Equation 6.4, except that it has its own related attributes. As illustrated in Table 9, the estimation results in a model with eighteen variables and an adjusted ρ^2 of 0.274. Therefore, this model explains 27.4% of the initial uncertainty. The LRS value shows that increase of model fit compared to model B is significant at the 99% level (LRS= 61.656, df= 5), which means that the final model fits the data the best out of all models. The estimated parameters of the final model are illustrated in Table 10. The interpretations are given in the following section.

$$\begin{aligned}U_{alt1} = C_{SHA} + \beta_{IC} * IC_{alt1} + \beta_{OC} * OC_{alt1} + \beta_{LS} * LS_{alt1}\\ +\beta_{RE} * RE_{alt1} + \beta_{ST1} * ST1_{alt1} + \beta_{ST2} * ST_{alt1}\\ +\beta_{C1} * C1 + \beta_{C2} * C2\\ +\beta_{C2-C1} * C2 * C1\\ +\beta_{C1-ST2} * C1 * ST2_{alt1}\\ +\beta_{C2-ST1} * C2 * ST1_{alt1} + \beta_{C2-ST2} * C2 * ST2_{alt1}\\ +\beta_{Gender} * Gender + \beta_{Age1} * Age1 + \beta_{Age3} * Age3\\ +\beta_{Profstatus1} * Profstatus1 + \beta_{Profstatus2} * Profstatus2\end{aligned} \tag{6.4}$$

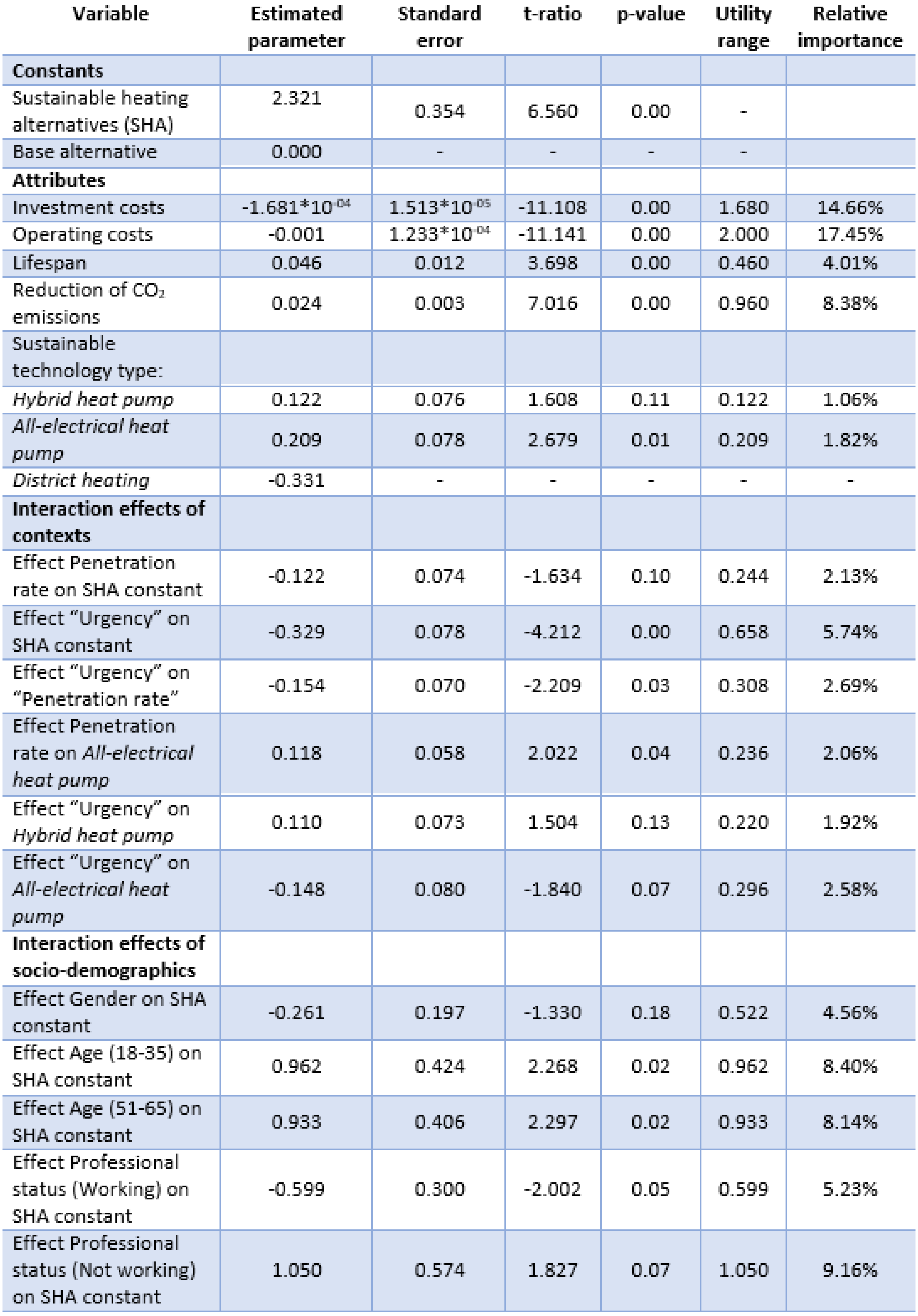
$$U_{base} = 0 \tag{6.5}$$

Table 9: Model performance of all estimated models



Model	**Number of parameters**	**Df difference previous model**	**Adjusted rho square**	**Final Log-Likelihood**	**LRS**	**Chi-square value (p= 0.01)**
Null model	0	-		-1252.418	-	
Basic model: *Attributes*	7	7	0.247	-936.125	632.586	18.48
Model B: *Attributes* *Context variables*	13	6	0.256	-918.952	17.173	16.81
Final model: *Attributes* *Context variables* *Socio-demographics*	18	5	0.278	-857.296	61.656	15.09

Table 10: Estimates of final MNL model



Variable	Estimated parameter	Standard error	t-ratio	p-value	Utility range	Relative importance
Constants						
Sustainable heating alternatives (SHA)	2.321	0.354	6.560	0.00	-	
Base alternative	0.000	-	-	-	-	
Attributes						
Investment costs	-1.681*10^{-04}	1.513*10^{-05}	-11.108	0.00	1.680	14.66%
Operating costs	-0.001	1.233*10^{-04}	-11.141	0.00	2.000	17.45%
Lifespan	0.046	0.012	3.698	0.00	0.460	4.01%
Reduction of CO$_2$ emissions	0.024	0.003	7.016	0.00	0.960	8.38%
Sustainable technology type:						
Hybrid heat pump	0.122	0.076	1.608	0.11	0.122	1.06%
All-electrical heat pump	0.209	0.078	2.679	0.01	0.209	1.82%
District heating	-0.331	-	-	-	-	-
Interaction effects of contexts						
Effect Penetration rate on SHA constant	-0.122	0.074	-1.634	0.10	0.244	2.13%
Effect "Urgency" on SHA constant	-0.329	0.078	-4.212	0.00	0.658	5.74%
Effect "Urgency" on "Penetration rate"	-0.154	0.070	-2.209	0.03	0.308	2.69%
Effect Penetration rate on *All-electrical heat pump*	0.118	0.058	2.022	0.04	0.236	2.06%
Effect "Urgency" on *Hybrid heat pump*	0.110	0.073	1.504	0.13	0.220	1.92%
Effect "Urgency" on *All-electrical heat pump*	-0.148	0.080	-1.840	0.07	0.296	2.58%
Interaction effects of socio-demographics						
Effect Gender on SHA constant	-0.261	0.197	-1.330	0.18	0.522	4.56%
Effect Age (18-35) on SHA constant	0.962	0.424	2.268	0.02	0.962	8.40%
Effect Age (51-65) on SHA constant	0.933	0.406	2.297	0.02	0.933	8.14%
Effect Professional status (Working) on SHA constant	-0.599	0.300	-2.002	0.05	0.599	5.23%
Effect Professional status (Not working) on SHA constant	1.050	0.574	1.827	0.07	1.050	9.16%

6.3.1 Interpretation of estimated parameters

For each of the variable types, the interpretation of the parameters within the final model will be given. Furthermore, the utility contributions of the variables are plotted to show the importance and possible outcomes per variable. The utility contributions are calculated by multiplying the parameters with the attribute or (effect coded) category levels.

Estimated constant parameter

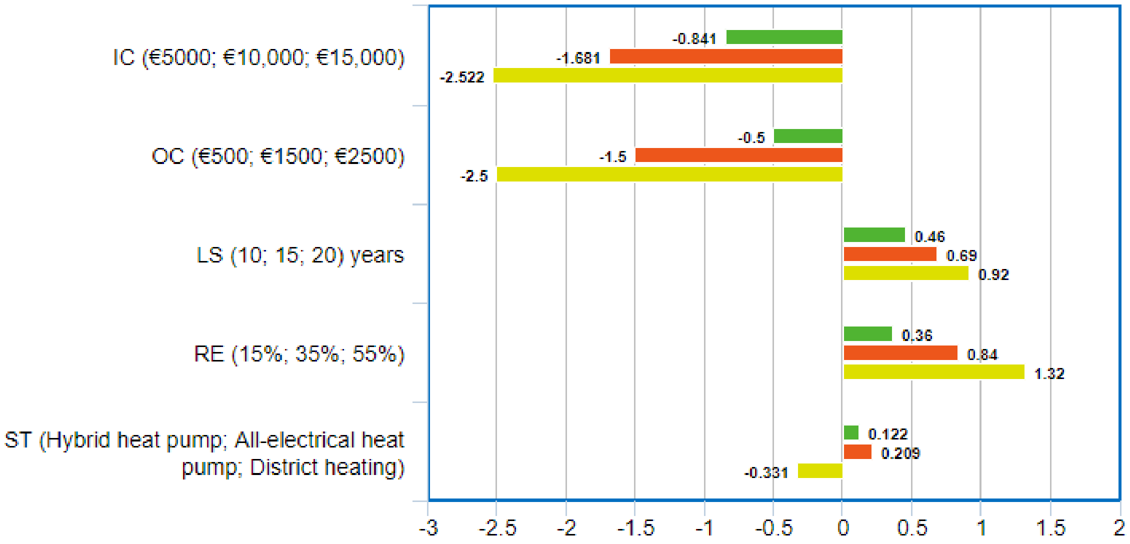
As stated in Table 10, the constant related to the sustainable heating alternatives is significant and has a positive sign. The constant represents the total utility of the sustainable hating alternatives when all variables are zero. In that particular case, the positive value of the constant implies that the respondents prefer to choose a sustainable alternative rather than to stay with the current situation (the base alternative). This outcome shows that overall the respondents are willing to change their residential heating technology, which means adopting a more sustainable one. However, this effect is only applicable for the attribute values of the sustainable alternatives and the base alternative as presented within the experiment. Lastly, the constant is based on all factors that are related to the sustainable heating alternatives, but which are not present within the model. The constant of the final model has a lower value than the constant of the basic model, which implies that adding the context variables and socio-demographics was meaningful to reduce the influence of unobserved variables.

Estimated attribute parameters

The parameters of the attributes within the final model are comparable to those within the basic model. The signs of the parameters are expected and all the parameters are seen as significant. While looking at the relative importance of the variables, it can be concluded that the respondents find the costs related to a sustainable heating technology the most important factor for their decision. The higher the costs of the sustainable heating alternatives, the more the respondents prefer the base alternative and vice versa. Furthermore, the first four attributes define the characteristics of the technologies and contain a higher relative importance than the technology type attribute. Therefore, the respondents find it more important for their decision what the characteristics of the technology are than which technology type it is.

The estimated parameters of the technology types show that the respondents find all-electrical heat pumps the preferred sustainable heating alternative while district heating is the least favourable. An explanation of this result could be that the respondents find it more difficult to imagine a situation whereby they adopted district heating. As stated in Chapter 4.1.1, this technology is mostly used in complete neighbourhoods in urban areas nearby industries for an efficient implementation. However, such a specific case could be contrary to the imagination of the respondents. Furthermore, the values of the parameters of the technology types are influenced by their corresponding estimated interaction effects. Therefore, these estimates can not be interpreted separately and are explained in this section. First, the penetration rate context variable has a significant effect on the choice for an all-electrical heat pump. The parameter value shows that all-electrical heat pumps become less popular in case of a higher penetration rate. However, the effect of penetration rate on hybrid heat pumps was non-significant so not translatable to the choice behaviour of the respondents. Second, the Urgency context is significant for both the estimated technology types. The parameters of the interaction effects show a logical outcome because the respondents let their decision depend on the year that natural gas usage is stopped by the Dutch government. The lower the urgency, the more hybrid heat pumps are preferred and the other way around regarding the popularity of all-electrical heat pumps. All in all, the utility contributions of the attributes are plotted in Figure 7.

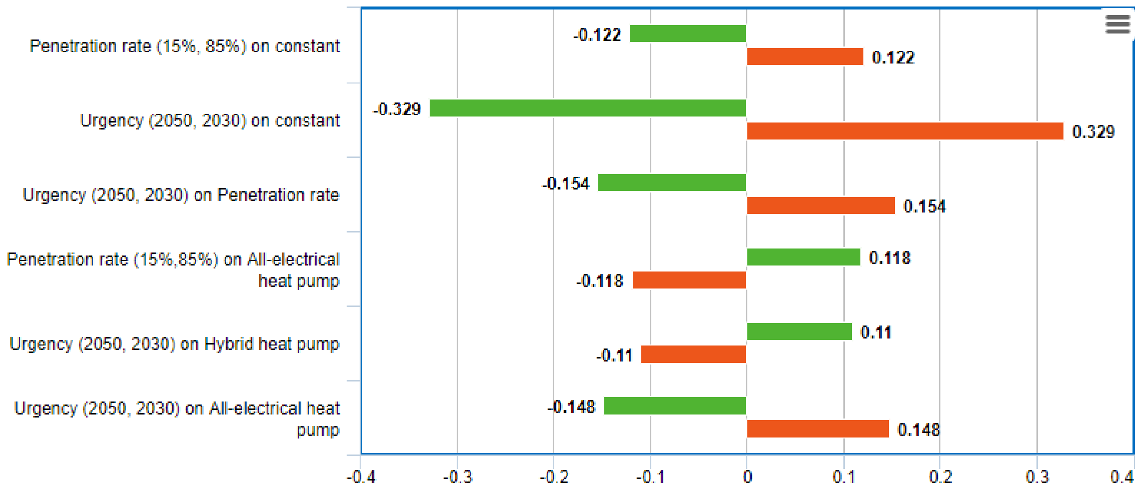
Figure 7: Utility contributions of attributes



Estimated context parameters

Within this section, the other interactions effects of the contexts are described. First, the interaction of the penetration rate with the constant has a negative sign, which indicates that sustainable heating alternatives are more preferred when they are already adopted by other people with comparable housing characteristics. This outcome confirms that technology adoption is influenced by interpersonal interaction, as stated in the literature review. Second, the interaction of the urgency context variable with the constant also have a negative sign. The outcome shows that the respondents are more likely to adopt a sustainable technology in case of high urgency. In a scenario with earlier shutting down of natural gas usage, the respondents see more future perspective in sustainable alternatives, which influences their choice behaviour. As stated in the previous section, the higher the urgency the more likely it is that all-electrical heat pumps are the preferred sustainable heating alternative. Third, the interaction effect between the two context variables shows that the influence of the penetration rate on the respondents' choice behaviour increases when the urgency increases as well. This effect also indicates that the sustainable energy behaviour (in terms of adoption) of the respondents is dependent on the natural gas policies of the Dutch national government. Lastly, the relative importance of the context variables shows that the urgency context variable is most influential. However, the interactions are barely influencing the choice behaviour of the respondents compared to other variables. In real life, this could be different because this outcome is caused by the explanation and framing of the context within the experiment, which is further discussed in Chapter 8.2. Overall, the utility contributions of the interaction effects of the contexts are illustrated in Figure 8.

Figure 8: Utility contributions of interactions effects of the context variables



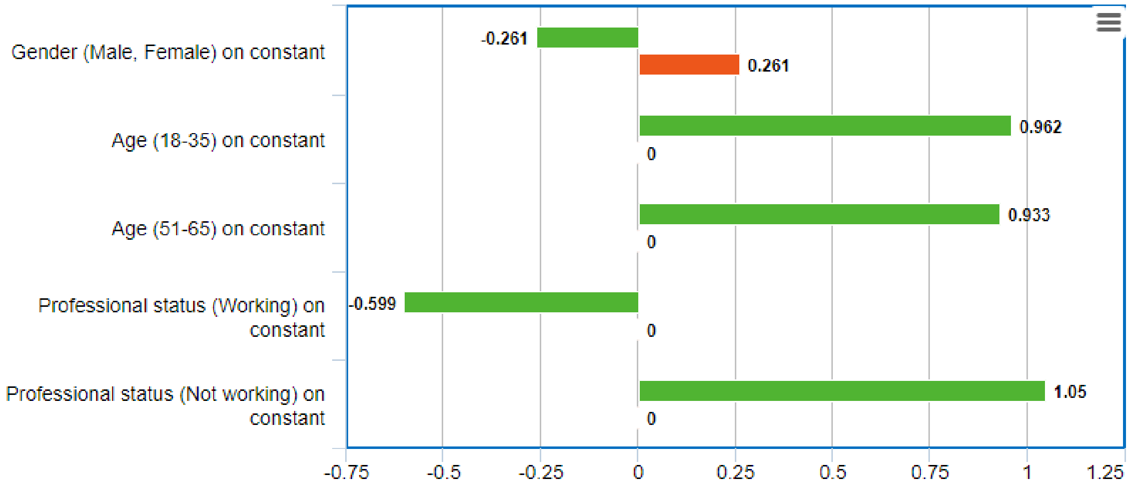
Estimated socio-demographic parameters

The last parameters that are interpreted are the interaction effects of the socio-demographics. As stated in Chapter 6.2, none of the estimated interaction effects with the attributes were significant. This means that the effects of age and educational attainment on the preferences regarding sustainable technology type were not applicable for declaring the choice behaviour of the respondents. This is also the case for the influence of education and household size on the constant. Both socio-demographic interaction effect can not be translated to the choice of adopting a sustainable alternative by the respondents.

However, other interaction effects were seen as significant and can be interpreted. First, the effect of gender on the constant shows that men are less likely to adopt sustainable heating alternatives than women. Table 6 shows that men are over-represented within the sample, which means that almost all the women choose to adopt a sustainable alternative instead of the base alternative. Second, the first (18-35) and third (51-65) age group have a positive effect on the constant, which indicates that the respondents of these ages are most willing to adopt a sustainable heating alternative rather than staying with their current technology. A possible explanation for these outcomes is the sense of urgency of the youngest age group regarding climate change and the Dutch energy transition and the prosperity of the third age group, which cause the intentions to adopt sustainable heating technologies. Third, the effect of professional status shows that the respondents without a job are more willing to adopt than respondent with a job. This outcome seems strange but can be declared by the overrepresentation of students within the sample. The consequences of the unrepresentative sample are further explained in the next section. Fourth, the interaction effects of the socio-demographics have a higher relative importance than the context variables, which indicates that personal aspects are more important than the overall context. The utility contributions of the interaction effects of the socio-demographics are stated in Figure 9.

Lastly, as stated in Chapter 5.3, the sample can not be seen as representative for the Dutch population. The influence of an unrepresentative sample on the interpretation of the results depends on the relation between the socio-demographics and the choice behaviour of the respondents. However, the relative importance of the estimated socio-demographics is showing that these variables are influential for the choice behaviour because they are responsible for approximately 35% of the total utility. Therefore, it can be concluded that the estimates of the final MNL model do not represents choice behaviour of the Dutch population in full, which has consequences for the previously covered interpretations. Namely, the findings could result in a distorted view because young and high educated students are over-represented, while low educated, lower-income and older persons are under-represented within the sample. Literature showed that such households are less likely to adopt sustainable energy technologies because their socio-demographics act as a barrier (Schleich, 2019; Cho, Shaygan & Daim, 2019). Therefore, the preferences of the sample towards sustainable heating technologies are probably less present within the Dutch society.

Figure 9: Utility contributions of interaction effects of the socio-demographics



6.4 Conclusion

The purpose of this chapter was to measure the influences of the design variables (attributes, contexts, and socio-demographics) by composing and estimating a MNL model that fits the choice behaviour of the respondents the best. To fulfill the purpose, a basic MNL model is composed and estimated. This model only consists of the attributes and illustrates the influence of the sustainable heating characteristics on the respondents' choice behaviour. To further improve the model fit, an optimisation process is started. The optimisation process is formed by adding the (1) contexts variables and (2) socio-demographics. The remained variables (based on their strength and significance) together form the final MNL model. As can be seen in Table 9, this model fits the respondents' choice behaviour the best as it explains 27.4% of the initial uncertainty of the choice data. The estimates of the basic, as well as the final model, are interpreted. An overview of the conclusions that can be drawn from these interpretations follows below:

- The positive value of the constant implies that the respondents prefer to choose a sustainable alternative rather than to stay within the current situation (the base alternative). This outcome shows that overall the respondents are willing to change their residential heating technology, which means adopting a more sustainable one. However, this effect is only applicable to the scenarios and corresponding technology characteristics as presented within the experiment.

- In total, the attributes are most influential for the choice behaviour of the respondents. The respondents find the costs related to a sustainable heating technology the most important factor that influences their decision. The higher the costs of the sustainable heating alternatives, the more the respondents tend to stick to natural gas-based solutions and vice versa.

- Overall, the respondents find all-electrical heat pumps the preferred sustainable heating alternative while district heating is the least favourable. This could be caused by the fact that district heating is only applied in specific cases, which could make the adoption within the household difficult to imagine for the respondents.

- The results show that the respondents are more likely to choose a sustainable alternative within a scenario that contains a high urgency, which means that they see more future perspective in these alternatives. Furthermore, the respondents prefer all-electrical heat pumps in case of a high urgency of the Dutch energy transition while hybrid heat pumps are preferred in the opposite scenario. This indicates that the choice behaviour of the respondents depends on their sense of urgency, which is stated as the year that natural gas usage is stopped by the Dutch government within this research.

- The respondents are more willing to adopt a sustainable heating technology when there is a high penetration rate (adoption of other people with comparable housing characteristics). This outcome confirms that technology adoption is influenced by interpersonal interaction, as stated within the literature review.

- The interaction between the context variables shows that the influence of the penetration rate on the respondents' choice behaviour increases when the urgency increases as well. This could mean that in urgent times the respondents let their choice behaviour depend more on the adoption experiences of relatives.

- The *Income* socio-demographic could not be estimated, due to the presence of too many missing values. The variables are tested, but the missing values declined all the model performances and negatively influenced the other parameters. Therefore, the influence of this socio-demographic on the respondent's choice behaviour is still unknown.

- In their entirety, the socio-demographics *Education* and *Household size* were seen as non-significant, which means that the effects of these variables on the preferences regarding sustainable technology type are not applicable for declaring the choice behaviour of the respondents. This is also the case for the influence of all the socio-demographics on the preferences between the sustainable technology types, which means that personal characteristics do not declare the differences in technology type preferences within the sample.

- Respondents that are part of the first (18-35) or third (51-65) age group are most willing to adopt a sustainable heating alternative rather than staying with their current technology. This outcome could be based on the sense of urgency of the youngest age group regarding climate change and the Dutch energy transition and the prosperity of the third age group, which cause the intentions to adopt sustainable heating technologies.

- The results show that people without a job or more likely to adopt sustainable heating alternatives than people with a job. However, this outcome is likely distorted due to the overrepresentation of students (that embrace environmental values) within the sample.

- The influence of the socio-demographics on the choice behaviour of the respondents is bigger than that of the context variables. This indicates that the respondents see their personal situation as more important than the overall choice context.

- Lastly, the unrepresentativeness of the sample combined with the significant influence of the socio-demographics on the respondents' choice behaviour results in the fact that the findings of the estimated final model do not represent the choice behaviour of the Dutch population in full. The consequences for the previously covered interpretations are that these findings could result in a distorted view because young and high educated students are overrepresented, while low educated, lower-income and older persons are underrepresented within the sample. These people as less likely to adopt sustainable energy technologies as their socio-demographics act as a barrier. Therefore, the preferences of the sample for sustainable heating technologies are likely to be less present in the Dutch society as a whole.

7 Model application - Scenario analysis

As a model application, a scenario analysis is performed to explore the choice behaviour of Dutch energy consumers. The estimated final MNL model provides insights into the choice behaviour of the energy consumer the best. Therefore, this model is used to evaluate the choice behaviour within several future scenarios of the Dutch energy transition. The evaluation shows which (policy) measures are effective for maximising the utility of the energy consumers and how the Dutch energy transition can be realised. Therefore, this model application is useful for the formulation of (policy) recommendations.

7.1 Future scenarios of the Dutch energy transition

In this chapter, four different scenarios are formed, which are explained in the sections below. The scenarios are formed by transforming the model variables, which serve as measures that influence the choice behaviour of the energy consumers. The overall design of the scenarios is stated in Table 11. The choice behaviour of the energy consumers is represented by determining the total utility and market shares of the sustainable heating alternatives. Furthermore, the preferences regarding the base alternative (reference of the current situation) are also measured but this alternative stays constant within the future scenarios.

7.1.1 Scenario 1 - Current roadmap of Dutch government

This scenario is based on the current goals of the Dutch government regarding achieving a sustainable future. The goals of their energy transition, which form the overall context, are to use natural gas until 2050 and achieving a high penetration rate regarding sustainable heating technologies. Furthermore, this scenario is composed as the most neutral scenario. Therefore, all the average attribute values are implemented.

7.1.2 Scenario 2 - Scientific innovation

This scenario is based on the TRANSFORM scenario of TNO's research (Scheepers et al., 2020). This scenario implies that the Netherlands switches to a sustainable economy that is less energy-intensive by using innovative energy technologies. New scientific findings were the cause of these innovations. The innovations result in improvements of the technical performances and costs reductions of the sustainable heating alternatives. Regarding the context, an average scenario is created, which means that there is a penetration rate of 50% and natural gas is used until 2040.

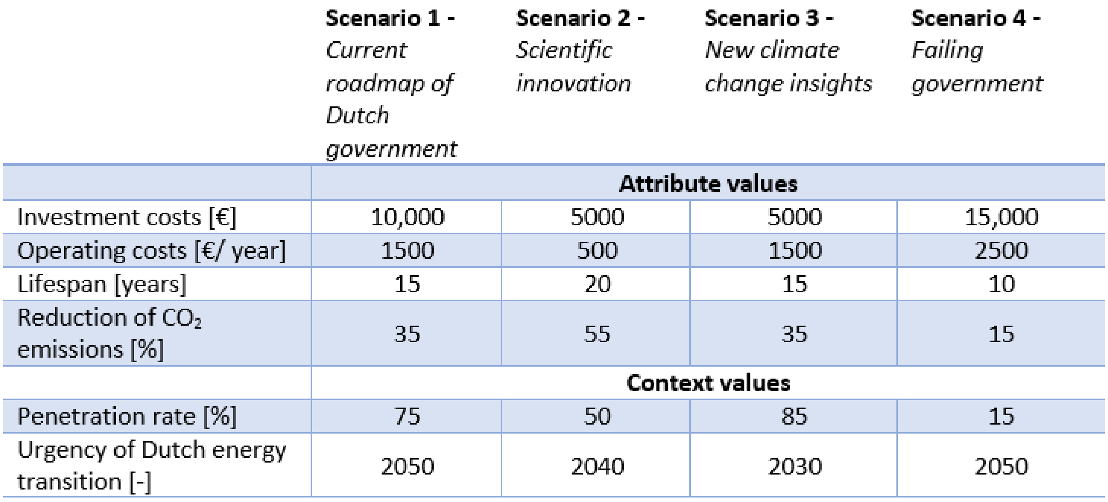
7.1.3 Scenario 3 - New climate change insights

Scientists found out that the effects of climate change occur sooner and with more consequences than expected. The scientific reports are taken seriously by the Dutch government and result directly in new governmental policies. Therefore, the Dutch government stops with natural gas in 2030 and provides subsidies for purchasing sustainable heating alternatives. Furthermore, the scientific report supports the public opinion regarding sustainability, which boosts the penetration rate of sustainable heating alternatives.

7.1.4 Scenario 4 - Failing government

In this scenario, the Dutch sustainable future is not bright. The government has a poor relationship with the citizens and companies due to disagreement about the costs that are accompanied with the sustainable future goals. Therefore, the sustainable heating technologies are poorly innovated, which results in bad technical performances and therefore a low penetration rate. Furthermore, the disagreement lowered the urgency feeling of the citizens, which led to natural gas usage until 2050.

Table 11: Design of scenario analysis



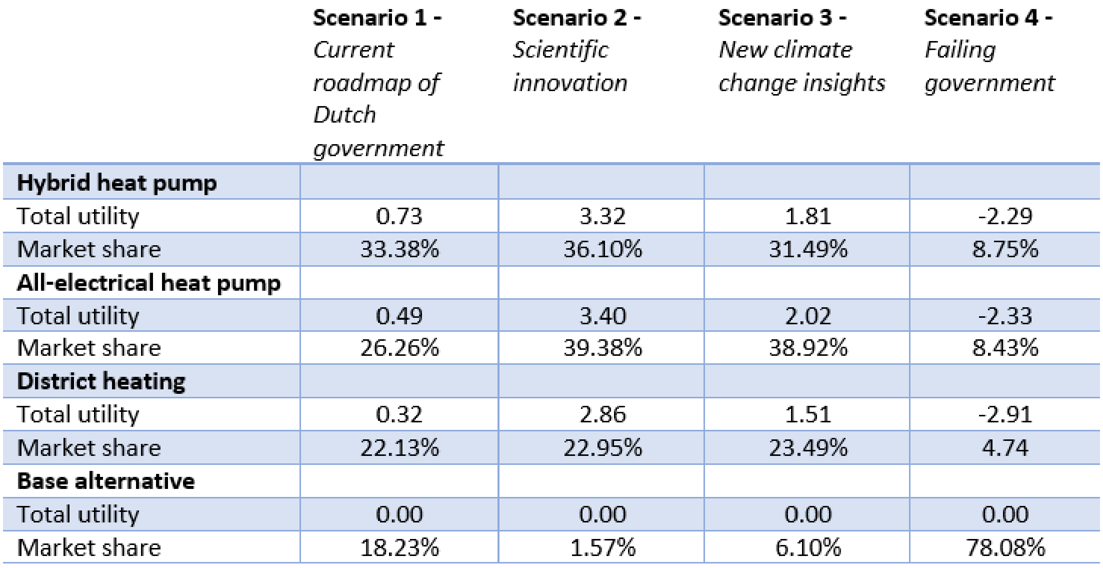
	Scenario 1 - *Current roadmap of Dutch government*	**Scenario 2 -** *Scientific innovation*	**Scenario 3 -** *New climate change insights*	**Scenario 4 -** *Failing government*
	Attribute values			
Investment costs [€]	10,000	5000	5000	15,000
Operating costs [€/ year]	1500	500	1500	2500
Lifespan [years]	15	20	15	10
Reduction of CO_2 emissions [%]	35	55	35	15
	Context values			
Penetration rate [%]	75	50	85	15
Urgency of Dutch energy transition [-]	2050	2040	2030	2050

7.2 Scenario analysis

As stated earlier, the final MNL model is used for the scenario analysis. Per scenario, the energy consumers preferences are represented by the total utility and market share of the sustainable heating alternatives as well as the base alternative. This model contains socio-demographics, which means that the preferences are calculated per respondent. The final preferences per scenario are therefore the average values of all respondents. The total utility of a technology is calculated by filling in the utility function of the final MNL model with the attribute, context, socio-demographic, and estimated parameter values as stated in Table 10 and Table 11. Thereafter, the market shares are calculated by implementing the total utilities of the alternatives within a Logit function.

The purpose of the scenario analysis is to serve as a model application to explore the choice behaviour of Dutch energy consumers within different scenarios. However, the previous chapter concluded that the findings of the estimated final model do not represent choice behaviour of the Dutch population in full. Which is due to the unrepresentative sample and influences of the socio-demographics. Therefore, the consequence is that the results are interpreted in light of the sample distribution. This is not desirable for the scenario analysis because it is impossible to compose policy recommendations if the results are only applicable to the sample. Therefore, to tackle this consequence, the effects of the socio-demographics within the utility function are multiplied with a factor to transform the sample distributions into the population distributions. In other words, the under-represented respondents will obtain a multiplier that supports the impact of their preferred heating alternative on the average preferences. This approach makes sure that the results of the scenario analysis can be interpreted to (effects on) choice behaviour of the Dutch population. All in all, the calculated preferences per scenario are stated in Table 12

Table 12: Dutch energy consumer preferences within constructed scenarios



	Scenario 1 - *Current roadmap of Dutch government*	**Scenario 2 -** *Scientific innovation*	**Scenario 3 -** *New climate change insights*	**Scenario 4 -** *Failing government*
Hybrid heat pump				
Total utility	0.73	3.32	1.81	-2.29
Market share	33.38%	36.10%	31.49%	8.75%
All-electrical heat pump				
Total utility	0.49	3.40	2.02	-2.33
Market share	26.26%	39.38%	38.92%	8.43%
District heating				
Total utility	0.32	2.86	1.51	-2.91
Market share	22.13%	22.95%	23.49%	4.74
Base alternative				
Total utility	0.00	0.00	0.00	0.00
Market share	18.23%	1.57%	6.10%	78.08%

7.2.1 Interpretation of results

When looking at the energy consumer preferences within the different scenarios several conclusions can be drawn. First, the worst-case scenario (scenario 4) shows that without stimulation from the Dutch government or businesses the current situation is maintained. It characterises the situation and consequences of doing nothing. In this situation, the technical characteristics are poorly innovated, which results in negative utility scores for the sustainable alternatives. As stated in Table 6.3, the costs related to the alternatives are most influential for the choice behaviour of the energy consumer. Within scenario 4, the costs of the sustainable alternatives are simply so high that the population prefers the usage of natural gas for residential heating. Lastly, this situation is dramatic and not likely to occur. Therefore, it will not be part of the other interpretations.

Second, the ratios between the market shares of the sustainable alternatives do not deviate that much over the scenarios, but the differences with the base alternative do. This indicates that the main dilemma of the energy consumers is the choice between adopting a sustainable alternative or maintaining the current situation. The choice between the exact typing of a sustainable technology is less important, which is also proven by the low relative importance of the technology type attribute.

Third, scenario 1 was representing the current roadmap of the Dutch government. The outcomes prove that this direction can contribute to the realisation of the climate goals. Together, the three sustainable alternatives have a penetration rate of 82%. The large-scale adoption will support the realisation of the Dutch energy transition. However, in the long run, the adoption of hybrid heat pumps is not preferred and needs to be scaled down because this technology still uses natural gas. Therefore, the characteristics of all-electrical heat pumps and district heating need to be further improved to obtain a scenario whereby these two technologies have market dominance.

Fourth, as the previous point, scenario 2, and 3 indicates, improvements regarding the technical characteristics of the sustainable alternatives and increasing the sense of urgency of the Dutch energy transition will lead to a drastic improvement in terms of technology adoption. Furthermore, in these two scenarios, the most utility is gained, which make these scenarios favourable. Again, these outcomes indicate that innovations and social interactions define the choice behaviour of the Dutch energy consumer and are the main drivers for the future of the energy transition.

Lastly, despite the differences in the attribute and context values, the market share of district heating did not change within the scenarios. The total utility did change between the scenarios but not as much as the other sustainable alternatives, which remains the same ratio. This could indicate that the energy consumers did not have enough knowledge about this alternative to make a well-considered choice regarding technology adoption. Another explanation is that the choice for adopting district heating is influenced by factors that are not implemented within the scenario analysis.

All in all, the scenario analysis as a model application provided an overview of the Dutch energy consumer preferences for various situations. The scenarios show the possible outcomes of hypothetical situations in terms of market shares of the residential heating alternatives. Furthermore, the influences of the attributes and context variables on choice behaviour became extra clear and tangible. Therefore, the outcomes of this analysis are used to compose policy recommendations for the Dutch national government regarding their energy transition. These recommendations are stated within Chapter 9.2.

8 Conclusion & discussion

In this chapter, the insights and corresponding conclusions that are gained by conducting the research are elaborated upon. These insights are provided by answering the research questions, which is executed in Chapter 8.1. Furthermore, in Chapter 8, the results from this study are discussed and reflected by using current literature.

8.1 Conclusion

The purpose of this research is to gain knowledge about the application of dynamic future contexts within stated choice experiments to produce energy consumer preferences that stay valid over time. Therefore, this research contributes by executing a context-dependent stated choice experiment with various future scenarios of the Dutch energy transition. To achieve the research objective, the research contribution is translated into the following main research question:

What are the energy consumer preferences regarding the adoption of sustainable residential heating technologies and how are these related to future contexts of the Dutch energy transition?

8.1.1 Influential contexts for the future of Dutch residential heating

The answer to this sub-question is provided by performing a literature study that identifies the contextual factors that are influential for energy transitions in general and the future of the Dutch energy transition in particular. The literature study shows two recurring types of contextual factors, which are social interactions and temporal contexts.

The literature showed that social aspects such as cultural meanings, norms, motivations, and social values are key for public support regarding the implementation of sustainable technologies. These social interactions are translated into one context variable, which is implemented in the choice experiment design. Namely, the *penetration rate*, which represents the percentage of technology adoption by people with comparable housing characteristics. This context represents the social interactions well because it is accompanied by the social pressure of other energy consumers, which stimulates the adoption of the individual consumer. Based on prior literature, the context levels are set at 15% and 85%.

With regard to the temporal contexts, the literature showed that time-based aspects such as threats and deadlines related to climate change are important for the (Dutch) energy transition. These influences are translated into the context variable of *urgency of the Dutch energy transition.* The variable represents the sense of urgency, which is caused by the consequences of climate change. This context variable is translated into the year in which the natural gas usage is phased out according to the legislation of the Dutch government. The context levels are based on the year 2050 (low urgency) and 2030 (high urgency).

8.1.2 The preferences of Dutch energy consumers related to the sustainable and non-sustainable heating technologies and the influence of the choice context and technology characteristics on these preferences

The descriptive statistics of the stated choice experiments shows that the base alternative (represents non-sustainable and currently used technology) is chosen 29% of the time, the hybrid heat pump 27%, the all-electrical heat pump 28%, and district heating within 16% of the observations. However, these numbers are not exactly defining the consumer preferences because they are dependent on the presented attribute values within the choice tasks. Therefore, a discrete choice model is estimated to determine the respondents' choice behaviour and the influences of the attributes and context variables on their preferences.

The value of the estimated constant related to the sustainable heating alternatives indicates that it is preferred to choose a sustainable alternative rather than to stay within the current situation (the base alternative). This outcome shows that the respondents are willing to change their residential heating technology, which means adopting a more sustainable one. However, this effect is only applicable to the scenarios and corresponding technology characteristics as presented within the experiment. Furthermore, the estimates show that the respondents find all-electrical heat pumps the most preferred sustainable heating alternative while district heating is the least favourable. This could be caused by the fact that district heating is only applied in specific cases, which could make the situation of adoption within their household difficult to imagine for the respondents.

Regarding the influence of the technology characteristics, the research outcomes show that the costs (Investment- and Operating costs) related to a sustainable heating technology are the most important factors for their decision. The higher the costs of the sustainable heating alternatives, the more a non-sustainable solution (base alternative) is preferred and vice versa. Furthermore, the respondents find it more important for their decision what the characteristics of the technology are than which technology type it is.

After determining the influences of the context variables it can be concluded that the respondents are more likely to choose a sustainable alternative within a scenario that contains a high urgency, which means that they see more future perspective in these alternatives. Sustainable heating technologies are also more preferred in case of a high penetration rate (adoption of other people with comparable housing characteristics). Moreover, the influence of the penetration rate on choice behaviour is influenced by the urgency context. The penetration rate becomes more important for decision-making in case of urgent times. The context variables are also influential for the preferences related to the technology type. Namely, all-electrical heat pumps are preferred in case of a high urgency of the Dutch energy transition while hybrid heat pumps are preferred in the opposite scenario. Lastly, the effect of the urgency context variable on the influence of the investment costs was not translatable to the choice behaviour of the sample due to a lack of statistical significance.

8.1.3 The effect of socio-demographic characteristics on the energy consumers preferences for the sustainable heating alternatives

In the experiment, socio-demographic questions are asked to determine the influence of these characteristics on energy consumer preferences. After analysing the socio-demographics of the respondents, several conclusions can be drawn. First, the influence of the yearly income of the respondents could not be estimated due to the presence of too many missing values. Second, none of the estimated interaction effects of the socio-demographics (age and education level) affected the influence of the technology type attribute that were applicable for declaring the choice behaviour of the respondents. Third, respondents that fit in the age group of 18-35 or 51-65 are most willing to adopt a sustainable heating alternative rather than staying with their current technology. The preference for sustainable technology adoption could be caused by the sense of urgency of the youngest age group regarding the Dutch energy transition and the prosperity of the third age group. Fourth, respondents without a job or more likely to adopt sustainable heating alternatives than people with a job. However, this outcome is likely distorted due to the overrepresentation of students (that embrace environmental values) within the sample. Lastly, the influence of the socio-demographics on the choice behaviour of the respondents is bigger than that of the context variables. This indicates that the respondents see their personal situation as more important than the overall choice context.

All the previously mentioned findings are based on the measured and estimated choice behaviour of the respondents within the sample. However, the descriptive statistics showed that the sample is unrepresentative for the Dutch population. The unrepresentativeness of the sample combined with the significant influence of the socio-demographics on the respondents' choice behaviour results in the fact that the findings do not represent the choice behaviour of the Dutch population in full. The consequences for the interpretations are that these findings could result in a distorted view. For example, young and high educated students are over-represented. While low educated, lower-income and older persons are under-represented within the sample. However, these people as less likely to adopt sustainable energy technologies as their socio-demographics act as a barrier. Therefore, the preferences of the sample towards sustainable heating technologies are probably less present within the Dutch society.

8.1.4 Main research question

To answer the main research question, the outcomes of the three sub-questions are applied within a scenario analysis. This model application is performed to explore the choice behaviour of energy consumers within several future scenarios of the Dutch energy transition. The estimated outcomes of the model that is used for the scenario analysis are transformed in such a way that they are representative to the Dutch population. Within the scenarios, the energy consumers preferences are represented by the total utility and market share of the alternatives.

Just like in the model estimates, the scenario analysis shows that the Dutch energy consumers prefer to choose a sustainable alternative rather than to stay within the current situation (the base alternative). In particular, in most scenarios, the all-electrical heat pump is seen as the most preferred sustainable heating alternative while district heating is the least favourable. However, the ratios between the market shares of the sustainable alternatives do not deviate that much over the scenarios but the differences with the base alternative do. This indicates that the main dilemma of the energy consumers is the choice between adopting a sustainable alternative or maintaining the current situation. The choice between the exact typing of a sustainable technology seems less important.

Concerning the influence of the future contexts on these energy consumer preferences, the results of this research show that the context variables are influential. For example, both a high penetration rate and a sense of urgency regarding the Dutch energy transition support the adoption of sustainable heating technologies. However, the effects of the context variables on the preferences are less impactful than that of the technology characteristics. The model estimation, as well as the scenario analysis, emphasised the importance of the technology characteristics on the choice behaviour of the Dutch energy consumer. Lastly, the scenario analysis states that the degree of innovation and government interference regarding the technology characteristics are drastically changing the outcomes of the Dutch energy transition. Therefore, to achieve the Dutch climate goals, the national government needs to take an active role in optimising the technology characteristics to realise large-scale adoption of sustainable residential heating technologies.

8.2 Discussion of results

8.2.1 Influence of sustainable technology adoption on success energy transitions

This research is focused on the adoption of sustainable technologies because they facilitate energy transitions by improving energy behaviour and help to achieve energy-related goals (Essletzbichler, 2012). However, as stated by Stern (1999), to improve sustainable energy transitions, a wide range of changes in energy behaviour is needed. Steg et al. (2015) investigated these behavioural changes and concluded that besides the adoption of energy-efficient technologies, investments in the energy efficiency of buildings and changes in energy use behaviour are important as well. These findings would indicate that the adoption of sustainable technologies only partially contributes to a successful energy transition. This is also emphasised by the "Trias Energetica" principle. This principle is a three-step strategy for achieving optimal sustainable energy use. The three steps are: continuous improvement of energy efficiency, large-scale deployment of sustainable energy sources, and a cleaner and more efficient use of the remaining fossil fuels. The three steps are in practice realised by executing energy-saving measures and optimising the efficiency of sustainable and non-sustainable energy sources (Entrop & Brouwers, 2010). The adoption of sustainable technologies is only related to the second strategy of the Trias Energetica. Therefore, the results and corresponding policy recommendations of this research should be combined with knowledge and measures related to the other aspects of the Trias Energetica. This would optimize the success of the Dutch energy transition.

8.2.2 Sustainability of district heating

Within this research, the focus was related to three sustainable heating technologies. Namely, hybrid heat pumps, all-electrical heat pumps, and district heating. These technologies were chosen because they are good transition techniques or because of their potential to become carbon neutral (Heynen et al., 2018; Klip, 2017). However, sceptics have doubts about the sustainability of some of these alternatives. For example, the large-scale deployment of district heating via residual heat from industries is not seen as sustainable, due to greenwashing. Greenwashing is a principle that is executed by companies and implies misleading energy consumers related to the environmental performance of their product or service (Delmas & Burbano, 2011). Delivering residual heat provides these companies with sustainability labels. Such labels result in the fact that they have to pay less CO_2 taxes, which does not support the companies to decrease their energy use. Therefore, the performances of industries that deliver residual heat are greenwashed by misleading the energy consumers. Lastly, Scheepers, et al. (2020) predicted that natural gas use in the built environment is replaced by residual heat from industries on a large scale. Therefore, it should be questioned whether this alternative is pushing the Dutch energy transition in the right direction.

8.2.3 Differences in views regarding the importance of contexts on choice behaviour

In this research, the influence of Dutch energy transition contexts on energy consumer preferences for adoption sustainable residential heating technologies is determined. The is achieved by conducting a context-dependent stated choice experiment. This method is chosen because prior literature stated that energy consumer behaviour strongly depends on contextual factors (Black, Stern & Elworth, 1985; Steg et al., 2015; Steg & Vlek, 2009: Stern, 1999; Thøgersen,2005). Therefore, based on the literature review, the *Penetration rate* and *Urgency of the Dutch energy transition* context variables are implemented in the stated choice experiment design due to their influence on the future of the Dutch energy transition.

However, the model estimations related to the choice behaviour of the respondents show that the (interaction) effects of the context variables are the least influential. This indicates that the technology characteristics and the socio-demographic variables have a bigger influence on the preferences of energy consumers. Therefore, there seems to be a discrepancy between the importance of these contexts as stated in the literature and with the outcomes of this research. A reason for this result is the degree of framing of the context variables within the experiment. The two context variables are representing influential contexts regarding social interactions and temporal aspects that were found within the literature review. However, the respondents were possibly biased due to the definition and explanation of these context variables within the experiment. All in all, the outcomes of this research on their own can not claim that contexts are not influential for the choice behaviour of energy consumer. The relationship between these two aspects is only applicable to the context setting as created within this research. Therefore, within a different research setting, it should be tested whether context variables are influential for the choice behaviour of energy consumers.

9 Limitations & recommendations

Within this last chapter, the research is reflected by stating limitations related to the data-gathering process, the usefulness of the methodology, and interpretations of the results. These limitations are held in Chapter 9.1. Lastly, as a response to these limitations, recommendations regarding policies and future research are provided. These recommendations serve as solutions to the limitations and are elaborated in Chapters 9.2 and 9.3.

9.1 Research limitations

9.1.1 Limitations and consequences of data-gathering process

The first limitation of this research is related to the data-gathering process and its consequences. Unfortunately, due to the Covid-19 pandemic, it was not possible to gather data physically. Surveying in various residential or public areas would increase the overall response rate and mix up the sample in terms of socio-demographics. However, the circumstances resulted in an online distribution approach, which is accompanied by multiple consequences for the validity of the data. The descriptive statistics analysis shows that (in terms of academic research) a low amount of responses is achieved (95), which is mainly caused by the high dropout rate (54%). Another limitation of the data-gathering process is the possible occurrence of selection bias. This phenomenon implies that the researcher was unintentionally biased regarding the selection of respondents. For example, by distributing the survey among friend and family while they are not diverse regarding socio-demographics. Furthermore, the bias could also be caused by the self-selection intentions of respondents. For example, people who are concerned about the future of the environment are more likely to fill in the survey, while people who do not share such values will not. Altogether, these limitations contributed to the consequence of an unrepresentative sample, which could bias the results and their interpretations.

9.1.2 Selection of representative attributes

For composing the experimental design of the state choice experiment, literature regarding the important attributes of the sustainable heating alternatives is analysed. The analysis resulted in the inclusion of characteristics that describe the usefulness of the technologies, such as their costs, lifespan, environmental friendliness, and typing. However, it was not possible to include characteristics related to the ease of use of the technologies in the choice experiment. These characteristics are subjective (based on feeling and attitudes) and can not be expressed in numbers. Not including this variable in the experiment could reduce the validity of the choice data because it is influential for technology acceptance according to the Technology Acceptance Model (Lu, Yu, Liu & Yao, 2003). This is also emphasised by the feedback of some respondents, they mentioned that they were missing an attribute related to the ease of implementation. This shows that perceived ease could be influential for the choice behaviour of the respondents.

9.1.3 Usefulness of methodology

The literature study showed that the future of the Dutch energy transition is dynamic, uncertain, and influenced by many contextual factors. Within the scientific landscape, there is a trend (that is supported by leading researchers) whereby extensive experiments that reflect real-world choice situations are preferred. These experiments would increase the validity of data by minimising the presence of the hypothetical bias. However, extensive experiments decrease the reliability of preference data and are difficult to apply in the form of a survey related to a context-dependent stated choice experiment. Implementing all important contexts is just not possible due to the limit of possible nested choice sets within a design (otherwise the survey is too long or contains too many blocks). Furthermore, some respondents already experienced the survey as complex and time-consuming, while the design only contains 5 attributes, 2 contexts and 12 choice tasks. Therefore, it is debatable whether extensive choice experiments are a sufficient method to measure consumer preferences related to energy transitions.

9.1.4 Limitations of psychological effect

The research objective was based on the detected academic knowledge gap, which implies that current knowledge is lacking regarding how the dynamic and uncertain future scenarios of energy transitions can be applied as choice context within context-dependent stated choice experiments. Therefore, to overcome this gap, a context-dependent stated choice experiment related to the adoption of sustainable energy technologies is performed. Within this experiment, choice behaviour regarding technology adoption is measured by presenting hypothetical choice situations to the respondent. These choice situations were accompanied by contexts, which present hypothetical future scenarios. However, prior academic research stated that people find it difficult to oversee future scenarios, which could bias the consumer preferences. This is also emphasised within the psychological method *mental time travel* (Suddendorf & Corballis, 2007). The method refers to the ability that allows people to mentally project themselves backwards or forwards in time. Despite the usefulness of the method, it also contains difficulties. Namely, the future predictions are prone to error since they could be based on very small memories of events. Furthermore, the human mind constructs future visions on previously gained experiences, which means that means people often expect the future to be more like the past/present than it will be.

Another psychological effect that could be influential for the energy consumer preferences is *temporal discounting* (Green, Myerson, Lichtman, Rosen & Fry, 1996). Temporal discounting refers to the effect that people assign less value to rewards that are delayed. When people have to choose between long- and short term options, they mostly weigh the direct reward more heavily than the benefits of the long-term. Regarding this research, this would mean that it is likely that the respondents lean towards maintaining their currently used technology instead of adopting a sustainable one. Therefore, the respondents can be biased towards the adoption of future sustainable heating alternatives, which makes temporal discounting a limitation for measuring energy consumer preferences within future scenarios.

9.1.5 Hypothetical bias

The last limitation of this research is also related to the validity of the outcomes. Namely, stated choice experiments measure choice behaviour in hypothetical situations but do stated choices reflect what people choose in reality? This discrepancy between stated and revealed preferences is also known as the hypothetical bias (Murphy, Allen, Stevens,& Weatherhead, 2005). To increase the validity of the experiment, the bias can be reduced by providing the respondents with complete information, optimising the clarity of the choice context, and fully describing the alternatives within the same format as in real markets.

9.2 Policy recommendations

Based on the research findings and the described limitations of Chapter 9.1, several policy recommendations are formulated. These recommendations can be seen as advice for policymakers to optimise the adoption of sustainable heating technology to realise the Dutch energy transition. The following policy recommendations are stated:

Support innovations of sustainable heating technologies

The model estimates showed that the respondents are willing to adopt a sustainable heating alternative rather than staying within the current situation. Furthermore, was found that the technological characteristics (attributes) are the most influential for the choice behaviour. In particular, the costs related to a sustainable heating technology are determining the preferences of the respondents. By executing the scenario analysis, these outcomes are also applicable for the preferences of the Dutch energy consumer within future scenarios. The scenarios show that innovations, which could cause better performances and cost reduction, will lead to drastic changes in terms of sustainable technology adoption. Therefore, to stimulate technological innovation, it is recommended to enter into a partnership with specialised companies and research groups. Furthermore, the subsidies granted by the Dutch government should be retained and increased. The scenarios show that the investment costs should be around 5000 euros to achieve the preferred market share. All in all, the innovations that are supported by the national government will help to realise the Dutch energy transition.

Emphasise the sense of urgency related to the Dutch energy transition

The urgency of the Dutch energy transition serves as a context variable and represents the year that the Dutch government aims to get rid of natural gas usage. The sense of urgency is based on the (inter)national consequences of climate change. The results show that the respondents are more likely to choose a sustainable alternative within a scenario that contains a high urgency. This indicates that the respondents see more future perspective in these alternatives in case of an early shutdown of natural gas usage. Furthermore, the outcomes of this research determined that the sense of urgency influences the importance of the penetration rate. In urgent times the respondents let their choice behaviour depend more on the adoption experiences of relatives. Therefore, the context variables have a reinforcing effect on each other, which could be an ideal situation to convince the Dutch energy consumers by emphasising the needs for drastic changes to tackle climate change.

To stir up this sense of urgency, the start of a national promotion campaign is recommended. As stated in the scenario analysis, this will boost the preferences of the Dutch energy consumer towards sustainable heating adoption. It is recommended that this campaign is focused on energy consumers that fit in the age groups of 18-35 or 51-65 as the results show that these age groups are most willing to adopt a sustainable heating alternative. The strategy of the campaign could be based on the fact that the adoption by these consumer will encourage energy consumers that are less willing to adopt. This effect emphasises the importance of social interactions on sustainable technology adoption.

9.3 Future research recommendations

Based on the described limitations of Chapter 9.1, the following recommendations for future research are stated:

- Perform an experiment whereby the sample is representative for the Dutch population, which means that the results are directly interpretable to the preferences and choice behaviour of the Dutch energy consumer. To obtain a representative sample, it is recommended to increase the sample size and to adapt the data-gathering strategy during the distribution process. If the sample is monitored during the distribution process, then under-represented people can be approached to fill in the survey.

- Merge the lifespan and costs-related attributes into one attribute. Within this experiment, the investment costs, yearly costs and lifespan were given separately. However, this resulted in much calculation effort for the respondents, which is not desirable. Therefore, these three attributes should be transformed into the *payback period* attribute because this variable describes the costs over time as well as the lifespan. Unfortunately, this change was not implemented within this research because the data was already obtained when the recommendation was figured out.

- Try an efficient design (experimental designs based on prior information) to measure the choice behaviour of energy consumers. Due to time constraints, it was not possible to conduct extra experiments in advance to estimate prior information. Therefore, an efficient design could not be used. However, if prior information is known, this design type could lead to avoiding dominance, increased reliability of parameters, determination of the number of required respondents, and reduced number of choice sets.

- Implement socio-demographic questions about homeownership to test whether homeowners are more likely to adopt sustainable heating alternatives. The outcome of this test is especially important for the Dutch government because it determines the efficiency of their strategies to encourage adoption. For example, tenants could have less sense of responsibility because they are not in charge of the decision of whether their heating technology is changed, which implies that a different approach is needed.

- Perform an RP experiment among early adopters of sustainable heating alternatives. This research shows choice behaviour of energy consumers within real choice situations, which results in high validity models. However, RP experiments are contrary to the uncertain and dynamic nature of the Dutch energy transition. Therefore, the results of the RP experiment should be combined with the insights that are gained from SP experiments since the choice alternatives and market conditions are rapidly changing over time.
- Estimate a ML model to capture potential nesting effects. Nested effects are effects that are based on the correlations between choice alternatives. The principles of a MNL model ignore these correlations. The sustainable heating alternatives may be comparable in terms of characteristics that the respondents' choice behaviour is biased towards certain alternatives. It is not known if the sustainable heating alternatives contain nesting effects. Therefore, essential knowledge can be gained by executing a ML model.
- As mentioned in Chapter 9.1.3, it is impossible to test all the relevant context and attributes regarding the adoption of sustainable heating technologies within the same experiment. Therefore, an incremental approach is advised. By conducting smaller experiments the significant variables can be measured. The significant variables of all these experiments could then be merged into one extensive experiment.

10 Bibliography

Amrhein, V., Greenland, S., & McShane, B. (2019). Scientists rise up against statistical significance. *Nature (567)*, 305-307

Auty, S., & Elliott, R. (2001). Being like or being liked: identity vs. approval in a social context. *ACR North American Advances.*

Bech, M., & Gyrd-Hansen, D. (2005). Effects coding in discrete choice experiments. *Health economics, 14(10)*, 1079-1083.

Beelaerts van Blokland, R. E. F. (2008). *Designing Stated Choice Experiments: An Analysis of the Effect of Airport Location on Air Passenger's Travel Choice.*

Belk, R. W. (1975). Situational variables and consumer behavior. *Journal of Consumer research, 2(3)*, 157-164.

Ben-Akiva, M., & Bierlaire, M. (1999). Discrete choice methods and their applications to short term travel decisions. *In Handbook of transportation science*, 5-33. Springer, Boston, MA.

Black, J. S., Stern, P. C., & Elworth, J. T. (1985). Personal and contextual influences on househould energy adaptations. *Journal of Applied Psychology, 70(1)*, 3–21.

Boeters, B. (2019, July 1). *Warmtenetten in tien jaar drie keer zo groot.* Techniek & Wetenschap. Retrieved (November 19, 2020) from: `https://www.technischweekblad.nl/artikelen/tech-achtergrond/warmtenetten-in-tien-jaar-drie-keer-zo-groot`

Bosch, M. (2011). *Werkelijk vs. theoretisch energieverbruik.* Stichting Pioneering. Retrieved from: `http://www.pioneering.nl/SiteFiles/1/files/Werkelijk%20vs_%20Theoretisch%20energieverbruik%20-%20Michiel%20Bosch.pdf`

Bosman, R., Loorbach, D., Frantzeskaki, N., & Pistorius, T. (2014). Discursive regime dynamics in the Dutch energy transition. *Environmental Innovation and Societal Transitions, 13*, 45-59.

Butler, C., Parkhill, K. A., & Pidgeon, N. (2013). Deliberating energy transitions in the UK–Transforming the UK energy system: Public values, attitudes and acceptability. *UKERC, London.*

Carrington, M. J., Neville, B. A., & Whitwell, G. J. (2010). Why ethical consumers don't walk their talk: Towards a framework for understanding the gap between the ethical purchase intentions and actual buying behaviour of ethically minded consumers. *Journal of business ethics, 97(1)*, 139-158.

Caussade, S., de Dios Ortúzar, J., Rizzi, L. I., & Hensher, D. A. (2005). Assessing the influence of design dimensions on stated choice experiment estimates. *Trans-*

portation research part B: Methodological, 39(7), 621-640.

CBS. (2020, June 2). *Renewable energy consumption up by 16 percent.* Retrieved from: https://www.cbs.nl/en-gb/news/2020/22/renewable-energy-consumption-up-by-16-

CBS Statline. (2020, May 29). *Warmtepompen; aantallen, thermisch vermogen en energiestromen.* Retrieved (2020, November 19) from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82380NED/table

CE Delft. (2020a). *Factsheet Luchtwartmepomp.* Retrieved from: ce.nl/assets/upload/file/Rapporten/2020/Factsheets%20warmtetechnieken/04_Factsheet%20Luchtwarmtepomp_DEF.pdf

CE Delft. (2020b). *Factsheet HT-warmtenet.* Retrieved from: https://www.ce.nl/assets/upload/file/Rapporten/2020/Factsheets%20warmtetechnieken/07_Factsheet_HT%20warmtenet_DEF_extra.pdf

CE Delft. (2020c). *Factsheet Hybride warmtepomp.* Retrieved from: https://www.ce.nl/assets/upload/file/Rapporten/2020/Factsheets%20warmtetechnieken/06_Factsheet%20Hybride%20warmtepomp_DEF.pdf

CE Delft. (2020d). *Factsheet HR-combiketel.* Retrieved from: https://www.ce.nl/assets/upload/file/Rapporten/2020/Factsheets%20warmtetechnieken/01_Factsheet%20HR-combiketel_DEF.pdf

Chang, H. J., Yan, R. N., & Eckman, M. (2014). Moderating effects of situational characteristics on impulse buying. *International Journal of Retail & Distribution Management.*

Chen, B., & Sintov, N. (2016). Bridging the gap between sustainable technology adoption and protecting natural resources: Predicting intentions to adopt energy management technologies in California. *Energy research & social science, 22*, 210-223.

Cho, Y., Shaygan, A., & Daim, T. U. (2019). Energy technology adoption: Case of solar photovoltaic in the Pacific Northwest USA. *Sustainable Energy Technologies and Assessments, 34*, 187-199.

ChoiceMetrics. (2018). *Ngene 1.2 User Manual & Reference Guide.* ChoiceMetrics. Retrieved from: http://www.choicemetrics.com/NgeneManual120.pdf

Chorus, C. G. (2019). SEN1221 Lecture 1 - *Statistical Analysis of Choice Behaviour: Discrete choice modelling and the MNL model.*

Chung, J. B., & Kim, E. S. (2018). Public perception of energy transition in Korea: Nuclear power, climate change, and party preference. *Energy Policy, 116*, 137-144.

Cialdini, R. B., Reno, R. R., & Kallgren, C. A. (1990). A focus theory of normative conduct: recycling the concept of norms to reduce littering in public places. *Journal of personality and social psychology, 58(6)*, 1015.

Creutzig, F., Goldschmidt, J. C., Lehmann, P., Schmid, E., von Blücher, F., Breyer, C., ... & Susca, T. (2014). Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition. *Renewable and Sustainable Energy Reviews, 38*, 1015-1028.

Daly, A., Dekker, T., & Hess, S. (2016). Dummy coding vs effects coding for categorical variables: Clarifications and extensions. *Journal of Choice Modelling, 21*, 36-41.

Darnall, N., Ponting, C., & Vazquez-Brust, D. A. (2012). Why consumers buy green. *In Green growth: Managing the transition to a sustainable economy* (pp. 287-308). Springer, Dordrecht.

De Brauw, K. (n.d.). *CO2-compensatie, waarom eigenlijk?* vandebron. Retrieved from: `https://vandebron.nl/blog/co2-compensatie-hoezo-eigenlijk#:~:text=Tijd%20voor%20een%20rekensommetje%3A%20de,2%2C7%20ton%20CO2%20uit.`

Deci, E. L., & Ryan, R. M. (1987). The support of autonomy and the control of behavior. *Journal of personality and social psychology, 53(6)*, 1024.

Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California management review, 54(1)*, 64-87.

Den Ouden, B. (2018). *Verduurzaming en open toegang in warmtenetten.* Berenschot.

Dharshing, S. (2017). Household dynamics of technology adoption: A spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. *Energy research & social science, 23*, 113-124.

ECW. (n.d.). *Strategiefactsheets.* Retrieved from: `https://expertisecentrumwarmte.nl/themas/de+leidraad/strategiefactsheets/default.aspx`

ECW. (2020a). *Strategie 1: Individuele elektrische warmtepomp.* Retrieved from: `https://expertisecentrumwarmte.nl/themas/de+leidraad/strategiefactsheets/strategie+1+individuele+elektrische+warmtepomp/default.aspx`

ECW. (2020b). *Strategie 2: Warmtenet met midden- en hogetemperatuurbron.* Retrieved from: `https://expertisecentrumwarmte.nl/themas/de+leidraad/strategiefactsheets/strategie+2+warmtenet+met+midden-+en+hogetemperat/default.aspx`

Energieregio Rotterdam Den Haag. (2020). *Concept Energiestrategie Regio Rot-*

terdam Den Haag. Retrieved from: https://www.resrotterdamdenhaag.nl/wp-content/uploads/2020/04/Concept-Deel-A-Energiestrategie-Regio-Rotterdam-Den-Haag.pdf

Entrop, A. G., & Brouwers, H. J. H. (2010). Assessing the sustainability of buildings using a framework of triad approaches. *Journal of Building Appraisal, 5(4)*, 293-310.

Essletzbichler, J. (2012). Renewable energy technology and path creation: A multi-scalar approach to energy transition in the UK. *European Planning Studies, 20(5)*, 791-816.

Eurostat. (2021, March 4). *Share of energy from renewable sources.* Retrieved (2021, March 14) from: `https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren/default/table?lang=en`

Feltham, T. S. (1998). Leaving home: brand purchase influences on young adults. *Journal of consumer marketing.*

Green, L., Myerson, J., Lichtman, D., Rosen, S., & Fry, A. (1996). Temporal discounting in choice between delayed rewards: the role of age and income. *Psychology and aging, 11(1)*, 79.

Gu, G., Yang, D., Feng, T., & Timmermans, H. (2019). Influence of the adoption of new mobility tools on investments in home renewable energy equipment: Results of a stated choice experiment. *Sustainable Cities and Society, 50*, 101641.

Harackiewicz, J. M., Manderlink, G., & Sansone, C. (1992). Competence processes and achievement motivation: Implications for intrinsic motivation. *Achievement and motivation: A social-developmental perspective*, 115-137.

Hess, S., & Palma, D. (2019). Apollo: a flexible, powerful and customisable freeware package for choice model estimation and application. *Journal of choice modelling, 32*, 100170.

Heynen, R., Groot, P., Vrisekoop, H., Witkop, D., & Kolenbrander, K. (2018). *Nationaal warmtepomp trendrapport 2018.* Dutch new energy research.

Howard-Grenville, J., Buckle, S. J., Hoskins, B. J., & George, G. (2014). Climate change and management.

IPCC. (2014). Climate change 2014: impacts, adaptation and vulnerability. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Evi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. Maccracken, P.R. Mastrandrea, & L.L. White. (eds.). *Working Group II contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* Cambridge: Cambridge University Press.

Kammermann, L., & Dermont, C. (2018). How beliefs of the political elite and citizens on climate change influence support for Swiss energy transition policy. *Energy research & social science, 43*, 48-60.

Kemp, R. (2011). The Dutch energy transition approach. In *International Economics of Resource Efficiency* (pp. 187-213). Physica-Verlag HD.

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

Klimaatakkoord. (2019). In *Klimaatakkoord.* Retrieved from: `https://www.rijksoverheid.nl/documenten/rapporten/2019/06/28/klimaatakkoord`

Klip, D. (2017). *The transition of the residential heating system: ensuring a clean, affordable and reliable residential heating system.* Clingendael International Energy programme (CIEP).

KVGN. (2017). *Gas op maat: De propositie van de Nederlandse gassector voor een klimaatneutrale energievoorziening.*

Larimer, M. E., Turner, A. P., Mallett, K. A., & Geisner, I. M. (2004). Predicting drinking behavior and alcohol-related problems among fraternity and sorority members: examining the role of descriptive and injunctive norms. *Psychology of Addictive Behaviors, 18(3)*, 203.

Leibenstein, H. (1950). Bandwagon, snob, and Veblen effects in the theory of consumers' demand. *The quarterly journal of economics, 64(2)*, 183-207.

Lewis, J. (1990). The vulnerability of small island states to sea level rise: the need for holistic strategies.*Disasters, 14(3)*, 241-249.

Liao, F., Molin, E., Timmermans, H., & van Wee, B. (2019). Consumer preferences for business models in electric vehicle adoption. *Transport Policy, 73*, 12-24.

Loorbach, D. (2007). *Transition management. New mode of governance for sustainable development.* Utrecht: International Books.

Loorbach, D., Van der Brugge, R., & Taanman, M. (2008). Governance in the energy transition: Practice of transition management in the Netherlands. *International Journal of Environmental Technology and Management, 9(2-3)*, 294-315.

Louviere, J. J., Hensher, D. A., & Swait, J. D. (2000). *Stated choice methods: analysis and applications.* Cambridge university press.

Lu, J., Yu, C., Liu, C., & Yao, J. E. (2003). Technology acceptance model for wireless Internet. *Internet Research, 13(3)*, 206–222.

Malla, A., & Ruokamo, E. (2019). *Determinants of home heating system choice–a stated preference experiment.*

Manski, C. (1977). The structure of random utility models, *Theory and Decision, 8(3)*, 229-254.

McHugh, M. L. (2013). The chi-square test of independence. *Biochemia medica, 23(2)*, 143-149.

Michelsen, C. C., & Madlener, R. (2012). Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany. *Energy Economics, 34(5)*, 1271-1283.

Molin, E. (2019a). SEN1221 Lecture 1 - *Introduction to experimental designs*

Molin, E. (2019b). SEN1221 Lecture 2 - *Constructing choice sets: orthogonal designs (part II)*

Molin, E. (2019c). SEN1221 Lecture 3 - *Efficient designs*

Molin, E. (2019d). SEN1221 Lecture 4 - *Complex variables & non-linearity*

Molin, E. (2019e). SEN1221 Lecture 5 - *Context-dependent state choice experiments*

Molin, E. J., & Timmermans, H. J. (2010). Context dependent stated choice experiments: The case of train egress mode choice. *Journal of choice modelling, 3(3)*, 39-56.

Murphy, J. J., Allen, P. G., Stevens, T. H., & Weatherhead, D. (2005). A meta-analysis of hypothetical bias in stated preference valuation. *Environmental and Resource Economics, 30(3)*, 313-325.

Naber, N., & Schepers, B. (2017). *Scenario's voor de warmtetransitie in Den Haag.* CE Delft.

Neighbors, C., Larimer, M. E., & Lewis, M. A. (2004). Targeting misperceptions of descriptive drinking norms: efficacy of a computer-delivered personalized normative feedback intervention. *Journal of consulting and clinical psychology, 72(3)*, 434.

NPRES. (2020). *Factsheet Warmte: Achtergrond informatie per warmtebron.*

Olonscheck, M., Walther, C., Lüdeke, M., & Kropp, J. P. (2015). Feasibility of energy reduction targets under climate change: The case of the residential heating energy sector of the Netherlands. *Energy, 90*, 560-569.

Oppewal, H., & Timmermans, H. (1991). Context effects and decompositional choice modeling. Papers in *Regional Science, 70(2)*, 113-131.

Paris Agreement. (n.d.). *European Commission.* Retrieved from: `https://ec.europa.eu/clima/policies/international/negotiations/paris_en`

Parkhill, K., Demski, C. C., Butler, C., Spence, A., & Pidgeon, N. F. (2013). Transforming the UK energy system: public values, attitudes and acceptability-synthesis report.

Parry, M. L., Canziani, O. F., Palutikof, J. P., Van Der Linden, P. J., & Hanson, C. E. (2007). IPCC, 2007: climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. *Cambridge University Press, Cambridge, UK.*

Rose, J. M., & Bliemer, M. C. (2009). Constructing efficient stated choice experimental designs. *Transport Reviews, 29(5)*, 587-617.

Rotmans, J., Kemp, R., & Van Asselt, M. (2001). More evolution than revolution: transition management in public policy. *Foresight-The journal of future studies, strategic thinking and policy, 3(1)*, 15-31.

Rouvinen, S., & Matero, J. (2013). Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment. *Biomass and Bioenergy, 57*, 22-32.

Ruokamo, E. (2016). Household preferences of hybrid home heating systems–A choice experiment application. *Energy Policy, 95*, 224-237.

Ryan, R. M., Mims, V., & Koestner, R. (1983). Relation of reward contingency and interpersonal context to intrinsic motivation: A review and test using cognitive evaluation theory. *Journal of personality and Social Psychology, 45(4)*, 736.

Sagebiel, J., Müller, J. R., & Rommel, J. (2014). Are consumers willing to pay more for electricity from cooperatives? Results from an online Choice Experiment in Germany. *Energy Research & Social Science, 2*, 90-101.

Scheepers, M. J. J., Faaij, A., & Brink, R. (2020). *Scenario's voor klimaatneutraal energiesysteem: slimme combinaties van energie-opties leiden tot duurzame en betaalbare energiehuishoudens.* TNO.

Schilling, J., Naber, N., & Schepers, B. (2019). *Energiestrategie Haarlem.* CE Delft

Schleich, J. (2019). Energy efficient technology adoption in low-income households in the European Union–What is the evidence? *Energy Policy, 125*, 196-206.

Scholten, D., & Bosman, R. (2016). The geopolitics of renewables; exploring the political implications of renewable energy systems. *Technological Forecasting and Social Change, 103*, 273-283.

Shukla, P. (2009). Impact of contextual factors, brand loyalty and brand switching on purchase decisions. *Journal of Consumer Marketing, 26(5)*, 348–357.

Sinha, I. (1994). A conceptual model of the role of situational type on consumer choice behavior and consideration sets. *Advances in Consumer Research, 21*, 477-482.

Steg, L., Perlaviciute, G., & van der Werff, E. (2015). Understanding the human dimensions of a sustainable energy transition. *Frontiers in psychology, 6*, 805.

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29(3)*, 309–317.

Stern, P. C. (1999). Information, Incentives, and Pro-environmental Consumer Behavior. *Journal of Consumer Policy, 22(4)*, 461–478.

Stern, P. C. (2000). New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues, 56(3)*, 407–424.

Stieß, I., & Dunkelberg, E. (2013). Objectives, barriers and occasions for energy efficient refurbishment by private homeowners. *Journal of Cleaner Production, 48*, 250–259.

Stuurgroep Energieregio Noord-Holland Zuid. (2020). *Concept-RES Noord-Holland Zuid*. Retrieved from: https://energieregionhz.nl/app/uploads/2020/05/Online-PDF-Concept-RES-Noord-Holland-Zuid-22-april-2020.pdf

Suddendorf, T., & Corballis, M. C. (2007). The evolution of foresight: What is mental time travel, and is it unique to humans?. *Behavioral and brain sciences, 30(3)*, 299-313.

Testa, F., Cosic, A., & Iraldo, F. (2016). Determining factors of curtailment and purchasing energy related behaviours. *Journal of Cleaner Production, 112*, 3810-3819.

Thøgersen, J. (2005). How May Consumer Policy Empower Consumers for Sustainable Lifestyles? *Journal of Consumer Policy, 28(2)*, 143–177.

Thomadsen, R., Rooderkerk, R. P., Amir, O., Arora, N., Bollinger, B., Hansen, K., ... & Wood, W. (2018). How context affects choice. *Customer Needs and Solutions, 5(1)*, 3-14.

Train, K. E. (2009). *Discrete choice methods with simulation.* Cambridge university press.

Triandis, H. C. (1994). *Culture and social behavior.* New York: McGraw-Hill

Utgikar, V. P., & Scott, J. P. (2006). Energy forecasting: Predictions, reality and analysis of causes of error. *Energy Policy, 34(17)*, 3087-3092.

Vakulchuk, R., Overland, I., & Scholten, D. (2020). Renewable energy and geopolitics: A review. *Renewable and Sustainable Energy Reviews, 122*, 109547.

Van de Kaa, G., & de Vries, H. J. (2015). Factors for winning format battles: A comparative case study. *Technological Forecasting and Social Change, 91*, 222-235.

Van den Eerenbeemt, M. (2020). Meeste Nederlanders schaffen nog steeds een nieuwe cv-ketel aan, en dus blijft aardgas de norm. *de Volkskrant.* Retrieved from: `https://www.volkskrant.nl/nieuws-achtergrond/meeste-nederlanders-schaffen-nog-ste`

Verbong, G., & Geels, F. (2007). The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy policy, 35(2)*, 1025-1037.

Warlop, L., & Ratneshwar, S. (1993). The role of usage context in consumer choice: A problem solving perspective. *Advances in Consumer Research, 20*, 377-382.

Wiener, J. L., & Doescher, T. A. (1991). A framework for promoting cooperation. *Journal of Marketing, 55(2)*, 38-47.

Appendices

A Constructing choice sets in Ngene

As stated in section 4.1.3, the choice sets are constructed by using the Ngene software. The choice sets will be part of the experimental design, which is constructed as an orthogonal fractional factorial design. In this research. the alternatives are present as unlabeled sustainable heating alternatives within the choice sets. This means that the alternatives and choice sets are constructed sequentially. An advantage of this construction method is that it results in fewer choice sets than when simultaneous constructing is used. A disadvantage of this method is that attributes can be correlated between the alternatives. However, this is not problematic since the parameters can still be estimated (Molin, 2019b).

Within Ngene a syntax code needs to be given for constructing the choice sets. The syntax includes the alternatives, the minimum amount of choice sets, the constructing method and the utility functions per alternative. Each choice between the alternatives within a choice set is derived from the utility functions and consist of the attributes, attribute levels, parameters related to the attributes, and an ASC. The utility functions of the alternatives are based on the functions as stated in section 4.1.4. The following Ngene syntax was used to construct the design:

```
Design
;alts = alt1,alt2
;rows = 12
;orth = seq
;model:

U(alt1) = b1*IC[5000,10000,15000] + b2*OC[500,1500,2500] + b3*LS[10,15,20] +
b4*RE[15,35,55]+ b5*ST[0,1,2]/

U(alt2) = b1*IC + b2*OC + b3*LS + b4*RE + b5*ST
$
```

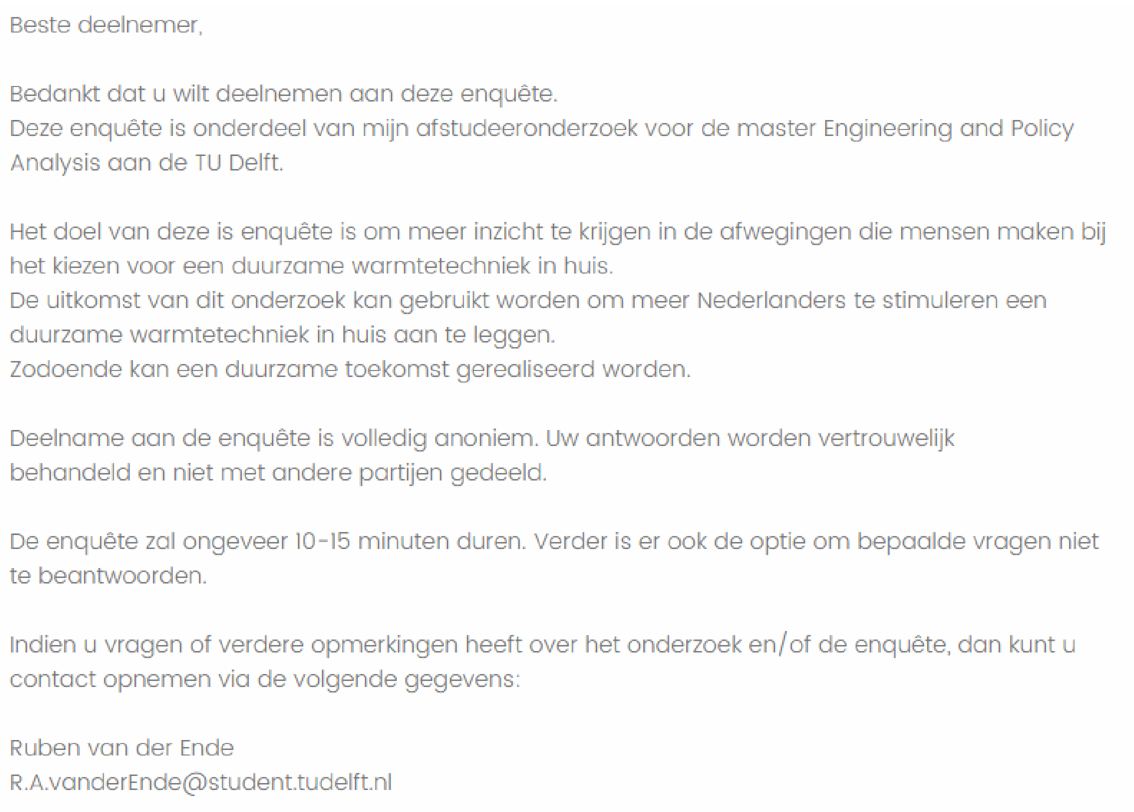
With regard to the syntax, the 'rows' command indicates the minimum amount of choice sets that are needed to form an orthogonal fractional factorial design. Due to the orthogonality, attribute level balance is guaranteed, which means that each attribute level occurs within four choice sets per alternative. Within the utility functions, the attributes are coded according to their attribute levels. However, the attribute Sustainable technology type is coded as 0 (Hybrid heat pump), 1 (All-electrical heat pump), and 2 (District heating) since the syntax of Ngene only understands numbers instead of categories. After running the syntax, Ngene formulated 12 choice sets, which together formed the choice set design. The choice set design can be seen in table 13 below.

Table 13: Final choice set design

Choice set	**alt1.IC**	**alt1.OC**	**alt1.LS**	**alt1.RE**	**alt1.ST**	**alt2.IC**	**alt2.OC**	**alt2.LS**	**alt2.RE**	**alt2.ST**
1	15.000	500	15	15	1	15.000	1500	20	15	0
2	5000	2500	15	15	1	10.000	2500	20	35	2
3	10.000	500	10	35	2	5.000	500	15	55	0
4	5000	1500	20	55	1	5.000	2500	15	15	1
5	10.000	2500	20	35	2	5.000	1500	20	55	1
6	10.000	2500	10	35	2	5.000	1500	10	15	0
7	15.000	2500	15	55	0	10.000	500	10	35	2
8	15.000	1500	20	15	0	10.000	2500	10	35	2
9	5000	500	15	55	0	10.000	500	20	35	2
10	5000	1500	10	15	0	15.000	1500	10	55	1
11	10.000	500	20	35	2	15.000	500	15	15	1
12	15.000	1500	10	55	1	15.000	2500	15	55	0

B Final survey

After the stated choice experiment and its corresponding experimental design is constructed, the experiment is translated into a survey to gather the data. The survey consists of the state choice experiment as well as questions related to the user experience, sustainable attitudes, and socio-demographics. The final survey is constructed after implementing the feedback from the test version, as stated in chapter 4.2.4. An example of the final survey is stated within this appendix. For convenience, only one choice set is illustrated within this appendix. However, each respondent filled in twelve choice sets, as stated in chapter 4.2. Unfortunately, due to time constraints, the sustainable attitudes are not implemented within the model estimates. Therefore, they are not mentioned within the main text.



Beste deelnemer,

Bedankt dat u wilt deelnemen aan deze enquête.
Deze enquête is onderdeel van mijn afstudeeronderzoek voor de master Engineering and Policy Analysis aan de TU Delft.

Het doel van deze is enquête is om meer inzicht te krijgen in de afwegingen die mensen maken bij het kiezen voor een duurzame warmtetechniek in huis.
De uitkomst van dit onderzoek kan gebruikt worden om meer Nederlanders te stimuleren een duurzame warmtetechniek in huis aan te leggen.
Zodoende kan een duurzame toekomst gerealiseerd worden.

Deelname aan de enquête is volledig anoniem. Uw antwoorden worden vertrouwelijk behandeld en niet met andere partijen gedeeld.

De enquête zal ongeveer 10-15 minuten duren. Verder is er ook de optie om bepaalde vragen niet te beantwoorden.

Indien u vragen of verdere opmerkingen heeft over het onderzoek en/of de enquête, dan kunt u contact opnemen via de volgende gegevens:

Ruben van der Ende
R.A.vanderEnde@student.tudelft.nl

Uitleg keuze-experiment

Het eerste gedeelte van deze enquête zal bestaan uit een keuze-experiment. Binnen dit keuze-experiment is het van belang dat u uitgaat van de volgende denkbeeldige situatie:
binnen vijf jaar gaat uw huidige warmtetechniek (bijv. boiler of hr-ketel) stuk. Wat voor warmtetechniek zou u kiezen als vervanging, met het oog op een duurzamere toekomst?

Binnen het keuze-experiment krijgt u 12 situaties voorgelegd die te maken hebben met het gebruik van duurzame warmtetechnieken. Binnen elke situatie dient u een keuze te maken tussen de opties die omschreven zijn in de keuzeset. Elke keuzeset bestaat uit (duurzame) warmtetechnieken, hun kenmerken en twee contexten. Per situatie zijn alle twee de contexten van toepassing, maar de waarden van de contexten zullen per vraag verschillen!

Hierbij volgt een voorbeeldvraag uit het keuze-experiment (deze hoeft u niet in te vullen):

Binnen vijf jaar gaat uw huidige warmtetechniek stuk, daarom bent u op zoek naar vervanging.
Vergelijk de warmtetechnieken die beschreven zijn in de keuzeset, gegeven de onderstaande denkbeeldige context.

Context

- Maar **15%** van de Nederlandse huishoudens gebruikt een duurzame warmtetechniek
- Pas in **2050** gaat Nederland volledig van het gas af

Keuzeset 1

	Duurzame warmtetechniek 1	Duurzame warmtetechniek 2	Huidige warmtetechniek
Investeringskosten	€15.000	€15.000	€1500 - €3000
Gebruikskosten	€500 per jaar	€1500 per jaar	€1450 per jaar
Levensduur	15 jaar	20 jaar	15 jaar
Vermindering van CO_2 uitstoot	15%	15%	0%
Technologie type	Elektrische warmtepomp	Hybride warmtepomp	Cv- of hr- ketel

Indien alleen een duurzame optie mogelijk is, welke van de twee duurzame warmtetechnieken heeft dan uw voorkeur?

○ Warmtetechniek 1

○ Warmtetechniek 2

Indien het wel mogelijk is om bij uw huidige warmtetechniek te blijven, zou u dan gebruik maken van de gekozen duurzame warmtetechniek of uw huidige oplossing?

○ Gekozen duurzame warmtetechniek

○ Huidige warmtetechniek

Toelichting kenmerken warmtetechnieken

In elke keuzeset worden verschillende warmtetechnieken voorgelegd. Deze warmtetechnieken worden beschreven aan de hand van kenmerken en zijn weergegeven in een tabel, zoals in de voorbeeldvraag te zien is. Deze kenmerken zijn in iedere keuzeset hezelfde. Maar, let op! De waardes van deze kenmerken (weergegeven in de tabel) zullen wel per vraag verschillen.

In dit experiment komen de volgende kenmerken aan bod:

- **Investeringskosten**: alle kosten gerelateerd aan de aanschaf en installatie van de warmtetechniek.
- **Gebruikskosten**: alle kosten gerelateerd aan het jaarlijkse energieverbruik, onderhoud en reparatiekosten.
- **Levensduur**: levensduur van alle technische componenten binnen een huishouden. Infrastructuur buitenshuis wordt niet meegerekend.
- **Vermindering van CO2-uitstoot**: omschrijft de klimaatvriendelijkheid ten opzichte van huidige warmtetechnieken die gebruikmaken van aardgas.
- **Technologie type**: geeft aan om welke warmtetechniek het gaat. Deze technieken worden in het volgende scherm kort beschreven.

Uitleg warmtetechnieken
Binnen het keuze-experiment zijn er drie duurzame warmtetechnieken en daarnaast uw huidige warmtetechniek.

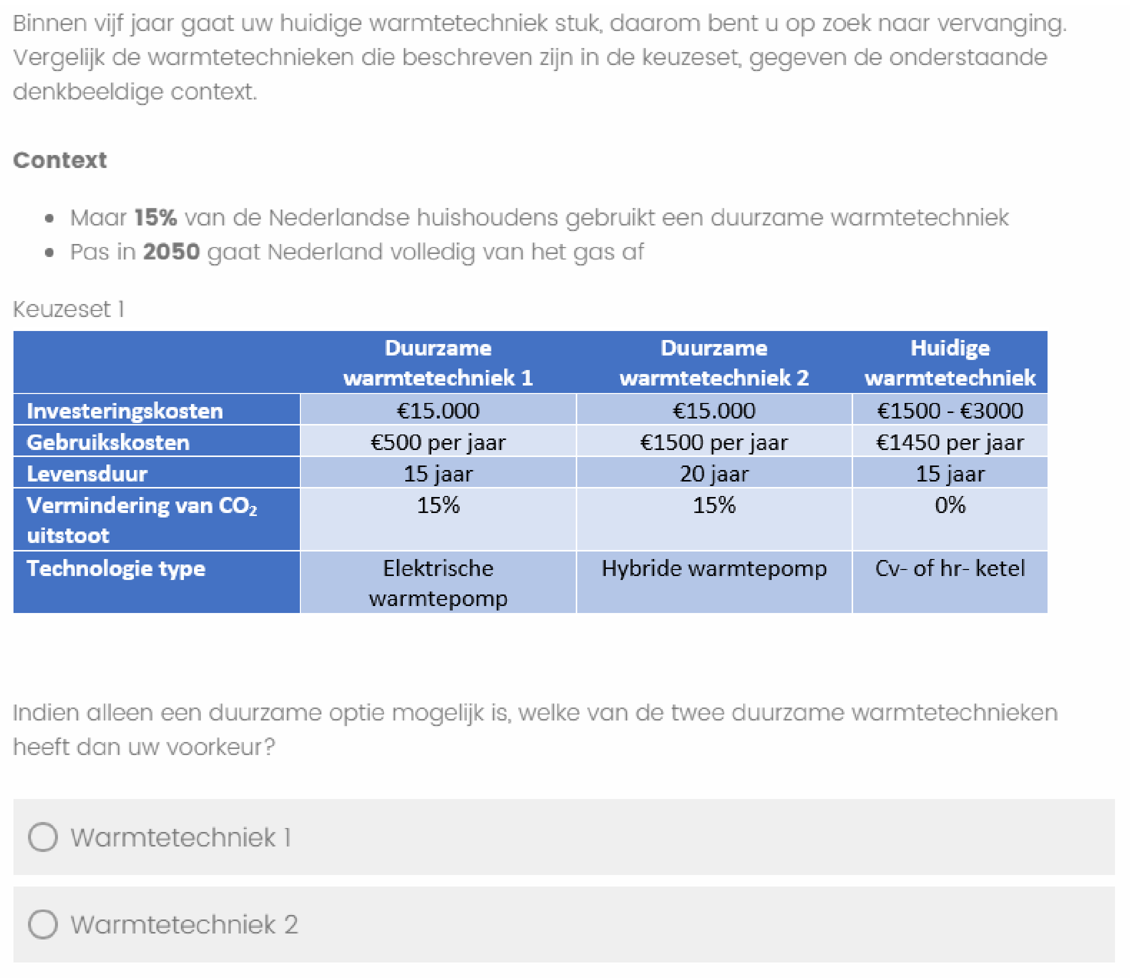
Elektrische warmtepomp
Een elektrische warmtepomp gebruikt energie uit de lucht of uit de bodem, die met behulp van elektriciteit woningen kan verwarmen. Dit alternatief gebruikt duurzame energie en maar een beperkte hoeveelheid elektriciteit, hierdoor heeft het een hoog rendement. Hierbij is goede isolatie wel noodzakelijk om het rendement hoog te houden.

Hybride warmtepomp
De hybride warmtepomp combineert een elektrische warmtepomp met de hr-ketel op gas. De elektrische warmtepomp kan ongeveer voor de helft van de warmtevraag zorgen. Ongeveer een vijfde van de tijd springt de hr-ketel bij op momenten dat de warmtepomp niet voldoende warmte kan leveren.

Stadsverwarming
Stadsverwarming is een collectieve oplossing waarbij meerdere woningen worden aangesloten op een warmtenet. Een collectieve bron verwarmt water dat via een buizennetwerk naar de woning wordt vervoerd. Kanttekeningen bij dit alternatief zijn: dat een gehele wijk akkoord moet gaan met deze oplossing en dat slechts op enkele plekken in Nederland de juiste infrastructuur aanwezig is voor deze techniek.

Huidige warmtetechniek
Binnen deze enquête vraag ik u aan te nemen dat uw huis gebruik maakt van een warmtetechniek die aangesloten is op het aardgasnetwerk, zoals een cv- of hr-ketel.

Let op! Na deze pagina is het niet meer mogelijk om de uitleg terug te lezen.



Binnen vijf jaar gaat uw huidige warmtetechniek stuk, daarom bent u op zoek naar vervanging. Vergelijk de warmtetechnieken die beschreven zijn in de keuzeset, gegeven de onderstaande denkbeeldige context.

Context

- Maar **15%** van de Nederlandse huishoudens gebruikt een duurzame warmtetechniek
- Pas in **2050** gaat Nederland volledig van het gas af

Keuzeset 1

	Duurzame warmtetechniek 1	Duurzame warmtetechniek 2	Huidige warmtechniek
Investeringskosten	€15.000	€15.000	€1500 - €3000
Gebruikskosten	€500 per jaar	€1500 per jaar	€1450 per jaar
Levensduur	15 jaar	20 jaar	15 jaar
Vermindering van CO_2 uitstoot	15%	15%	0%
Technologie type	Elektrische warmtepomp	Hybride warmtepomp	Cv- of hr- ketel

Indien alleen een duurzame optie mogelijk is, welke van de twee duurzame warmtetechnieken heeft dan uw voorkeur?

○ Warmtetechniek 1

○ Warmtetechniek 2

Indien het wel mogelijk is om bij uw huidige warmtetechniek te blijven, zou u dan gebruik maken van de gekozen duurzame warmtetechniek of uw huidige oplossing?

○ Gekozen duurzame warmtetechniek

○ Huidige warmtetechniek

Ervaringen keuze-experiment

In dit onderdeel worden een aantal stellingen voorgelegd om te meten hoe u het keuze-experiment heeft ervaren.

In welke mate kunt u zich vinden in de volgende stellingen?

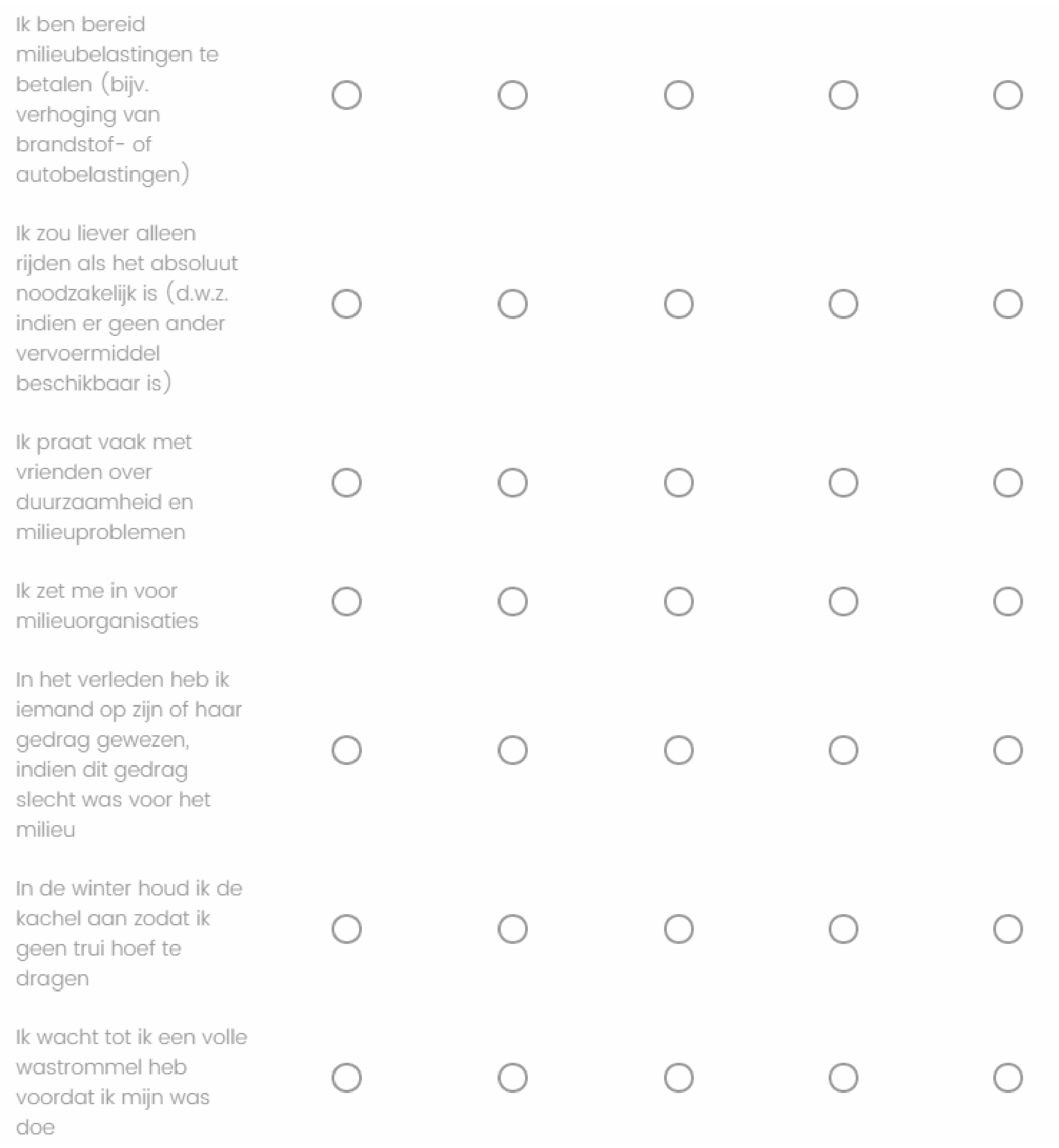
	Helemaal mee oneens	Oneens	Niet oneens, niet eens	Eens	Helemaal mee eens
De uitleg en toelichting van het keuze experiment heb ik als duidelijk ervaren.	○	○	○	○	○
De lay-out en manier van presenteren van het keuze experiment heb ik als duidelijk ervaren.	○	○	○	○	○
Ik heb de beschreven contexten als helder en duidelijk ervaren.	○	○	○	○	○
Ik heb de contexten en de contextwaardes die de scenario's vormden als realistisch ervaren.	○	○	○	○	○
Er zijn bepaalde aspecten die mijn uiteindelijke keuze beïnvloeden, maar die binnen dit experiment niet zijn meegenomen.	○	○	○	○	○

Percepties omtrent verduurzaming

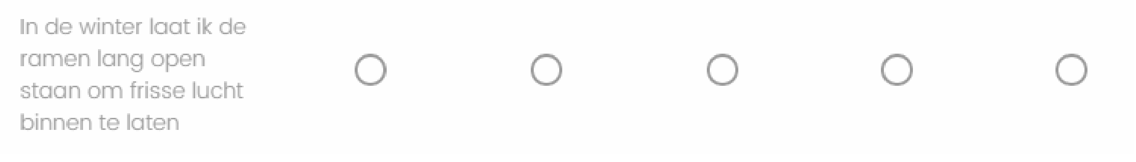
In dit onderdeel worden een aantal stellingen voorgelegd om uw percepties omtrent verduurzaming te meten.

In welke mate kunt u zich vinden in de volgende stellingen?

	Helemaal mee oneens	Oneens	Niet oneens, niet eens	Eens	Helemaal mee eens
Fossiele brandstoffen (bijv. gas, olie) produceren CO2 in de atmosfeer bij verbranding	○	○	○	○	○
Een mondiale klimaatverandering zal plaatsvinden als CO2 in de atmosfeer blijft worden uitgestoten in zulke grote hoeveelheden als nu	○	○	○	○	○
Alle dingen, of het nu mensen, dieren, planten of stenen zijn, hebben bestaansrecht	○	○	○	○	○
De waarde van de aarde is niet afhankelijk van mensen; het is op zichzelf waardevol	○	○	○	○	○



Ik ben bereid milieubelastingen te betalen (bijv. verhoging van brandstof- of autobelastingen)	○	○	○	○	○
Ik zou liever alleen rijden als het absoluut noodzakelijk is (d.w.z. indien er geen ander vervoermiddel beschikbaar is)	○	○	○	○	○
Ik praat vaak met vrienden over duurzaamheid en milieuproblemen	○	○	○	○	○
Ik zet me in voor milieuorganisaties	○	○	○	○	○
In het verleden heb ik iemand op zijn of haar gedrag gewezen, indien dit gedrag slecht was voor het milieu	○	○	○	○	○
In de winter houd ik de kachel aan zodat ik geen trui hoef te dragen	○	○	○	○	○
Ik wacht tot ik een volle wastrommel heb voordat ik mijn was doe	○	○	○	○	○



In de winter laat ik de ramen lang open staan om frisse lucht binnen te laten	○	○	○	○	○

Algemene vragen

In dit onderdeel zullen wat korte persoonlijke vragen gesteld worden. Er is altijd de optie om een vraag niet te beantwoorden.

Wat is uw geslacht?

○ Man

○ Vrouw

○ Wil ik niet zeggen

Wat is uw geboortejaar?

Wat is uw opleidingsniveau? (hoogst afgeronde opleiding)

○ Basisonderwijs

○ Vmbo-b/k, mbo1

○ Vmbo-g/t, havo-, vwo-onderbouw

○ Mbo2, mbo3

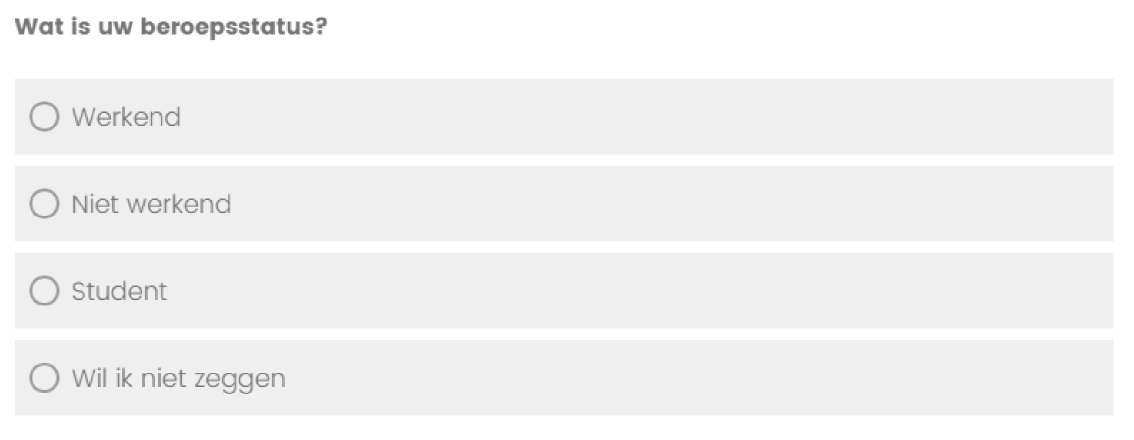
○ Mbo4

○ Havo, vwo

○ Hbo-, wo-bachelor

○ Hbo-, wo-master, doctor

○ Wil ik niet zeggen



Wat is uw beroepsstatus?

○ Werkend

○ Niet werkend

○ Student

○ Wil ik niet zeggen

Wat is het brutojaarinkomen van uw huishouden?

○ Minder dan 10.000 euro

○ 10.000 tot 20.000 euro

○ 20.000 tot 30.000 euro

○ 30.000 tot 40.000 euro

○ 40.000 tot 50.000 euro

○ 50.000 tot 60.000 euro

○ 60.000 tot 70.000 euro

○ 70.000 tot 80.000 euro

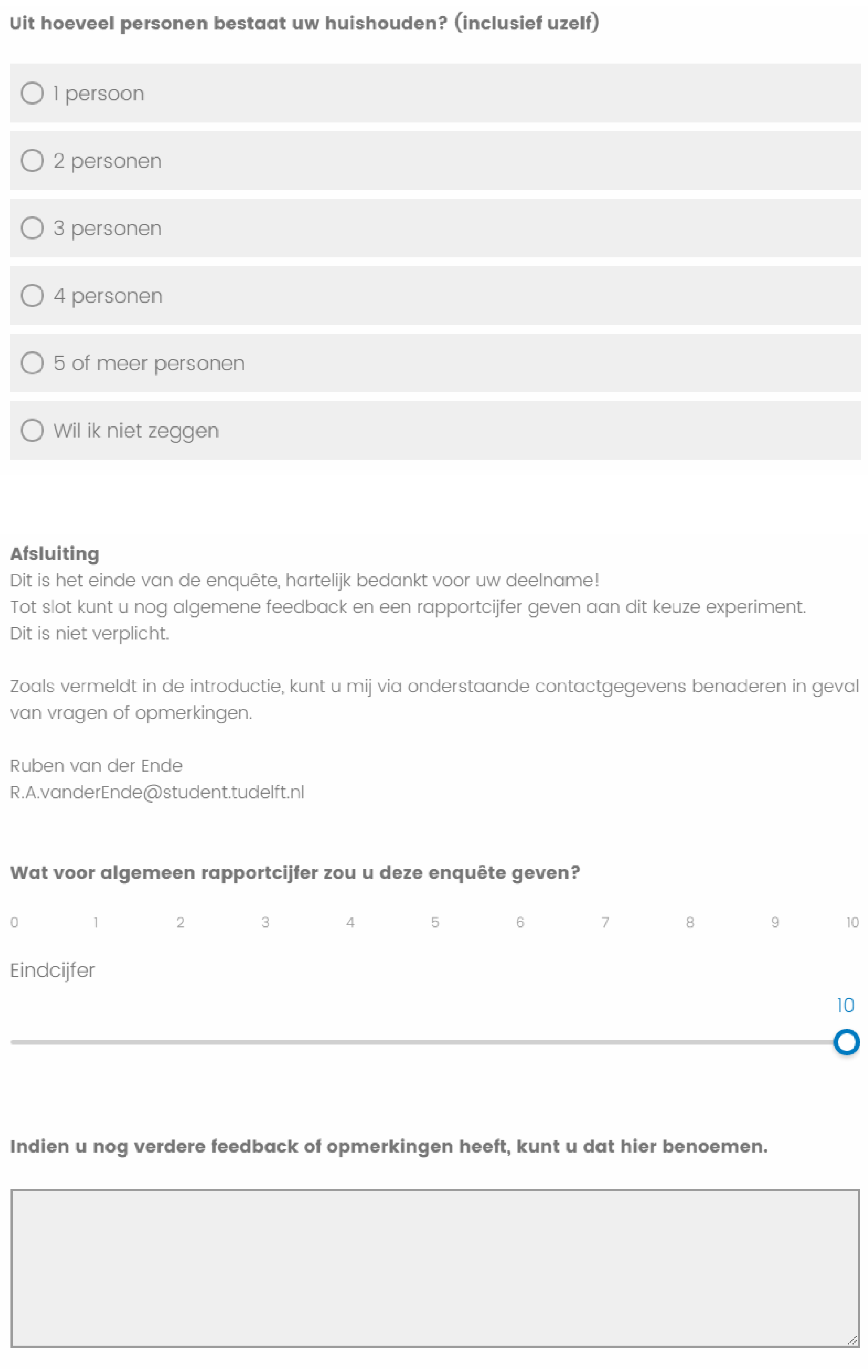
○ 80.000 tot 90.000 euro

○ 90.000 tot 100.000 euro

○ 100.000 tot 200.000 euro

○ 200.000 euro of meer

○ Wil ik niet zeggen/ weet ik niet



Uit hoeveel personen bestaat uw huishouden? (inclusief uzelf)

○ 1 persoon

○ 2 personen

○ 3 personen

○ 4 personen

○ 5 of meer personen

○ Wil ik niet zeggen

Afsluiting
Dit is het einde van de enquête, hartelijk bedankt voor uw deelname!
Tot slot kunt u nog algemene feedback en een rapportcijfer geven aan dit keuze experiment.
Dit is niet verplicht.

Zoals vermeldt in de introductie, kunt u mij via onderstaande contactgegevens benaderen in geval van vragen of opmerkingen.

Ruben van der Ende
R.A.vanderEnde@student.tudelft.nl

Wat voor algemeen rapportcijfer zou u deze enquête geven?

Eindcijfer: 10

Indien u nog verdere feedback of opmerkingen heeft, kunt u dat hier benoemen.

C Survey distribution

As stated in chapter 4.2.5, the survey is shared and promoted via social media to encourage as many people as possible. First, the survey is promoted within my own network via LinkedIn. This post can be seen in figure 10. Second, to improve the size and representativeness of the sample, the survey is promoted within the public Facebook group named "Groep Duurzaam Nederland" (3000 members) and the public LinkedIn group "Duurzame energie" (16000 members). That Facebook post can be seen in figure 11. The LinkedIn post within the public group is not illustrated but was very comparable to the Facebook post. Unfortunately, due to Covid-19, online distribution was the only effective distribution possibility.

Ruben van der Ende
Master student Engineering & Policy Analysis (EPA)
1 w •

OPROEP!

Beste netwerkcontacten,

Op dit moment schrijf ik mijn afstudeerscriptie voor het Energy Transition Lab van de TU Delft. Het doel van mijn onderzoek is het verkrijgen van inzichten in de afwegingen die mensen maken bij het kiezen voor een duurzame warmtetechniek in huis.

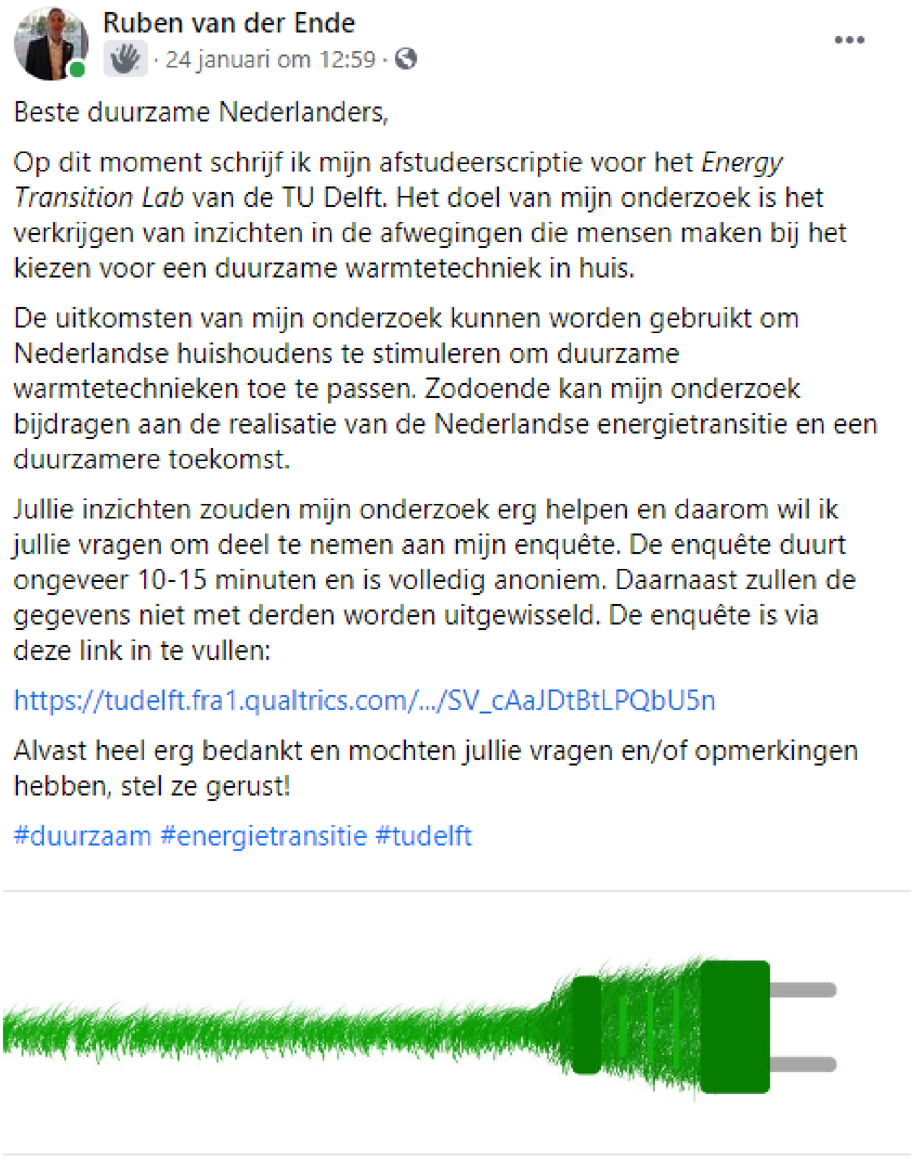
De uitkomsten van mijn onderzoek kunnen worden gebruikt om Nederlandse huishoudens te stimuleren om duurzame warmtetechnieken toe te passen. Zodoende kan mijn onderzoek bijdragen aan de realisatie van de Nederlandse energietransitie en een duurzamere toekomst.

Jullie inzichten zouden mijn onderzoek erg helpen en daarom wil ik jullie vragen om deel te nemen aan mijn enquête. De enquête duurt ongeveer 10-15 minuten en is volledig anoniem. Daarnaast zullen de gegevens niet met derden worden uitgewisseld. De enquête is via deze link in te vullen:
https://lnkd.in/e7f-VfF

Alvast heel erg bedankt en mochten jullie vragen en/of opmerkingen hebben, stel ze gerust!

#tudelft #energietransitie #duurzaamheid #enquete

Figure 10: LinkedIn message



Ruben van der Ende

· 24 januari om 12:59 ·

Beste duurzame Nederlanders,

Op dit moment schrijf ik mijn afstudeerscriptie voor het *Energy Transition Lab* van de TU Delft. Het doel van mijn onderzoek is het verkrijgen van inzichten in de afwegingen die mensen maken bij het kiezen voor een duurzame warmtetechniek in huis.

De uitkomsten van mijn onderzoek kunnen worden gebruikt om Nederlandse huishoudens te stimuleren om duurzame warmtetechnieken toe te passen. Zodoende kan mijn onderzoek bijdragen aan de realisatie van de Nederlandse energietransitie en een duurzamere toekomst.

Jullie inzichten zouden mijn onderzoek erg helpen en daarom wil ik jullie vragen om deel te nemen aan mijn enquête. De enquête duurt ongeveer 10-15 minuten en is volledig anoniem. Daarnaast zullen de gegevens niet met derden worden uitgewisseld. De enquête is via deze link in te vullen:

https://tudelft.fra1.qualtrics.com/.../SV_cAaJDtBtLPQbU5n

Alvast heel erg bedankt en mochten jullie vragen en/of opmerkingen hebben, stel ze gerust!

#duurzaam #energietransitie #tudelft

Figure 11: Facebook message

D Data cleaning steps

Within this appendix, the data cleaning steps that are mentioned in section 5.1.1 are explained in detail. The following steps were made:

- All the questions were mandatory. Therefore, there were no responses that should be deleted due to too many missing values. However, several unnecessary columns were removed from the original Qualtrics data output. Such as the respondent's IP address, start date, end date, longitude, latitude, and user language. This resulted in a raw data file with only the necessary columns for the data analysis.
- The blocking scheme created four different versions of which each respondent only fills in one. For the overview, four different data files were formed. Each contains all the answer related to one block.
- Each file was restructured in the format that is needed for the model estimation. This means that each choice task is represented by one row. This means that each respondent has twelve rows that each consist of the answers related to that specific choice task and all the other answers that were given in the survey (which are constant for each row). Furthermore, an user ID and choice set ID column is added and linked to each row to keep track of the specific respondent and choice task.
- For each variable that is effect coded, which is elaborated in the next section, extra variables are added to the data file. These variables contain the coding scheme that fits their number of categories according to effect coding.
- With regard to the choices of the choice tasks, two columns are included per file. One with the choice between the two sustainable heating technologies as stated in the choice set and one between the chosen sustainable technology and the base alternative. The first column represents the first question of the choice task and is coded with the values 1 (sustainable alternative 1) and 2 (sustainable alternative 2). The second column represents the second question and contains the values 1, 2 and 3 (base alternative).
- The questions that are answered with "I don't know/ I don't want to say" are seen as missing values due to anonymity. Therefore, they are coded as 9999 for the model estimation. If this answer is given for an effect coded variable then the variable is coded as 0. However, when a variable contains too many missing values, it will not be included in the model estimations.
- Lastly, after restructuring, the four data files are combined into the overall data file that is used for the model estimation with the R package Apollo
- All the data within the final file is copied in separate files and is used to analyse the descriptive statistics of the choice data, socio-demographics and attitudes of the respondents.

E Descriptive statistics of sample

Within this appendix, the descriptive statistics of chapter 5 are explained in detail. This is applied by providing plots and calculations regarding the characteristics of the sample. Within Appendix E.1, the sample distributions of the socio-demographics, which are shortly mentioned in section 5.2, are further explained and plotted. Furthermore, within Appendix E.2, the representativeness of the sample is statistically tested by performing chi-square tests. The outcomes of these tests support the conclusions that are formed within sub-chapter 5.3.

E.1 Socio-demographic characteristics

Within Table 6, the sample distributions of the socio-demographics are presented and compared to the Dutch population. However, within this appendix, each of the distributions are plotted and described separately. First, Figure 12, describes the sample distributions of *Age* and *Educational attainment*. The figure shows that most of the respondents are between 18 and 35 years old (52.6%) and mostly followed middle- or higher-level education (45.3% and 38.9%). Second, Figure 13, shows the sample distributions of *Income* and *Professional status*. Regarding *Income*, most of the respondents have a household income between 50,000 and 100,000 euros (25.3%). This is not surprising because this category has the widest range. The second largest group have a household income of fewer than 10,000 euros (15.8%), which probably is caused by the responses of students. Furthermore, this socio-demographic had the most amount of missing data (20%), which indicates that quite some respondents want to keep their income private. Regarding *Professional status*, most of the respondents have a job (53.7%). However, students are also presented in big numbers (28.4%), which influence the other socio-demographic distributions due to their low age, low income and high education level. Third, Figure 14 illustrates the the sample distributions of *Gender* and *Household size*. Surprisingly, mostly men responded to the survey (67.3%). Why this happened is not known. Furthermore, most of the respondents are part of a household with the size of 2 persons (42.5%) or 1 person (20.2%). Lastly, whether these distributions are representative of the Dutch population is statically tested within the next section.

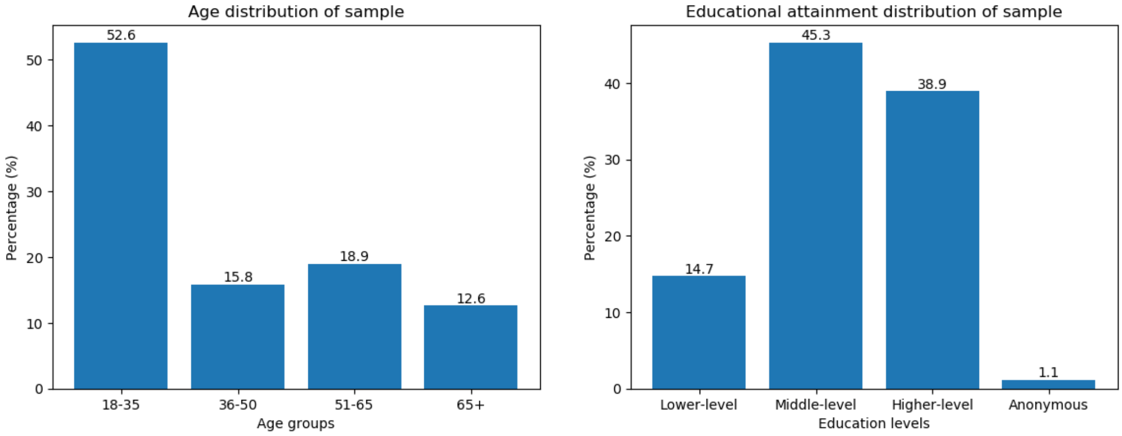


Figure 12: Sample distributions of variables Age and Educational attainment

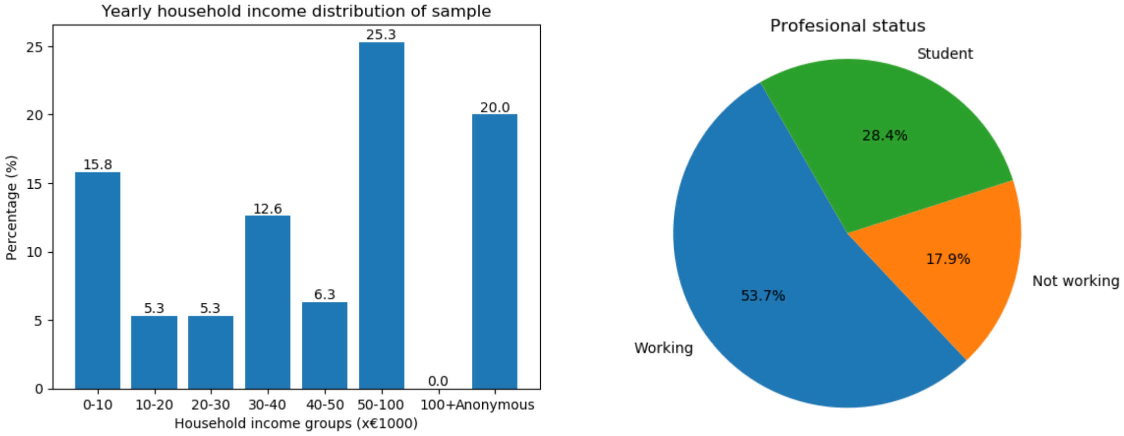


Figure 13: Sample distributions of variables Income and Professional status

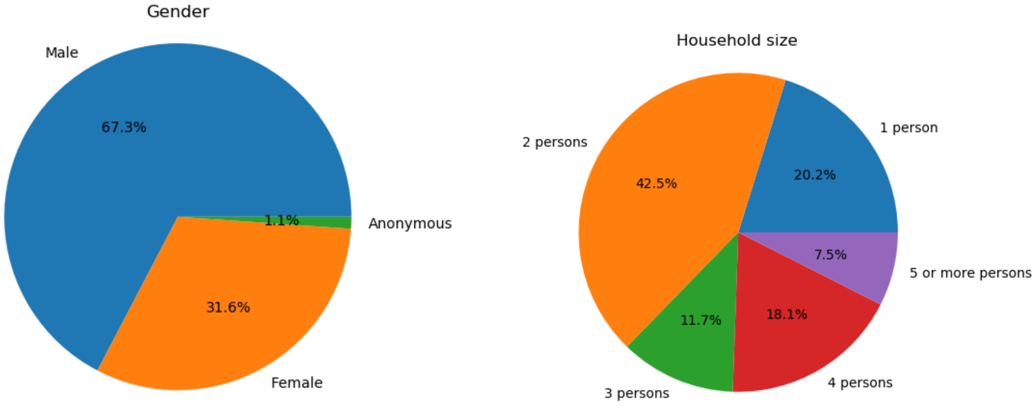


Figure 14: Sample distributions of variables Gender and Household size

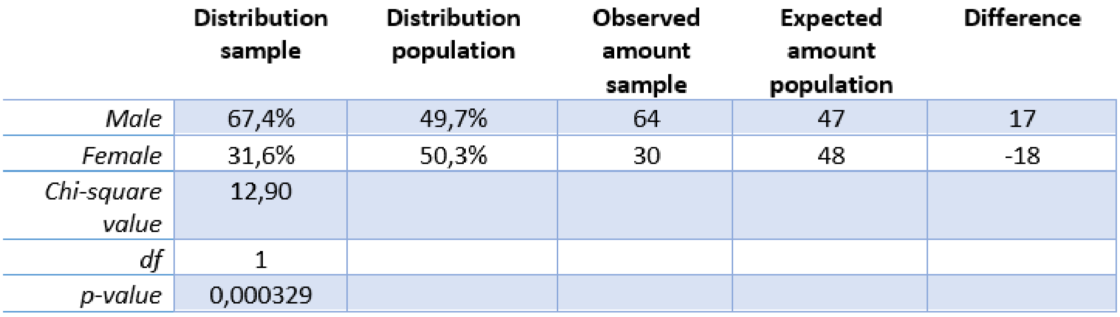
E.2 Representativeness of sample

As mentioned in sub-chapter 5.3, the representativeness of the sample is statically tested by performing a chi-square test. The test is a tool for analysing group differences and tests hypotheses for nominal and categorical variables, which is the case for all socio-demographics. Another restriction for conducting the test is that the values of the expected population amount should be five or more in 80% of the time (McHugh, 2013). This is the case for all the variables as can be seen in the tables below. Per test, a H0 hypothesis is formed that states that the sample is statistically independent, which means that the sample differs from the population. Whether the hypotheses is accepted depends on the calculated chi-square value and its corresponding p-value. The chi-square value is calculated by applying Equation E.1. Per category of a socio-demographic, the squared difference between the observed amount in the sample (O_i) and the expected amount of the population (E_i) is calculated and divided by E_i. The sum of all these categorical values results in the chi-square value (χ^2). Thereafter, the p-value of each variable is looked up within a chi-square table by combining the degrees of freedom (df) with the chi-square value.

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad (E.1)$$

As seen in Table 14, 15, 16, 17, 18, and 19 all the chi-square tests of the socio-demographics results in a p-value that is less than 0.05. This means that the results are statistically insignificant and the H0 hypotheses are therefore accepted. All in all, the socio-demographics do significant deviate between the sample and the population. Therefore, this sample can not be seen as representative of the Dutch population. The implications of the unrepresentativeness for the interpretations of the results within this research are further explained in sub-chapter 5.3.

Table 14: Chi-square test of socio-demographic Gender



	Distribution sample	Distribution population	Observed amount sample	Expected amount population	Difference
Male	67,4%	49,7%	64	47	17
Female	31,6%	50,3%	30	48	-18
Chi-square value	12,90				
df	1				
p-value	0,000329				

Table 15: Chi-square test of socio-demographic Age

	Distribution sample	Distribution population	Observed amount sample	Expected amount population	Difference
18-35 years	52,6%	19,2%	50	18	32
36- 50 years	15,8%	18,7%	15	18	-3
51- 65 years	18,9%	21,0%	18	20	-2
65+ years	12,6%	13,9%	12	13	-1
Chi-square value	57,67				
df	3				
p-value	0,000				

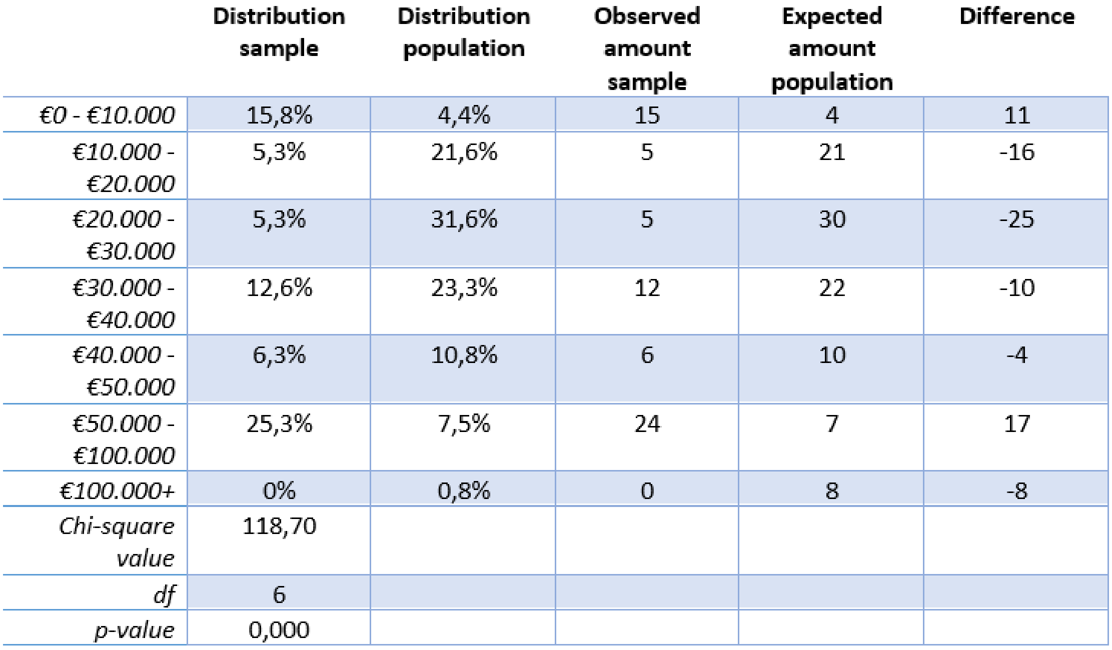
Table 16: Chi-square test of socio-demographic Educational attainment

	Distribution sample	Distribution population	Observed amount sample	Expected amount population	Difference
Lower-level education	14,7%	65,5%	14	62	-48
Middle level education	45,3%	20,8%	43	20	23
Higher level education	38,9%	12,1%	37	11	26
Chi-square value	125,07				
df	2				
p-value	0,000				

Table 17: Chi-square test of socio-demographic Professional status

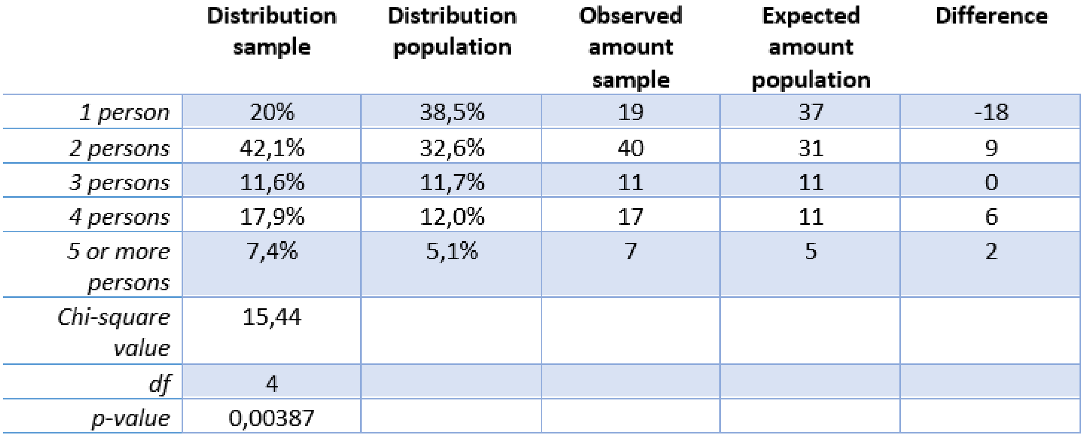
	Distribution sample	Distribution population	Observed amount sample	Expected amount population	Difference
Working	53,7%	51,3%	51	49	2
Not working	17,9%	23,0%	17	22	-5
Student	28,4%	7,3%	27	7	20
Chi-square value	58,36				
df	2				
p-value	0,000				

Table 18: Chi-square test of socio-demographic Yearly household income



	Distribution sample	**Distribution population**	**Observed amount sample**	**Expected amount population**	**Difference**
€0 - €10.000	15,8%	4,4%	15	4	11
€10.000 - €20.000	5,3%	21,6%	5	21	-16
€20.000 - €30.000	5,3%	31,6%	5	30	-25
€30.000 - €40.000	12,6%	23,3%	12	22	-10
€40.000 - €50.000	6,3%	10,8%	6	10	-4
€50.000 - €100.000	25,3%	7,5%	24	7	17
€100.000+	0%	0,8%	0	8	-8
Chi-square value	118,70				
df	6				
p-value	0,000				

Table 19: Chi-square test of socio-demographic Household size



	Distribution sample	**Distribution population**	**Observed amount sample**	**Expected amount population**	**Difference**
1 person	20%	38,5%	19	37	-18
2 persons	42,1%	32,6%	40	31	9
3 persons	11,6%	11,7%	11	11	0
4 persons	17,9%	12,0%	17	11	6
5 or more persons	7,4%	5,1%	7	5	2
Chi-square value	15,44				
df	4				
p-value	0,00387				

F Model estimation syntaxes

Within this appendix, the R syntaxes of the estimated models are given. First, in sub-chapter F.1, the syntax of the basic MNL model is given. This model only contains the attributes. Thereafter, in sub-chapter F.2, the syntax of the final MNL model is given. This model consists of all the significant variables from the previous models and consists of attributes, context variables and socio-demographics.

F.1 Basic MNL model

```
 # ################################################################# #
#### LOAD LIBRARY AND DEFINE CORE SETTINGS                       ####
# ################################################################# #

### Clear memory
rm(list = ls())

### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="Basic_model",
  modelDescr ="MNL model (without contexts/socio-demographics)",
  indivID    ="ID"
)

# ################################################################# #
#### LOAD DATA AND APPLY ANY TRANSFORMATIONS                     ####
# ################################################################# #

database = read.csv("Apollo_data_sortedby_userID.csv",header=TRUE, sep=";")

# ################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# ################################################################# #

### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(asc_base    = 0,
              c_sha       = 0,
              b_IC        = 0,
              b_OC        = 0,
              b_LS        = 0,
              b_RE        = 0,
              b_ST_1      = 0,
```

```
              b_ST_2      = 0)

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

# ################################################################# #
#### GROUP AND VALIDATE INPUTS                                   ####
# ################################################################# #

apollo_inputs = apollo_validateInputs()

# ################################################################# #
#### DEFINE MODEL AND LIKELIHOOD FUNCTION                        ####
# ################################################################# #

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

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

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

  ### List of utilities: these must use the same names as in mnl_settings,
  order is irrelevant

  V = list()
  V[['alt1']]  = c_sha + b_IC  * IC1 +  b_OC  * OC1 +  b_LS  * LS1
  +  b_RE  * RE1 +  b_ST_1  * ST1_1 + b_ST_2 * ST1_2

  V[['alt2']]  = c_sha + b_IC  * IC2 +  b_OC  * OC2 +  b_LS  * LS2
  +  b_RE  * RE2 +  b_ST_1  * ST2_1 + b_ST_2 * ST2_2

  V[['base']]  = asc_base

  ### Define settings for MNL model component
  mnl_settings = list(
    alternatives  = c(alt1=1, alt2=2, base=3),
    avail         = list(alt1= 1, alt2=1, base=1),
    choiceVar     = Choice_with_base,
    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                                               ####
# ################################################################# #

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO SCREEN)                               ----
# ----------------------------------------------------------------- #

apollo_modelOutput(model)

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO FILE, using model name)               ----
# ----------------------------------------------------------------- #

apollo_saveOutput(model)
```

F.2 Final MNL model

```
# ################################################################# #
#### LOAD LIBRARY AND DEFINE CORE SETTINGS                       ####
# ################################################################# #

### Clear memory
rm(list = ls())

### Load Apollo library
library(apollo)

### Initialise code
apollo_initialise()

### Set core controls
apollo_control = list(
  modelName  ="Final MNL model",
  modelDescr ="MNL model including attributes, contexts, and socio-demographics",
  indivID    ="ID"
)

# ################################################################# #
#### LOAD DATA AND APPLY ANY TRANSFORMATIONS                     ####
# ################################################################# #

database = read.csv("Apollo_data_sortedby_userID.csv",header=TRUE, sep=";")

### Remove missing values for socio-demographics###

database = subset(database,database$Gender!=9999 & database$Age!=9999
& database$Education!=9999 & database$Prof_status!=9999
& database$Household_size!=9999)

# ################################################################# #
#### DEFINE MODEL PARAMETERS                                     ####
# ################################################################# #

### Vector of parameters, including any that are kept fixed in estimation
apollo_beta=c(asc_base    = 0,
              c_sha       = 0,
              b_IC        = 0,
              b_OC        = 0,
              b_LS        = 0,
              b_RE        = 0,
              b_ST_1      = 0,
              b_ST_2      = 0,
              b_C1        = 0,
              b_C2        = 0,
```

```
             b_C2_C1     = 0,
             b_C1_ST2    = 0,
             b_C2_ST1    = 0,
             b_C2_ST2    = 0,
             b_Gender    = 0,
             b_Age1      = 0,
             b_Age3      = 0,
             b_Prof1     = 0,
             b_Prof2     = 0)

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

apollo_fixed = c("asc_base")

# ################################################################# #
#### GROUP AND VALIDATE INPUTS                                   ####
# ################################################################# #

apollo_inputs = apollo_validateInputs()

# ################################################################# #
#### DEFINE MODEL AND LIKELIHOOD FUNCTION                        ####
# ################################################################# #

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

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

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

  ### List of utilities: these must use the same names as in mnl_settings,
  order is irrelevant

  V = list()
  V[['alt1']]  = c_sha + b_IC * IC1 + b_OC * OC1 + b_LS * LS1 + b_RE * RE1 +
  b_ST_1 * ST1_1 + b_ST_2 * ST1_2 + b_C1 * Context1 + b_C2 * Context2 +
  b_C2_C1 * Context2 * Context1 + b_C1_ST2 * Context1 * ST1_2 +
  b_C2_ST1 * Context2 * ST1_1 + b_C2_ST2 * Context2 * ST1_2 +
  b_Gender * Gender + b_Age1 * Age_1 + b_Age3 * Age_3 +
  b_Prof1 * Prof_status_1 + b_Prof2 * Prof_status_2

  V[['alt2']]  = c_sha + b_IC * IC2 + b_OC * OC2 + b_LS * LS2 + b_RE * RE2
  + b_ST_1 * ST2_1 + b_ST_2 * ST2_2 + b_C1 * Context1 + b_C2 * Context2
```

```
  + b_C2_C1 * Context2 * Context1 + b_C1_ST2 * Context1 * ST2_2
  + b_C2_ST1 * Context2 * ST2_1 + b_C2_ST2 * Context2 * ST2_2
  + b_Gender * Gender + b_Age1 * Age_1 + b_Age3 * Age_3
  + b_Prof1 * Prof_status_1 + b_Prof2 * Prof_status_2

  V[['base']]  = asc_base

  ### Define settings for MNL model component
  mnl_settings = list(
    alternatives  = c(alt1=1, alt2=2, base=3),
    avail         = list(alt1= 1, alt2=1, base=1),
    choiceVar     = Choice_with_base,
    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                                               ####
# ################################################################# #

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO SCREEN)                               ----
# ----------------------------------------------------------------- #

apollo_modelOutput(model)

# ----------------------------------------------------------------- #
#---- FORMATTED OUTPUT (TO FILE, using model name)               ----
# ----------------------------------------------------------------- #

apollo_saveOutput(model)
```