Homeowners' preferences regarding sustainable residential heating systems

A stated choice experiment to assess the residential heating system choice behaviour of Delft homeowners

Master thesis

J.Q. Voskuyl

Delft University of Technology

TU Delft

Homeowners’ preferences regarding sustainable residential heating systems

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J.Q. Voskuyl

Student number: 4483618

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Graduation committee

Chairman:	Prof. dr. ir. C.G. Chorus, Section Transport and Logistics
First Supervisor:	Dr. ir. M. Kroesen, Section Transport and Logistics
Second Supervisor:	Dr. T. Hoppe, Section Organisation & Governance

TU Delft

Preface

Well, there it is. The final deliverable of the master Complex Systems Engineering and Management: my master thesis. In hindsight, the first seeds for the topic of this thesis were planted during the first-year courses Statistical Analysis of Choice Behaviour and Design of Integrated Energy Systems. I first thought of combining the topic of heat transition with the method of choice modelling in the summer of 2020. Many conversations, meetings, and a research proposal later and the topic was born. In (very) short, the aim of this thesis is to gain insights into the choice behaviour of homeowners with respect substitute natural gas-free residential heating systems. Although the master thesis is, in theory, an individual project, I could not have done it without the help of numerous people to which I want to express my gratitude.

First of all, thank you Caspar for helping me fine-tune my topic, compose a magnificent graduation committee, and for all your constructive feedback on my report. Secondly, many thanks to Maarten. Your feedback during our weekly meetings was immensely helpful and your way of supervising was exactly what I wanted and needed. Thirdly, Thomas, your sharp comments and great ability to find weak spots in my work were greatly appreciated. Fourthly, I would also like to thank Elze and Lukas for the endless conversations about my thesis and for your advice. Finally, I want to thank my parents for always being there for me and supporting me in all the choices I have made in the past six years.

I am grateful to have been able to study at Delft University of Technology and to live in Delft. This city has given me a valuable education, friends for life, and has made me to the person I am nowadays.

J.Q. Voskuyl
The Hague, July 2021

Executive summary

Resulting from the Dutch commitment to the 2015 Paris Agreement, the Dutch government has set the goal of making all 7.9 million Dutch houses natural gas-free. The present study has focussed on the challenge of removing the currently predominantly installed natural gas fired central heating boiler since such residential heating systems (RHS) are responsible for 78% of the natural gas demand in houses. Municipalities are responsible for this so-called heat transition and use public participation to gain insights into the needs and wishes of citizens, which will help to speed up the transition towards natural gas-free RHS. The present study focusses on homeowners in the municipality of Delft and argues that a variety of insights cannot be obtained by the current participation process in Delft. The main research question of this study is:

How do different classes of Delft homeowners make trade-offs between attributes of substitute residential heating systems and how do these trade-offs change due to relocation?

This question has been answered with a context dependent latent class discrete choice model for which a stated preference survey was conducted. In this survey, respondents were asked eight times to choose between three natural gas-free RHS which each varied on six characteristics. The varied characteristics are: the type of RHS (all-electric heat pump, district heating, and hybrid heat pump with green gas), investment costs, operational costs, popularity in the neighbourhood (as a percentage of people with a particular RHS), required inside space (compared to the space required for a conventional central heating boiler), and construction time (needed for the installation of the RHS and insulation work).

The results of the present study show that the RHS choice of Delft homeowners is positively influenced by higher values for the popularity in the neighbourhood. The higher the value for investment costs, operational costs, required inside space, and construction time the lower the chance that a homeowner chooses that RHS. Although all homeowners show similar reactions with respect to these five characteristics, the severity of these reactions does differ between homeowners. The model results show that Delft homeowners can be separated into two groups which each make different trade-offs. The first and largest group is characterised by homeowners with a relatively high income living in poorly insulated houses. These homeowners base their natural gas-free RHS choice primarily on investment costs, operational costs, and required inside space. Moreover, this group prefers district heating. The second group is likely to be consisting of low income homeowners living in relatively well insulated houses. This group is, similar to the first group, heavily influenced by investment costs and operational cost, but also by the type of RHS (preference for all-electric heat pumps and hybrid heat pumps with green gas) and popularity in the neighbourhood. When homeowners are moving to a new house, they pay less attention to investment costs, while paying more attention to construction time. The effect of relocation is especially strong in the second group of homeowners.

Given the results for investment costs and operational costs and that the national government is responsible for the affordability of the heat transition, the municipality of Delft should try to influence the national government. It should do this via four ways: the Association of Netherlands Municipalities, the G40 city network, the Metropolitan Region Rotterdam The Hague, and via the inter-government layer lobby connections between municipal aldermen and national ministers of the same political party. The inside space requirement concerns of the first group of homeowners should be mitigated by Energieloket Delft and 015 Duurzaam. The municipality should also have citizen organisations (Platform Energietransitie Delft and neighbourhood associations) to gather and spread information to the second group of homeowners about the popularity in the neighbourhood. The municipality of Delft should take advantage of the window of opportunity that relocation provides by starting partnerships with real estate offices. In this way, new homeowners can be made aware of the heat transition in an early stage and can account for the extra required construction time and investment costs for a natural gas-free RHS in their bid. The municipality and real estate agent should have an advisor from Energieloket Delft or 015 Duurzaam to formulate a plan in which is stated what the best natural gas-free RHS is for a to-be-sold house, including an overview of the required investment costs and construction time. The advisor should consider increasing the investment costs in order to decrease the required construction time.

Summary

Climate is changing drastically. In order to turn the tide, the 2015 Paris Agreement was reached by 196 countries. The Dutch contribution to the Paris Agreement is stated in the 2019 Climate Agreement. One of the goals in that agreement is to make all 7.9 million Dutch dwellings natural gas-free. At this moment, 78% of the natural gas demand in houses is used for space heating. Currently, the natural gas fired central heating boiler is used in 90% of the Dutch dwellings. The transition towards natural gas-free dwellings consists therefore primarily of a change in residential heating systems (RHS) and is called the heat transition. Municipalities are responsible for the organisation and execution of this transition. The general goal of municipalities is to increase the adoption rate of substitute (i.e., natural gas-free) RHS in houses. In order to achieve this, municipalities use public participation to gain insights into the needs and wishes of citizens. However, the present study believes that a variety of insights cannot be obtained via the current participation process and have not been obtained in previous studies. First of all, little is known about how Dutch citizens trade off different characteristics (i.e., attributes) of RHS. Secondly, the participation process cannot correctly determine to what extent these trade-offs differ between citizens with different characteristics (i.e., covariates). Finally, there are no insights yet whether relocation provides a window of opportunity to change the RHS of a house. The addition of life events, of which relocation is an example, in RHS choice behaviour research is the primary scientific contribution of this study. In order to maximise its societal contribution and due to practical reasons, the present study focusses on the municipality of Delft and on homeowners. The time frame of interest in the present study is 2030-2050, because most dwellings will be made natural gas-free in this period of time. It is likely that the absolute differences between the CO_2 emissions of substitute RHS are neglectable in this time frame, which is why CO_2 emissions are not considered in this study. The present study assumes that the choice to change the current natural gas based RHS into a substitute natural gas-free RHS has already been made by the homeowner in cooperation with the municipality of Delft or solely by the municipality. The latter is possible as it is assumed that a number of laws that are in an advanced stage that arrange this ability will have come into effect by 2030. Considering the above, the main research question of this study is:

How do different classes of Delft homeowners make trade-offs between attributes of substitute residential heating systems and how do these trade-offs change due to relocation?

Methodology and conceptualisation

A literature review was conducted in order to find which attributes and covariates potentially influence the trade-offs of Delft homeowners. Covariates are used to explain the variety in choice behaviour among homeowners (i.e., taste heterogeneity). In the review, previously included attributes were categorised, which ensured having a wide range of relevant attributes in the choice experiment of this study. Given that such an experiment was conducted, the economic theory of utility maximisation was inherently central in this research. Within the boundaries of the economic viewpoint, a two-sided psychological viewpoint on choice behaviour was added. This has resulted in three attribute categories: economic, theory of planned behaviour (subjective norm), and the hassle factor. The definition of the hassle factor by De Vries et al. (2020) was extended to hassle experienced during the construction work of a substitute RHS (construction hassle) and during the operation of a substitute RHS (operational hassle). With the help of experts, a final selection of relevant attributes was made: substitute RHS, investment costs (economic), operational costs (economic), popularity in the neighbourhood (theory of planned behaviour), required inside space (operational hassle), and construction time (construction hassle). The popularity in the neighbourhood is a descriptive norm operationalisation of the determinant subjective norms of the theory of planned behaviour. Such a norm is better suited to include in a choice experiment than the more conventional social norm operationalisation of subjective norms. This attribute was included to analyse the influence of the social surrounding of homeowners on their choice behaviour. Furthermore, the substitute RHS itself (all-electric heat pump, district heating, and hybrid heat pump with green gas) was also added as an attribute, which allowed to check the extent to which homeowners prefer a particular RHS. Relevant covariates were also obtained from previous studies, placed into three categories (socio-demographic, dwelling, and attitudes), and selected with the help of experts. The selected socio-demographic covariates were: gender, age, education, household income, household composition, and household size. The dwelling covariates were: house type, construction year, living area, dwelling location, energy label, current RHS, and monumental status.

Finally, community feeling and the influence of others in one's decision are the two selected attitudes. The insights from the choice experiment combined with an analysis of the decision-making process of the Delft heat transition are used to formulate policy recommendations to the municipality of Delft. These could not have been formulated using the insights from the current municipal participation process. The analysis is conducted by doing a policy document review and by interviewing three experts. The aim of the policy recommendations is to increase the adoption rate of substitute RHS. This is needed because only 6.8% of the Delft dwellings is currently natural gas-free and 41% of the Delft homeowners has a negative opinion regarding the municipal goal to become natural gas-free, which indicates that the adoption rate will not increase enough voluntarily. The policy recommendations form the societal contribution of this study.

The required data for the choice model was obtained via an online stated preference survey in which Delft homeowners were presented with eight choice sets in which they had to choose from three substitute RHS alternatives. Respondents had to imagine that they stayed living in their current house in four choice tasks and that they were moving to another house in the other four choice tasks. The alternatives were constructed by Ngene using an efficient design and combined into choice sets with the Modified Federov algorithm. The survey was distributed to Delft homeowners via Platform Energietransitie Delft, Belangenvereniging Olofsbuurt-Westerkwartier, Belangenvereniging Voorhof II West, Buurtvereniging Delftzicht, and Belangenvereniging de Oude en de Nieuwe Delf. In addition, homeowners of the neighbourhood Indische Buurt Zuid were reached by email. Lastly, the survey has been distributed on social media via the Facebook account of Delft wordt groen and the LinkedIn account of City Deal Kennis Maken Delft. In total, the survey reached 6,033 people of which 304 opened the survey and 168 finished it. Thus, the response rate is 2.8% and the dropout rate equals 44.7%. The data of 167 respondents was used to estimate a context dependent latent class discrete choice model.

Findings

The model results have shown that Delft homeowners can be separated into two homogeneous classes, which are characterised by the household income level, dwelling energy label, and whether the house is (partially) heated by a gas heater. A gas heater should not be confused with a natural gas fired central heating boiler. This means that socio-demographic and dwelling covariates are relevant covariate categories and that attitudes is not such a category. The relative importance that each latent class allocates to each of the attributes in both the non-relocation as well as in the relocation context is shown in figure 0.1. Class 1, i.e., the largest class with 79%, is characterised by a broad range of homeowners, but most likely consists of homeowners with a relatively high income, poor energy label, and without a gas heater. Homeowners in this class strongly base their choice on economic attributes (investment costs and operational costs) and to a lesser extent also on required inside space (operational hassle). Homeowners in both classes value these three attributes negatively, i.e., a substitute RHS with high values on these attributes will be less often chosen than a substitute RHS with lower values on these attributes. Popularity in the neighbourhood (i.e., the operationalisation of subjective norms from the theory of planned behaviour) and construction time (construction hassle) are relatively unimportant considerations for this class. The former attribute is positively valued by both classes, which is in contrast to the reaction to a higher construction time. Even though class 1 has a preference for district heating, their substitute RHS choice is only relatively mildly influenced by this preference. Low income homeowners living in relatively well insulated dwellings with possibly a gas heater are more likely to belong to the second class. Homeowners in this class base their choice on a wider variety of attributes, albeit that they are also mostly (although less than class 1) influenced by economic attributes. In contrast to the first class, this class is more influenced by the substitute RHS itself (preference for all-electric and hybrid heat pumps) and popularity in the neighbourhood. Both hassle types are of little importance to homeowners in this class.

Relocation has, as hypothesised, a positive effect on the sensitivity to investment costs. However, the change in relative importance of investment costs due to relocation is largest in class 2. The same difference between the reaction of relocation is found with respect to the sensitivity to construction time (construction hassle). However, the sensitivity to construction time increases as a consequence of relocation, which was not expected. In both classes, homeowners are only significantly influenced by construction time when they are moving to a new house. Given the above, class 1 consists of cost conscious homeowners and class 2 is characterised by relocation sensitive homeowners.

The finding that relocation increases the sensitivity to construction time is contrary to common belief and exemplifies the necessity and scientific contribution of including relocation as a context in the RHS choice behaviour research field. Relocation is, namely, only a window of opportunity for change if the increased sensitivity for construction time is taken into account.

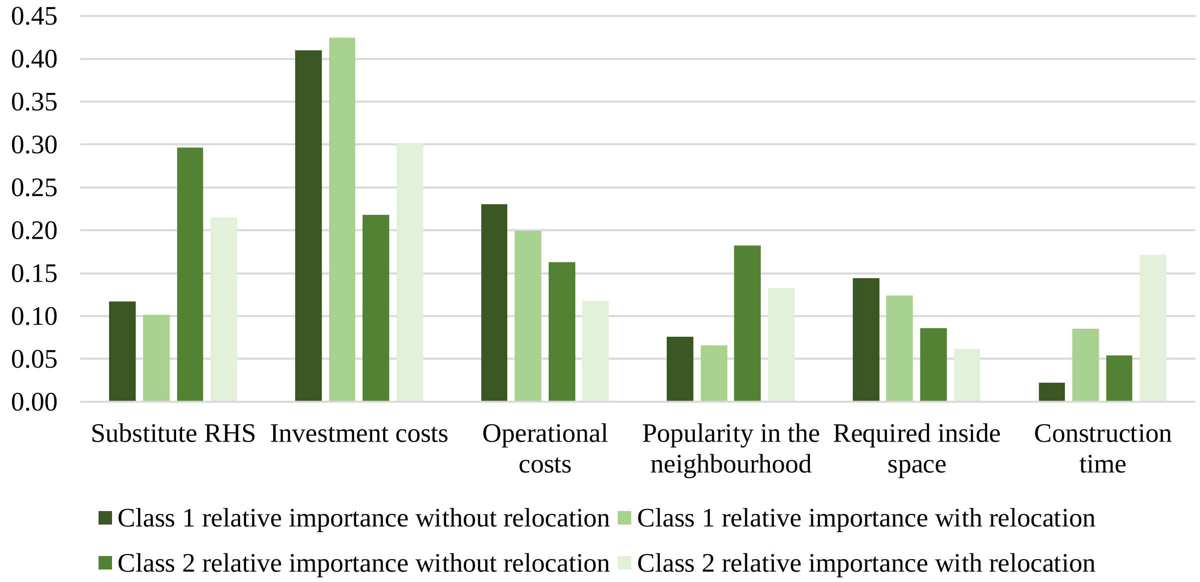

Figure 0.1: relative importance allocated to each attribute in both contexts by both latent classes.

It must be noted, however, that the sample was not representative for the Delft homeowner population, which might cause the effects of investment costs, operational costs, and required inside space to be underestimated in the second class. As a result, it is possible that the trade-offs of homeowners in this class are more comparable to that of class 1 if a more representative sample is acquired.

Policy recommendations

The model results showed that the economic attribute category (investment costs and operational costs) is most important to both latent classes. Besides that, the national government is the responsible actor to come up with measures to help homeowners with the investment costs and operational costs of a substitute RHS. Therefore, it is recommended that the municipality of Delft tries to influence the national government via four ways: the Association of Netherlands Municipalities, the G40 city network, the Metropolitan Region Rotterdam The Hague, and via the inter-government layer lobby connections between municipal aldermen and national ministers of the same political party. Furthermore, the municipality should inform its homeowners via the concept version of the transition vision about the following five points: the municipality acknowledges and prioritises the concerns of homeowners about costs, the national government is responsible for solving this affordability issue, the ways in which the municipality is trying to influence the national government, the guarantee that no changes will be made to the houses of homeowners before the cost issue is addressed but that it is necessary to parallelly investigate other aspects of the heat transition in order to be ready when the cost issue is solved, and the affordability issue will most likely be solved in time and during the formulation process of the implementation plans.

In order to mitigate the concerns of class 1 homeowners about the inside space requirements of substitute RHS, the municipality should use the advisors of Energieloket Delft and 015 Duurzaam. These advisors can help homeowners with planning and organising a transition towards a natural gas-free RHS. The municipality should also have citizen organisations (Platform Energietransitie Delft and neighbourhood associations) to gather and spread information about the popularity in the neighbourhood of a substitute RHS. This will help to increase the adoption rate of substitute RHS among class 2 homeowners who are relatively sensitive for this attribute. Furthermore, the municipality should focus the conversations with class 2 homeowners on the attributes of RHS and not on the substitute RHS itself.

This is needed in order to avoid a conflict of preference between district heating by the municipality and heat pumps by class 2 homeowners. In addition, the municipality should allocate less attention to relatively irrelevant attributes in the stakeholder analysis of the district analyses. So, in a non-relocation context, construction time should receive little attention. Furthermore, required inside space should play a small role in the analyses of low income homeowners living in relatively well insulated dwellings. Moreover, popularity in the neighbourhood should receive little attention in case of a neighbourhood with relatively many high income households living in poorly insulated houses.

The primary recommendation based on the results about relocation is that the municipality should start a partnership with all real estate offices, starting with the largest ones. Such a partnership enables the municipality to provide homeowners who are interested in buying a house with information about changing to a natural gas-free RHS before the first viewing. In this way, homeowners can account for the extra required construction time and investment costs for a substitute RHS in their bid. The second recommendation is that the municipality and real estate agent should have an advisor from Energieloket Delft or 015 Duurzaam to formulate a plan in which is stated what the best substitute RHS is for that house, including an overview of the required investment costs and construction time. The advisor should consider increasing the investment costs in order to decrease the required construction time. After the plan is made, the house can be placed on the housing market and the plan can be provided to those who are interested in buying a house. A further explanation about all of the above recommendations can be found in section 7.3.

Recommendations for future research

The present study should be performed again every five years from now with a representative sample of Delft homeowners in order to improve the validity of the results of this study. Future research should also specify the choice experiment of this study for smaller groups of homeowners, for example for those of particular house types or in a particular neighbourhood. The present study should also be extended in future research by investigating the effects of other life events on the tastes and preferences of homeowners, such as work related changes, marriage, parenthood, and retirement. Furthermore, a choice experiment based on revealed preference data should be conducted when the adoption rate of substitute RHS is high enough. Moreover, the psychological viewpoint on RHS choice behaviour should be centralised in a structural equation model. In addition, noise pollution should be included as an attribute in the choice experiment by treating it as complex variable. This requires the execution of a rating experiment. Finally, it is recommended to conduct this choice experiment in cities that are substantially smaller than Delft (e.g., less than 50,000 inhabitants) and in rural areas. This allows to check whether the trade-offs observed for Delft homeowners can also be generalised to these areas or not.

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List of Abbreviations

BIC	Bayesian Information Criterion
BS	Ben-Akiva and Swait
DCM	Discrete Choice Model(s)
DSO	Distribution System Operator
HT	High Temperature
IIA	Independence from Irrelevant Alternatives
KMO	Kaiser-Meyer-Olkin Measure of Sampling Adequacy
LC	Latent Class
LC DCM	Latent Class Discrete Choice Model
LL	Log-Likelihood
LRS	Likelihood Ratio Statistic
LT	Low Temperature
MNL	Multinominal Logit Model
ML	Mixed Logit
NDC	Nationally Determined Contribution
PAF	Principal Axis Factoring
PCA	Principal Component Analysis
RHS	Residential Heating System(s)
RP	Revealed Preference
RRM	Random Regret Minimisation
RUM	Random Utility Maximisation
SP	Stated Preference
TPB	Theory of Planned Behaviour

1 Introduction

Earth's climate is undeniably changing drastically, which could have detrimental effects across the world. In Europe, for example, climate change will lead to extreme weather conditions, increased health risks, and high societal costs (European Environment Agency, 2012). In order to prevent this from happening, a unique collaboration between 196 countries resulted in the 2015 Paris Agreement. In this binding agreement, the goal was set to limit global warming to well below 2 °C and preferably below 1.5 °C compared to pre-industrial levels (United Nations, 2015). This goal will be reached by reducing greenhouse gas emissions. The European Commission and European Council have agreed to set the European contribution to the Paris Agreement to a greenhouse gas emission reduction of 55% in 2030 compared to 1990 (European Commission, 2020; European Council, 2020).

The Dutch government, one of the countries involved in the Paris Agreement, has nationalised the international commitments by formulating its nationally determined contribution (NDC): the 2019 Climate Agreement. The main goal is to reduce the Dutch greenhouse gas emissions by 49% in 2030 and by 95% in 2050 compared to 1990 (Government of the Netherlands, 2019). It is currently unknown whether the 2019 Dutch NDC will be changed since the EU goal is now -55% by 2030 (Schmidt, 2020; Hekkenberg et al., 2020). Therefore, the present study assumes that the 2030 Dutch greenhouse gas emission reduction goal is 49%. It is also important to mention that greenhouse gas emissions are measured as CO_2 equivalents and in megatonnes (Mt).

The Climate Agreement is divided up into five sector platforms, which were each assigned a sector-specific CO_2 equivalent reduction goal: electricity (20.2 Mt), industry (14.3 Mt), mobility (7.3 Mt), agriculture and land use (3.5 Mt), and built environment (3.4 Mt). The present study focusses on the latter sector platform. The most impactful change for all involved actors lies in the goal of removing all 7.9 million dwellings from the natural gas grid before 2050 (Statistics Netherlands, 2020a). Apart from the contribution to the reduction of greenhouse gas emissions, this goal is also set to stop seismic activity as a result of natural gas extraction in Groningen (Government of the Netherlands, 2019).

However, currently, only 10% of Dutch houses is disconnected from the natural gas network (Jansma et al., 2020). Natural gas is used by households for space heating (78% of household natural gas demand), water heating (20%), and cooking (2%) (Scholte et al., 2020). The transition towards natural gas-free dwellings consists therefore primarily of a change in residential heating systems (RHS). In short, a new residential space heating system design is needed. The most common technology nowadays is the natural gas fired central heating boiler. Thus, 7.1 million households will need to choose in the coming few decades with what natural gas-free heating technology they will replace their central heating boiler. Central in this research is the question how these households would make this choice. Well-known examples of natural gas-free RHS include heat pumps, district heating, and hybrid heat pumps using green gas. Sustainable heating technologies can have a substantial impact on the environment, since the residential sector is responsible for 9% of national CO_2 emissions (Jansma et al., 2020).

1.1 Problem description

It is evident that the gap between the current situation and the desired natural gas-free target of 2050 is still very wide despite the potential of dwellings to contribute to reducing CO_2 emissions. Although a tremendous challenge is still ahead, progress is as planned when looking at the public policy-making process. The Climate Agreement states that municipalities are the facilitator of the heat transition and that they have to formulate a transition vision for heat ('Transitievisie Warmte' in Dutch) by 2021. In these visions, municipalities draw a high-level time path when each of their neighbourhoods will be made natural gas-free. Furthermore, for those neighbourhoods which will be made natural gas-free before 2030, more details are already given in the vision concerning potential alternative energy infrastructures and societal and end-user costs. Across the Netherlands, 1.5 million dwellings have to be natural gas-free before 2030. Subsequently and within two years after the 2021 deadline, municipalities must have made a district-specific implementation plan ('Uitvoeringsplan' in Dutch). This is a more detailed plan which also sets out the specific heating alternatives per neighbourhood (Government of the Netherlands, 2019). In short, municipalities are in the process of making their transition vision and progress is as it should be (Van Mil, 2020).

As municipalities are currently making their transition vision, they are also in the midst of a participation process with their citizens. Public participation is mandatory according to the Climate Agreement since it has the crucial ability to improve the quality of the policy decision-making process and to increase the adoption rate of substitute RHS (Government of the Netherlands, 2019). The latter is the case because the lion's share of the heat transition will take place inside dwellings and outside the jurisdiction of municipalities (HIER, 2020). Public participation processes differ across municipalities and neighbourhoods within municipalities. Therefore, the national government has not formulated a prescribed participation process for the heat transition. As a result, a wide variety of public participation processes can be observed. The exact participation process of the municipality central in this research is explained in section 7.2, i.e., the municipality of Delft.

However, as the present study argues, that participation process is not able to retrieve a specific type of information: the variety in importance allocated by different types of Delft households to attributes of RHS. That information can also not be found in scientific literature (see section 3.4). The trade-off information is retrieved by means of a discrete choice model (DCM). Furthermore, people are different and could therefore make different trade-offs in terms of the importance allocated to the attributes. This so-called taste heterogeneity is captured by extending the choice model to a latent class discrete choice model (LC DCM). It is important to account for taste heterogeneity because that allows for formulating class specific policy recommendations, which increases the societal contribution of this study. Moreover, the travel behaviour research field suggests that life events, such as marriage or relocation, can change the way in which people make trade-offs. The effect of life events has not been researched yet within the field of RHS choices. The present study will examine whether relocation has an effect on the importance allocated to different RHS attributes by making the LC DCM context dependent. Relocation is theorised to open a window of opportunity for households to change their RHS. All in all, the acquired information of this study can be used to formulate policy recommendations which will help to increase the adoption rate of substitute RHS in Delft. This is needed because the gap between the current situation and the desired situation is also in large in Delft. Currently, only 6.8% of the Delft dwellings is natural gas-free (Statistics Netherlands, 2021). Since 41% of the Delft homeowners currently has a negative opinion regarding the municipal goal to become natural gas-free, it is likely that the adoption rate will not increase voluntarily (Municipality of Delft, 2021a). Section 2 provides a complete overview of the used research methods.

1.2 Scope

The transition towards a sustainable RHS is a complex socio-technical problem in which municipalities act as facilitators. That problem can be analysed in various ways depending on the perspective that a municipality takes. The present study approaches the heat transition from the perspective of households: What are according to households important aspects to be considered by the municipality in the heat transition? Although many perspectives play an important role and although all perspectives are interrelated, two other perspectives are especially relevant to consider when analysing the household perspective: the technical-economic perspective and the institutional perspective. The former refers to the mix of substitute RHS which result into the lowest end-user and societal costs and the technical possibilities within a municipality. The latter perspective involves all relevant laws and regulations with respect to the heat transition. Each perspective brings its own opportunities and constraints which together form the solution space for a municipality. In order to be able to add the 'household perspective puzzle piece' to the heat transition puzzle, a series of choices are made with respect to the scope of this study.

First of all, and as mentioned earlier, the present study focusses on one municipality, namely the municipality of Delft. In principle, one could argue that the heat transition is a national challenge since all dwellings have to be natural gas-free in 2050. However, the Dutch government has decided in the national Climate Agreement that the heat transition takes place on municipal level, which makes municipalities the most relevant actors to consider. Each municipality has drawn or is drawing its own transition path towards 2050. The municipality of Delft already committed itself to climate neutrality in 2011 and already took steps to achieving this goal before 2019 (Municipality of Delft, 2013). However, the 2019 Climate Agreement imposed a policy-making process with certain nationwide policy documents (see section 1.1). A more elaborate analysis of the heat transition decision-making process is provided in section 7.2.

By focussing on one municipality, the potential improvement that insights into the choices of homeowners provide is maximised, because policy recommendations can be tailor-made for the to be made municipal heat transition policy documents. The municipality of Delft is specifically selected because the researcher has already conducted relevant research within this municipality. This research was part of a master course and focussed on the future roles of hydrogen, insulation, and biogas in space heating. Besides that, the researcher has lived for five years in Delft, which provided in-depth knowledge about the different neighbourhoods and inhabitants in the city. This knowledge is especially useful for interpreting the latent classes. Even though the present study focusses on Delft, it is interesting to reflect upon the generalisability of the results to other municipalities. Depending on the significant covariates of the context dependent LC DCM, different characteristics are important to consider when looking at the generalisability. Therefore, the generalisability of the results will be explained in section 8.2.

Secondly, the present study will focus on one type of households: homeowners. The survey of this study would have been too large and complex for respondents if tenants would also have been included. Furthermore, the most relevant and pressing issue in rented dwellings, namely the principal-agent problem, has already been investigated within the context of RHS choices, for example by Jansma et al. (2020) and Phillips (2012).

Thirdly, the time frame of interest in this study is 2030-2050. This is selected because the lion's share of dwellings (6.4 million out of 7.9 million) is expected to be made natural gas-free during this period of time. One could argue that it is irrelevant to examine the current trade-offs of homeowners for choices that they will make in the future. However, all municipal heat transition policies are currently being made. In order to be able to formulate recommendations for these policies now, it is necessary to already examine the choice behaviour of homeowners. The time frame has important consequences with respect to the relevancy of CO_2 emissions. By 2030, dwellings connected to district heating will have already reduced their emissions by 70% compared to current natural gas fired central heating boilers. Moreover, a decent part of the planned produced 70 PJ of green gas in 2030 can be used for the built environment. Although this 2030 production goal is ambitious and production capacity growth is lower than projected, studies have shown that the goal is achievable with additional government support (Vermaat, 2021; Wiebes, 2020; Gigler & Paap, 2020; Van der Veen et al., 2020). Furthermore, 70% of all electricity (needed to power heat pumps) is sustainable in 2030 (Government of the Netherlands, 2019). In short, heat sources for the built environment will have already become substantially more sustainable by 2030. Although different RHS will have different CO_2 emissions before all heat sources are completely sustainable (i.e., in 2050), the differences will become, in absolute terms, smaller and smaller between 2030 and 2050. Therefore, the present study assumes that different substitute RHS have comparable CO_2 emissions. As a result, CO_2 emissions are not taken into account by this study.

Fourthly, the most important and relevant insight from the institutional perspective for this study is the extent to which a municipality can force its citizens to remove their natural gas fired central heating boiler. This also has an impact on the scope of this study. Municipalities request such an ability in order to cope with citizens who do not change their RHS voluntarily (Dekker, 2021). In principle, all dwellings constructed after July 1st, 2018, are already natural gas-free (Overheid.nl, 2018). Citizens planning to move to a recently built dwelling, thus, have no other choice than to adopt a substitute RHS. However, municipalities cannot yet force citizens of existing dwellings to remove their natural gas connection, because these dwellings have the right to a natural gas connection. This will change with the new Energy law and Environment and Planning Act, which are currently being made and are in an advanced stage. With these laws, the right to natural gas changes into a right to heat. Municipalities can relieve their distribution system operator (DSO) from their duty to connect dwellings to the natural gas grid in a certain area if an alternative heating system is available in that area. In this way, municipalities force citizens to change their natural gas fired RHS (Jager, 2019; Ministry of Economic Affairs and Climate Policy, 2020a; Ministry of Economic Affairs and Climate Policy, 2020b; Ministry of the Interior and Kingdom Relations, 2020). It is assumed that these laws will come into effect within a few years and that the municipality of Delft will have the ability to force people to adopt a natural gas-free RHS. It important to stress here that the municipality can only force homeowners away from natural gas fired central heating boilers and not towards a particular substitute RHS.

In other words, homeowners will keep their freedom of choice within the natural gas-free RHS.[1] Needless to say, the primary aim of the municipality is to cooperate with its citizens in such a way that forced measures are unnecessary. As a result of this and the previous assumption, the present study focusses, in terms of the diffusion of innovations theory, on the early majority and late majority (Rogers, 1983). It is assumed that this group will perceive the Climate Agreement as the primary motive for needing to invest in a new RHS. Innovators and early adopters are assumed to be people who are green minded and are interested in the heat transition. Given the assumptions that CO_2 emissions are not considered and that it is assumed that the choice to invest in a new RHS is already made (either by the municipality or by the homeowner in cooperation with the municipality), the trade-offs of innovators and early adopters do not exist anymore. Section 3.4 further explains this.

Finally, the present study will not consider the exact financing method of required investments in an RHS. Currently, various subsidies and loans with low interest are already available to homeowners in the municipality of Delft, such as 'ISDE', 'Lening Restauratiefonds Delft' and 'Lening Energiebesparingsfonds' (Netherlands Enterprise Agency, 2021; Municipality of Delft, n.d.a; Municipality of Delft, n.d.b). However, Dignum et al. (2021) have found that these subsidies and loans are not sufficient for making the transition towards a sustainable RHS attractive for the majority of people. However, it is currently unknown which additional measures will be taken by the national government. Section 7.3 provides various policy recommendations with regard to these measures.

1.3 Research objective and research questions

The primary objective of this research is to gain knowledge about the trade-offs that different classes of Delft homeowners make with respect to attributes of substitute RHS and how these trade-offs differ in a relocation context. Therefore, the main research question is:

How do different classes of Delft homeowners make trade-offs between attributes of substitute residential heating systems and how do these trade-offs change due to relocation?

The research question is divided up into several sub-questions. First, a general overview is created of the factors that might influence the choice homeowners (sub-question 1). Subsequently, the trade-offs of Delft homeowners are analysed (sub-question 2). Thereafter, the extent to which these trade-offs differ between different classes of homeowners and the covariates that determine these classes are investigated (sub-question 3). Fourthly, the effect of relocation on the trade-offs of homeowners is examined (sub-question 4). Finally, the gathered empirical data is used to formulate class specific policy recommendations to the municipality of Delft. Before policy recommendations can be drawn up, the decision-making process of the Delft heat transition is first thoroughly examined (sub-question 5).

1. *Which factors might influence the choice of homeowners of Delft for an RHS?*
2. *How do homeowners of Delft make trade-offs between attributes of substitute RHS?*
3. *Which homogeneous classes of Delft homeowners can be identified and what are the characteristics of these classes?*
4. *What is the effect of relocation on the trade-offs that homeowners of Delft make?*
5. *How is the decision-making process of the Delft heat transition structured and how can it be improved given the obtained context dependent class specific trade-off information?*

[1] The draft version of the Heat Act 2 states that homeowners automatically opt-in to be connected to the district heating network that a municipality is planning for their neighborhood. Homeowners can only opt-out for this if they can proof that their own substitute RHS is comparable to the district heating network in terms of its sustainability (Ministry of Economic Affairs and Climate Policy, 2020c; Ministry of Economic Affairs and Climate Policy, 2020d). In practice, this will only be the case for all-electric heat pumps. Such an RHS is often much more expensive to acquire, which will probably in the end often causes homeowners to still join the collective RHS (Over Morgen, personal communication, May 24, 2021). If the Heat Act 2 is passed into law, the freedom of choice of homeowners is, thus, constrained in the case of district heating. However, for the purpose of this study it is only necessary to consider the power of municipalities to force their citizens towards natural gas-free RHS.

1.4 Relevance to science, society and, master programme

The present study makes several scientific contributions of which two are highlighted here. First of all, the most important theoretical contribution is the addition of relocation as a context to a choice experiment. Context dependent choice experiments have not been conducted in the field of RHS choices yet. Secondly, studies using choice experiments to analyse RHS choices have not been conducted yet in the Netherlands. Li et al. (2018) stress the importance of country-specific research since influential factors vary considerably among countries. Section 3.4 explains all the scientific contributions of this study.

The societal relevance of this study lies in the fact that the obtained context dependent class specific trade-off insights can be used in combination with the heat transition decision-making process analysis to formulate policy recommendations to the municipality of Delft. These recommendations are aimed at increasing the adoption rate of substitute RHS in Delft. For example, if it is found that a particular homeowner class is concerned about costs and that the municipality has not taken this into account yet, a policy recommendation can be formulated regarding the way that the municipality can relief homeowners from their concern for costs. Since the acquired insights are from a specific type and cannot be created during the current participation process, the policy recommendations provide unique new insights.

The master Complex Systems Engineering and Management with the Energy track distinguishes itself by both analysing and designing complex socio-technical energy systems from various disciplines. The complex socio-technical energy system central in this research is the RHS in Delft. The analysis component consists of gaining insights into the trade-offs of different classes of Delft homeowners with respect to attributes of substitute RHS. The design component of this study is signified by the fact that the created knowledge is used to improve the design of the heating system in Delft in the form of policy recommendations.

1.5 Report structure

In section 1, the problem central in this research was introduced, the scope was explained, and research questions were formulated. Section 2 elaborates on the methodology used to answer these research questions. Previously conducted studies relevant for this research are reviewed and the conceptual model is shown in section 3. The design of the stated preference survey is explained in section 4. The data preparation actions and descriptive statistics of the obtained data are presented in section 5 and the model results are provided in section 6. Section 7 first describes the Delft decision-making process of the heat transition to which, subsequently, policy recommendations are formulated for. Section 8 contains the conclusion of this study, a discussion of the research methods and generalisability, and recommendations for future research. This structure is also visualised in figure 1.1.

Figure 1.1: report structure.

2 Methodology

This section will elaborate on the methodology used to answer the main research question and sub-questions. Firstly, section 2.1 provides an explanation why a literature review and expert interviews are used to find relevant influential factors. Section 2.2 explains the data collection method. Subsequently, section 2.3 delineates the methods used to analyse the gathered data. Section 2.4 explains how the fifth sub-question is answered. A short conclusion is provided in section 2.5.

2.1 Literature review and expert interviews

A literature review is performed to create insights into the current knowledge regarding the system characteristics and variables that influence the RHS choice of individuals. The review is the answer to the first sub-question. That answer forms the foundation of the choice which system characteristics are included as attributes and which variables are included as covariates in this research about Delft homeowners. The first part of the review will analyse which system characteristics have been included in previous research regarding choices for RHS. The second part will focus on the variables which have previously been included to explain differences between individuals. Scopus is used to obtain academic literature, which will be organised using EndNote X9. A more detailed explanation about what is included in the review is provided in section 3.1.

While the literature review is used to gain an overview of all included system characteristics and variables, expert interviews are conducted to select the relevant attributes and covariates for the context of this study. A system characteristic or variable is selected if it is considered to be important and relevant for homeowners of Delft when choosing a new RHS. The result of the review and interviews is the conceptual model of this study. Thus, these expert interviews act as a validation step for the conceptual model. The interviews last for one hour and are semi-structured since that allows asking specific questions regarding the relevant factors and leaves space open for follow-up questions, which can provide other valuable information. A potential disadvantage of interviews is that the findings can be too biased towards the beliefs of the interviewee (Bellasio et al., 2018). Each interviewee responds to questions from its own problem perception, which is by definition biased. In order to ensure a balanced and neutral position of this study as much as possible, different types of actors are interviewed. Section 3.4 states which actors are interviewed and why.

2.2 Type of preference data

As mentioned in section 1.1, the present study will estimate a discrete choice model. But why is this a suitable method to retrieve trade-off information about RHS? Households are facing a choice between different substitute RHS, which differ in their characteristics. But what are choices? Samuelson (1948) proved that choices are signals of underlying preferences. This means that consumer preferences can be analysed by looking at the choices they make. Moreover, choices are partly random due to the presence of noise (Luce, 1959). Consumer choices are, thus, not always rational and deterministic. Lancaster (1966) argued that an alternative (a substitute RHS in this case) can be seen as a bundle of features, i.e., attributes. Attributes of RHS are, for example, investment costs and operational costs. In line with this theory, households do not have a preference for a particular heating alternative in itself, but they do have a multi-dimensional preference for the attributes of the alternative (Chorus, 2019a). But why shouldn't municipalities ask their citizens how they make trade-offs? This can, namely, be easily incorporated in current participation processes, for example via regular surveys. An example question could be: Do investment costs play a larger role in your choice for an RHS than operational costs? Previous research has shown that there is a considerable difference between what people think that drives their choices and what actually drives their choices (Nisbett & Wilson, 1977; Chorus, 2019b). In other words, people have trouble with expressing their true trade-offs while choosing between different alternatives with multiple attributes. To tackle this problem, a more advanced method is needed: a discrete choice model. The data that is required for this model can be collected in two different ways: revealed preference and stated preference.

Revealed preference

With revealed preference (RP), the researcher observes the choices that people make in real-life. This results in a highly valid model. However, it is not possible to observe choices for new alternatives and attributes. Moreover, since the chosen alternative is the only observed alternative, the choice set from which a person chooses is unknown. Furthermore, parameters can be unreliable or cannot be estimated due to multicollinearity. Lastly, RP data collection can be time consuming due to the fact that only one choice per respondent is observed and many respondents are, thus, required (Molin, 2019a; Yang & Mesbah, 2013; La Paix & Geurs; 2016; Tseng et al., 2013).

Stated preference

In this data collection method, respondents choose an alternative from a choice set. This choice set is made by the researcher and can include both existing as well as hypothetical alternatives. An alternative is hypothetical when it is currently non-existing, includes new attributes or has attribute levels outside the existing range. This method solves the issues of RP and also presents the opportunity to find the relative importance of attributes to respondents (Molin, 2019a; Kløjgaard et al., 2012). However, stated preference (SP) has its limitations. First of all, SP has a partial inherent subjectivity since the researcher is responsible for presenting the respondent with relevant alternatives, attributes, and attribute levels (Bourguignon, 2015). However, the most pressing and well-known limitation of SP is the potential hypothetical bias. This is the notion that it is uncertain whether the observed hypothetical choice of a respondent is the same as the real-life choice of that respondent. The bias undermines the validity of the choice model (Molin, 2019a; Chorus, 2007; Wardman, 1988; Haghani, 2021a). Hypothetical bias can occur because hypothetical choices differ inherently from real-world choices for several reasons: the respondent does not feel the consequences of its choice, respondents are presented with perfect information, and new attributes and attribute levels are not experienced yet by the respondent (Molin, 2019a).

In this study, SP will be used as data collection method for several reasons. First of all, the choice for a substitute RHS consists of various hypothetical alternatives since such systems are new and have attribute levels beyond current levels (such as investment costs). One could argue the RP data of homeowners who have already switched to a natural gas-free RHS can be used for the choice model. However, it is likely that too little data will be available since only 1 out of 10 households have switched to a natural gas-free RHS. As a result, parameters are likely to be insignificant. Moreover, current RP data does not contain the same alternatives which will be available in the future, because green gas hybrid heat pumps are not available now (this is especially the case for hydrogen green gas). Secondly, the primary aim of this research is to gain insights into the attribute trade-offs of homeowners which requires that the choice set is fully known. Lastly, SP data requires a smaller sample size which better fits the time constraints of this study.

The limitations of SP are addressed in several ways. The bias of the researcher in designing the choice experiment is reduced by doing both a literature review as well as conducting multiple expert interviews (see section 2.1). Haghani (2021b) have proposed ten hypothetical bias mitigation strategies of which two are selected to include in this study: cheap talk and perceived consequentiality. This choice is based on the following (sometimes conflicting) notions: effectiveness, increased burden to fill out the survey, source of bias relevant in this study, and compatibility with SP. The exact application of the bias mitigation strategies is explained in section 4.4.

2.3 Context dependent laten class discrete choice model

In this section, the two main decision rules in choice modelling are first described. Subsequently, it is argued why a context dependent latent class discrete choice model best fits the purposes of this study.

2.3.1 Different decision rules

A discrete choice model (DCM) will be estimated based on the SP survey data. A DCM allows to quantify how respondents react to changes in attribute levels and therewith the degree of importance of different RHS attributes in one's decision (Koppelman & Bhat, 2006; Bennet & Blamey, 2001). Generally speaking, a DCM can be based on two different decision rules: Random Utility Maximisation (RUM) and Random Regret Minimisation (RRM).

Utility is an indicator of value that a person obtains from attributes of alternatives (Koppelman & Bhat, 2006). Someone experiences regret if the non-chosen alternative performs better than the chosen alternative. RUM states that individuals choose the alternative which provides them with the highest utility, while RRM claims that persons choose the alternative with the lowest regret (Walker & Ben-Akiva, 2002; Chorus, 2010; Chorus et al., 2014). The DCM of this study will be based on the RUM decision rule because it is assumed to be more suitable and appropriate within the context of purchasing a substitute RHS. Thus, the present study assumes that an individual (*n*) chooses alternative (*i*) if it has a higher utility than all other alternatives (*j*):

$$U_{in} > U_{jn} \; \forall j \neq i \qquad \text{(Equation 2.1)}$$

It is important to mention that the equations in this section are based on the multinominal logit model (see section 2.3.2). The total utility (U_{in}) that an individual (n) derives from an alternative (*i*) consists of two elements: the systematic utility (V_{in}) and an error term (ε_{in}).

$$U_{in} = V_{in} + \varepsilon_{in} \qquad \text{(Equation 2.2)}$$

The systematic utility (V_{in}) refers to the utility that is derived from all observed variables, i.e., the attributes. Section 3.4 explains which attributes are included in this study. The error term (ε_{in}) represents everything which has not been measured, such as the randomness of people in their choices, unobserved attributes, measurement errors, and taste heterogeneity. To reiterate, taste heterogeneity among people is the variety in the sensitivity to attributes. A parameter (β_m) is estimated for each observed factor (i.e., the attributes) in the utility function. The parameter can be interpreted as the average additional utility people derive from an increase of one step in the attribute level (X_{im}). If all p parameters are considered to be linear, equation 2.2 can also be expressed as the following linear additive utility function:

$$U_{in} = \sum_{m=1}^{p} \beta_m \times X_{im} + \varepsilon_{in} \qquad \text{(Equation 2.3)}$$

One of the aims of the present study is to examine whether different classes of homeowners have different tastes for parameters. Since the ranges of attribute levels differ across attributes, one cannot directly use the estimated parameter (β_m) as a measure of relative importance. The relative importance of attribute *m* ($\widetilde{W}_m$) is calculated by using the part-worth utilities of all attributes *p*:

$$\widetilde{W}_m = \frac{Max(\beta_m \times X_{im}) - Min(\beta_m \times X_{im})}{\sum_{m=1}^{p} Max(\beta_m \times X_{im}) - Min(\beta_m \times X_{im})} \qquad \text{(Equation 2.4)}$$

$Max(\beta_m \times X_{im})$ is the maximum utility of an attribute which signifies the most preferred attribute level (X_{im}), while $Min(\beta_m \times X_{im})$ refers to the utility of the least preferred attribute level of an attribute.

The systematic utility part of the utility function can be extended with interaction effects. This means that the utility contribution of one variable depends on the value of another variable. A separate parameter is estimated for each interaction effect. The estimation of all parameters is based in the maximum likelihood principle (the higher the log-likelihood (LL) the better). This means that the model is estimated by iteratively combining vales for the parameters which make the stated choices by respondents (i.e., the dependent variable) as likely as possible. Three model fit statistics are used in this study, namely the R^2, the ρ^2, and the Bayesian Information Criterion (see section 2.3.2). The R^2 is the proportional reduction of errors (i.e., the explained variance) in the estimated model compared to the baseline model:

$$R^2 = \frac{Error(baseline\ model) - Error(estimated\ model)}{Error(baseline\ model)} \qquad \text{(Equation 2.5)}$$

The ρ^2 is the percentage of explained initial uncertainty and is based on the LL of the estimated model (i.e., LL_β) and the LL_0, which is the LL of the model in which each alternative has an equal chance of being chosen.

$$\rho^2 = 1 - \frac{LL_\beta}{LL_0} \qquad \text{(Equation 2.6)}$$

2.3.2 Different types of discrete choice models

There is a wide range of different discrete choice models. This section describes the most commonly used models and argues which model fits the purpose of this study best.

Multinominal logit model

The oldest, most common, and simplest DCM is the multinominal logit model (MNL) by McFadden (Train, 2009; Hausman & McFadden, 1984; McFadden, 1973, McFadden, 2001). A key assumption of the MNL model is that the error term is independently drawn from an identical Extreme Value type 1 distribution with variance $\pi^2/6$ resulting in error terms that are independent from each other, i.e., the i.i.d. assumption. By fixing the variance, the scale of utility is normalised which enables the interpretation of the parameters, i.e., only differences in utility matter and not the absolute value. The effects of the observed variables are, thus, relative to the error term (Train, 2009). As a result of the i.i.d assumption, the choice probability formulation is in closed form (simulation is not needed) resulting in quick computations (Chorus, 2019a). The choice probability (P_{in}) that an individual (n) chooses an alternative (i) in this convenient linear-additive MNL model is defined as:

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{J} V_{jn}} \qquad \text{(Equation 2.7)}$$

The most important limitation of an MNL model for this study is the fact that it exhibits the Independence from Irrelevant Alternatives property (IIA). This means that the relative popularity between alternative A and B does not depend on alternative C. The IIA property is a problem if tastes (i.e., the β_m) vary across individuals (Chorus, 2019c). In other words, the MNL model assumes that everyone has the same taste parameters and with that the same preferences by estimating one parameter for all individuals (Wen & Lai, 2010). However, one of the objectives of this study is to examine the extent to which different homeowners have different tastes (see section 1.3). An MNL model can, thus, not accommodate this. Nevertheless, MNL models are often used in the reviewed literature field of RHS choices, which justifies using it as the starting model and as a reference model to a more advanced model.

Mixed logit model

The more recent Mixed logit models (ML) are better able to capture taste heterogeneity. ML models capture taste heterogeneity by assuming that tastes differ across individuals. To do this, ML models randomly vary the parameters across individuals using a pre-specified statistical distribution (Hess et al., 2011). In contrast to MNL models, ML models require simulation resulting longer estimation times. Although ML models can capture taste heterogeneity, they cannot explain where the heterogeneity originates from using for example socio-demographic variables. The latter is one of the aims of this study (see section 1.3). Therefore, ML is not a suitable DCM for this study.

Latent class discrete choice model

The latent class model (LC) can both capture as well as explain taste heterogeneity (via covariates) and with that solves the issues of MNL (IIA property) and ML (explaining taste heterogeneity). It can be argued that LC is a mixture of MNL and ML because it has both deterministic as well as random characteristics. In LC models, respondents are allocated to different classes and each class differs with respects to its characteristics, so called covariates. These covariates may correlate with each other. The classes are not directly observable, which is why they are called latent classes. LC models assume that the IIA property stands within each latent class, which is a valid assumption (Magidson et al., 2003). The class allocation is performed using a probabilistic model (the random part) which is based on deterministic covariates, such as socio-demographic variables (Hess et al., 2011). As opposed to ML models, LC models do not require the researcher to make assumptions about the shape of the taste distribution (Greene & Hensher, 2003). The goal is to maximise taste homogeneity within classes and heterogeneity across classes. For each class, different parameters are estimated making a LC model a combination of linear-additive MNL models (Van Cranenburgh, 2018). When deciding what the optimal number of latent classes is, model parsimony needs to be taken into account. Other conventional statistics that do not take this into consideration, such as the Likelihood Ratio Statistic (LRS) and the Ben-Akiva Swait (BS) test, will namely always improve with the addition of a latent class (and thus parameters).

The most suitable model fit method for LC models is the Bayesian Information Criterion (BIC) (Van Cranenburgh, 2018). The BIC (the lower the value the better) depends on the final log-likelihood (LL_β) of the model, the number of parameters to be estimated (k), and the number of observations (N):

$$BIC = -2 \times LL_\beta + k \times \ln(N) \quad \text{(Equation 2.8)}$$

As mentioned above, each individual is allocated to a latent class. The probability that an individual (n) is allocated to latent class (s) depends on class specific constants (δ_s), a vector of parameters (γ_s), and observed variables (z_n), such as socio-demographic variables:

$$\pi_{ns} = \frac{e^{\delta_s + g(\gamma_s, z_n)}}{\sum_{l=1}^{S} e^{\delta_l + g(\gamma_l, z_n)}} \quad \text{(Equation 2.9)}$$

The form of the utility function $g(°)$ is assumed to be linear-additive (Van Cranenburgh, 2018). Equation 2.9 is used in the equation of the probability that an individual (n) chooses alternative (i) conditional on the model parameters (β):

$$P_n(i|\beta) = \sum_{s=1}^{S} \pi_{ns} \times P_n(i|\beta_s) \quad \text{(Equation 2.10)}$$

Similar to an MNL model, a LC DCM also provides the opportunity to include interaction effects. The effect of one variable on the other is then made class specific. As argued in section 3.3, this possibility is used to examine the effect of relocation on the tastes of different classes of respondents. This is done by making the LC DCM context dependent. A context is the description of the choice situation. In other words, it explains what respondents need to assume while choosing an alternative from a choice set (Molin, 2019b). A choice experiment is made context dependent by nesting all choice sets of the regular choice experiment under the different context descriptions. Thus, the total number of choice sets of the context dependent experiment is equal to the number of choice sets of the regular experiment multiplied by the number of context descriptions (Molin & Timmermans, 2010). Choosing an alternative from a choice set is time consuming for respondents. Therefore, it is preferable to keep the number of choice tasks per respondent below 12. Blocking can be used to achieve this when the choice experiment consists of more than 12 choice sets.

In short, the present study will first use a base MNL model to gain generic insights into the preferences and tastes of respondents and to have a reference. Subsequently, the base MNL model is extended into a context dependent LC DCM which allows to capture and explain taste heterogeneity and to examine the effect of relocation. The optimal number of classes is determined by the lowest BIC value. The extended model is interpreted by discussing the parameter estimates and relative importance of the attributes, interaction effects, and covariates. The Wald statistic is used to check whether the estimated parameters for the attributes are statistically significantly different from 0 (H_a) or not (H_0). Furthermore, the Wald(=) statistic is utilised to check whether an effect should be treated as class independent (H_0) or not (H_a). In this study, a significance level of 5% is used. The exact experimental design of the SP survey that provides the data for the context dependent LC DCM including the utility formula is explained in section 4.3.

2.4 Policy document review and second round of interviews

The main research question can be answered by combining the answers of the first four sub-questions. However, the societal contribution of this research lies primarily in the fifth sub-question in which the model results are translated into policy recommendations for the municipality of Delft. Before policy recommendations can be formulated, an in-depth understanding of the decision-making process of the Delft heat transition is required for two reasons. First of all, the decision-making process analysis helps to target the policy recommendations to the correct policy. It would, namely, be redundant to recommend something to policymakers which cannot be changed anymore. Secondly, the analysis shows the extent to which the municipality is already accounting for concerns of homeowners with respect to RHS attributes. For example, the analysis shows what the municipality is doing to help homeowners about their concerns for costs. The decision-making process is scrutinised by means of reviewing policy documents, attending city talks, and conducting expert interviews.

City talks ('stadsgesprekken' in Dutch) are meetings during which the progress of the transition vision for heat is explained to citizens by civil servants from the municipality of Delft. Apart from gaining a better understanding of the decision-making process, the expert interviews will also act as a validation step of the model results and ensure that the recommendations are feasible in practice. Again, to prevent too much interviewee bias, various actors are interviewed. Section 7.1 explains which actors are interviewed and why.

2.5 Conclusion

In this section, the methodology used to answer the main research question and sub-question is explained. The first sub-question is answered by conducting a literature review and expert interviews. The subsequent three sub-questions are answered by means of a context dependent latent class discrete choice model. Finally, the last sub-question is answered with the help of policy documents, city talks, and a second round of expert interviews.

3 Theory: conceptualisation

This section describes the performed literature review to gain an understanding of what are potential relevant RHS characteristics for homeowners of Delft when choosing a new RHS. In section 3.1, RHS characteristics are reviewed using three theoretically founded categories. Previously included factors for explaining taste heterogeneity among respondents are also reviewed using three categories in section 3.2. Next, section 3.3 describes the relevance of including a life event as a context in the choice experiment. Both the conceptual model as well as the scientific contributions of this study are described in section 3.4. Finally, section 3.5 provides the conclusion.

3.1 Categorisation of previously included RHS characteristics using a multi-disciplinary approach

An important part of conducting a choice experiment is choosing relevant attributes. As mentioned in section 2.2, this choice could be subject to the bias of the researcher. In order to minimise that risk, the attributes of the choice experiment in this study are selected as structured and bias-free as possible using a three-step approach. The goal of this approach is to arrive at a set of attributes which are most important and relevant for homeowners of Delft when choosing a new RHS. The first step is finding what characteristics of RHS were included in previous studies. Secondly, the characteristics will be categorised, which will later help to find a balanced and relevant set of attributes for the choice experiment. For example, categorisation helps to prevent only including cost attributes, which would not resemble the way that homeowners make choices. Furthermore, categorisation enables the researcher to analyse and discuss the attributes more in-depth. The categorised characteristics will form the set of characteristics from which several will be selected to include as an attribute in the choice experiment of this study, i.e., step three (see section 3.4). That choice is made with the help of experts and will be explicitly explained. In this way, a well-argued and relevant set of attributes is found.

It is interesting to observe that such a structured approach for choosing attributes is not always followed in previous studies, at least not explicitly. Numerous studies only performed the first step, which means that they explain that their characteristics find their basis in previous studies (Troiano et al., 2019; Sopha et al., 2010; Chen, 2021; Rouvinen & Matero, 2013; Ruokamo, 2016). However, the characteristics are not explicitly categorised. Other studies have done that and have used a variety of categories. Kontu et al. (2015) used the following five categories: economic, environmental, social, technology, and usability. Michelsen & Madlener (2013) used the same first three categories and have included energy security of supply, comfort considerations, and general attitude as well. Mahapatra & Gustavsson (2008) used comparable categories and have added information provision as a category. The study of Li et al. (2018) is unique in the sense that they have clearly stated which categories of attributes are represented in their choice experiment, namely economic, technology, and environmental. Various studies report that the final choice of attributes is made with the help of experts (Chen, 2021; Decker & Menrad, 2015; Rouvinen & Matero, 2013, Ruokamo, 2016; Troiano et al., 2019). However, none of these studies have provided the exact reasons why certain attributes were included.

This literature review will also categorise previously included characteristics, but in a different way. The categories are determined by the implied academic discipline that lies behind the reason why characteristics were included in previous studies. The underlying idea is that different academic disciplines take different viewpoints on what determines the RHS choices of individuals, i.e., what characteristics are relevant. This categorisation extents on the work of Lillemo et al. (2013), Bjørnstad (2012), and Abrahamse (2019), who have already distinguished two main school of thoughts to analyse consumer energy behaviour: economics and psychology (theory of planned behaviour). The present study applies those viewpoints on the context of RHS characteristics and adds a second psychological viewpoint, namely the hassle factor. Using this recategorisation, a more theoretically founded choice can be made with regard to what characteristics are included as attributes in this study. By focussing on attributes (for the choice experiment), the present study centralises the economic viewpoint. However, the present study adds the psychological viewpoint within the constraints of the economic viewpoint to better resemble the way that individuals make RHS choices. RHS operate for decennia and are relatively expensive.

As a result, individuals carefully balance advantages and disadvantages, which requires an extensive decision-making process. The combination of viewpoints is considered to be a suitable approach to analyse such decision-making processes (Decker & Menrad, 2015; Jager, 2006).

A first set of articles was found using the following search terms in Scopus: household AND preferences AND residential AND heating. From there, the backward snowball method was used to find more relevant articles. In order to scope down the number of articles, only English studies dated from 2008 and later were included. A further scoping was made by solely including studies which mention quantitative results regarding the factors that influence the choice of households for a heating alternative. Studies focussing on other actors than households and/ or mention only qualitative results were, thus, excluded. As a result, and given the focus on preferences, most included studies used a choice experiment. Other included studies used, for example, (multinomial logistic) regression analysis, stochastic multicriteria acceptability analysis, or principal component analysis. Since the term attribute is specific for choice experiments and not all included studies used this method, a more general term will be used: system characteristics.

3.1.1 Economic viewpoint: rational decision-making

A RUM choice experiment is a methodology that typically fits within the economic viewpoint. In this case, it is assumed that people maximise their utility by weighing costs and benefits. Thus, people are rational decision-makers (Abrahamse & Shwom, 2018; Abrahamse, 2019). Being an economic theory based on costs and benefits, it is logical to observe a wide variety of economic system characteristics which have previously been included in other studies. Table 3.1 provides an overview of these characteristics, which can be regarded as objective characteristics. Furthermore, the number of times that a characteristic was included is also mentioned. The characteristic type of funding means whether there are grants and/ or loans with interesting rates available. This characteristic has a positive effect on utility. The utility effects of the other characteristics are assumed to be self-explanatory.

Table 3.1: economic system characteristics included to analyse RHS choices.

Characteristic	Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Investment costs	15	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
Operational costs	14	X		X	X		X	X		X	X	X	X	X	X	X	X	X
Payback period	4	X	X			X							X					
Amortisation time	1				X													
Change in rent	1								X									
Contract length	1																	X
Competing energy providers	1							X										
Guarantee period	1	X																
Increased home value	1											X						
Lifetime	1									X								
Price elasticity	1		X															
Replacement costs	1				X													
Type of funding	1	X																

Where: [1] Achtnicht (2011); [2] Bjørnstad (2012); [3] Chen (2021); [4] Decker & Menrad (2015); [5] Gu et al. (2019); [6] Jansma et al. (2020); [7] Kontu et al. (2015); [8] Phillips (2012); [9] Li et al. (2018); [10] Lillemo et al. (2013); [11] Mahapatra & Gustavsson (2008); [12] Michelsen & Madlener (2013); [13] Rouvinen & Matero (2013); [14] Ruokamo (2016); [15] Sopha et al. (2010); [16] Troiano et al. (2019); [17] Willis et al. (2011).

Observations

First of all, a wide variety can be observed with respect to the number of times that each system characteristic was included. Investment and operational costs are included by far the most in the reviewed studies. The payback period of an RHS is much less often included although still present in four of the sixteen reviewed studies. Ten characteristics were only included once.

Secondly, when looking at which characteristics were included in each study one interesting observation can be made. Almost each study included both investment costs and operational costs. Decker & Menrad (2015), Gu et al. (2019), and Phillips (2012) included only one of these costs explicitly. However, Decker & Menrad (2015) included amortisation time, which means that investments costs were also included indirectly. Gu et al. (2019) included the characteristic payback period, which also included operational costs indirectly. Phillips (2012) did not have such an indirect inclusion of operational costs. Bjørnstad (2012) included neither investment nor operational costs as explicit characteristics. However, this study used economic return as a characteristic which included both yearly net investment costs and operational costs. The former costs were calculated by accounting for subsidies, interest, and the lifespan of the RHS.

Thirdly, less often included characteristics were almost always included in combination with investment costs and/ or operational costs. The only exception to this is Bjørnstad (2012), but as mentioned above, this study indirectly included these system characteristics.

In short, investment costs and operational costs can be regarded as important and relevant characteristics to include as attributes in the choice experiment. With respect to the relative importance of these economic characteristics, Selvakkumaran & Ahlgren (2019) observe in their extensive literature review that these characteristics are among the most influential factors in the RHS choice of individuals.

3.1.2 Psychological viewpoint: theory of planned behaviour

However, as is well-known and recognised by a growing body of literature, people are not only influenced by economic characteristics when choosing an RHS in a rational way. Some studies explicitly mention this and account for it by including psychological factors as system characteristics, i.e., non-objective characteristics (Li et al., 2018; Lillemo et al., 2013). Bjørnstad (2012) did this as well but also went a step further by discussing several psychological theories that might play a role in the decision-making process of individuals. He discussed the theory on diffusion of innovations and the theory of planned behaviour. The present study will focus on the latter since it can be regarded *'as a social psychological variant of the general rational choice approach'* (Bamberg, 2012, p.222). It has therefore a clear connection with the economic viewpoint which states that people are rational decision-makers. This section argues which parts of the theory of planned behaviour (TPB) are suitable to incorporate into the choice experiment and thus into the economic viewpoint, which is central in this study.

The (TPB) states that someone's behaviour is determined by that person's intentions. Those intensions are in turn affected by three determinants: attitudes, subjective norms, and perceived behavioural control. The first determinant refers to the degree to which the behaviour is positively valued or not. Subjective norms denote the perceived social pressure to perform particular behaviour. It is important to mention that the subjective norm is originally meant as an injunctive and social norm. Within the context of this study, an injunctive social norm could be the perception of other people's opinions about which RHS an individual should choose. Thus, it concerns perceptions from an individual about other people (Ham et al., 2015; Abrahamse & Steg, 2011). However, Rivis & Sheeran (2003) argue that the conceptualisation of subjective norms as social norms is too narrow. They proved that adding descriptive norms to the subjective norms determinant is beneficial. Descriptive norms differ from injunctive social norms in the sense that they refer to actual behaviour of others. A descriptive norm in this study could be the extent to which a certain RHS is used by friends of an individual. This information tells the individual the extent to which an RHS is common to use, which helps in deciding whether he/ she will adopt the same RHS (Rivis & Sheeran, 2003; Steg & Vlek, 2009). Simply said, the individual could think: *'If everyone's doing it, then it must be a sensible thing to do'* (Cialdini et al., 1991, p.203). The third determinant refers to the perceived ease or difficulty to perform the behaviour. In this case, this means the degree to which people deem the choice for an RHS as doable (Ajzen, 1991, Abrahamse, 2019; Thorhauge et al., 2016). Table 3.2 provides an overview of previously included system characteristics which are argued to fit within the TPB. Again, the relation between the characteristics and utilities are assumed to be self-explanatory.

Table 3.2: TPB system characteristics included to analyse RHS choices.

Characteristic	Count	1	4	6	7	11	12	17	18
Opinion of someone else	5	X	X			X	X	X	
Ease of acquiring	3				X	X			X
Popularity	2				X				X
Communality	1			X					

Where: [1] Achtnicht (2011); [4] Decker & Menrad (2015); [6] Jansma et al. (2020); [7] Kontu et al. (2015); [11] Mahapatra & Gustavsson (2008); [12] Michelsen & Madlener (2013); [17] Willis et al. (2011); [18] Van Middelkoop et al. (2017).

Observations

Firstly, TPB characteristics are much less often included in previous studies compared to the objective characteristics. Furthermore, only four different characteristics were observed, which is also much less than in section 3.1.1.

Secondly, the determinant subjective norms is operationalised in three different ways: opinion of someone else, popularity, and communality. The opinion of someone else was included most often and either in the form of a positive recommendation (Achtnicht, (2011); Mahapatra & Gustavsson, 2008; Michelsen & Madlener, 2013; Willis et al., 2011) or a more generic influence by others (Decker & Menrad, 2015). The opinion of someone else could either be perceived as societal pressure or as help due to the fact that an individual has a lack of knowledge about RHS. The existing popularity of an RHS also belongs to the subjective norms determinant as it can be perceived by a homeowner as peer pressure. This characteristic was included by Kontu et al. (2015) and Van Middelkoop et al. (2017). The communality of an RHS is only included once and refers to whether an RHS is shared with others (district heating) or not (all-electric and green gas hybrid heat pumps). It is argued that this characteristic belongs to the determinant subjective norms because a communal RHS could present peer pressure to a homeowner (Jansma et al., 2020). All three operationalisations are descriptive norms, which shows that this type of subjective norm is more suitable to include in a choice experiment than injunctive social norms.

Thirdly, the system characteristic ease of acquiring can be interpreted as a clear operationalisation of the determinant perceived behavioural control and is only included in three studies (Kontu et al, 2015; Mahapatra & Gustavsson, 2008; Van Middelkoop et al, 2017). Furthermore, it can also be interpreted as a non-monetary measure of transaction costs.

Lastly, the determinant attitudes has not been operationalised as an RHS characteristic in the reviewed studies. The present study aims to include psychological factors as attributes in the choice experiment. Within the economic viewpoint, it makes no sense to hypothetically variate the attitudes of individuals in a stated preference survey as these cannot be influenced by the researcher of policy makers. The same line of reasoning can be used to argue why injunctive social norms are not suitable to include as attributes. Due to centralising the economic viewpoint, it is, thus, impossible to represent the entire TPB via attributes. In this study, the determinant attitudes is more suited to act as a covariate for latent classes and with that to act as an explainer of taste heterogeneity (see section 3.2.3). The direct effect of all the TPB determinants on the behaviour of individuals can be examined if the psychological viewpoint is centralised and a different methodology is used, such as structural equations modelling.

To summarise, only two out of three TPB determinants have been operationalised as system characteristics and are suitable to include as attributes in a choice experiment. The descriptive norms operationalisations of the determinant subjective norms seem be important. Selvakkumaran & Ahlgren (2019) obtain a similar result but note that previous results are inconclusive with respect to the exact influence of this type of characteristic. Another possible determinant to include as an attribute in the choice experiment in this study is perceived behavioural control, which could be operationalised as ease of acquiring.

3.1.3 Psychological viewpoint: hassle factor

The third category to which previously included characteristics are added is also based on the psychological view. Such an extension of that view is needed because the view would be too narrow if it is solely based on TPB. The narrow view would not reflect the variety of characteristics in previous studies and would therefore also not properly reflect what characteristics are relevant for individuals when choosing a new RHS. Since the goal of the three-step approach is to arrive at a set of attributes that are most relevant and important for homeowners of Delft, the psychological view needs to be widened. The characteristics which have not been categorised have all something in common: they reflect some type of subjective hassle.

De Vries et al. (2020) have recently studied the phenomenon of hassle within the context of sustainable homes. In this way, they extend on more general research about psychological barriers to sustainable consumption (e.g., Abrahamse & Steg, 2011). De Vries et al. (2020) theorise that hassle is a particular kind of effort which forms a barrier to obtaining a green home. Hassle is defined as *'… irritating, frustrating, distressing demands that to some degree characterize everyday transactions with the environment'* (Kanner et al., 1981, p.3). If someone experiences hassle or could experience hassle in the future over a longer period of time, stress levels increase, which decreases utility. De Vries et al. (2020) have focussed their study on hassle that could be experienced during three phases of the decision-making process towards a green home: the awareness, consideration, and decision stage. It can be argued that these hassle types fit within the determinant of perceived behavioural control and have already been operationalised in section 3.1.2 as the characteristic ease of acquiring.

However, the present study argues that hassle can also be experienced in two phases after someone has decided to adopt green measures. The first phase is during the construction work (construction hassle). Hassle could, for example, be experienced during insulation work, the installation of an RHS, or construction work in the street in front of one's house. The second phase is during the operation of the new RHS (operational hassle). Some RHS, for example, require time and effort from its owner to ensure its functionality. This could also be perceived as hassle. Previously included characteristics that fit within these two new categories of hassle are shown in table 3.3. The relation between characteristics and utility are again assumed to be self-explanatory.

Table 3.3: hassle system characteristics included to analyse RHS choices.

Characteristic	Count	2	3	4	6	7	9	10	11	12	13	14	15	17
Ease of operating	8			X		X	X	X		X	X	X	X	
Heat comfort	8	X	X		X		X	X	X	X			X	
Security of fuel supply	5		X					X	X	X			X	
Reliability	3					X		X					X	
Extra indoor space	2					X								X
Dig up garden	1													X
Safety	1		X											

Where: [2] Bjørnstad (2012); [3] Chen (2021); [4] Decker & Menrad (2015); [6] Jansma et al. (2020); [7] Kontu et al. (2015); [9] Li et al. (2018); [10] Lillemo et al. (2013); [11] Mahapatra & Gustavsson (2008); [12] Michelsen & Madlener (2013); [13] Rouvinen & Matero (2013); [14] Ruokamo (2016); [15] Sopha et al. (2010); [17] Willis et al. (2011).

Observations

Firstly, ease of operating and heat comfort are often included characteristics and are forms of operational hassle. Ease of operating refers to the amount of work needed to ensure the faultless operation of the RHS. Heat comfort has to do with the indoor air quality and the degree of automation that the RHS allows for. The observation that these system characteristics are often included can be explained when looking at which RHS were included in those studies. All studies which included either or both characteristics have also included some form of biomass RHS. This type of RHS requires the owner to add wood to the stove (lowers ease of operating) and emits fine particle emissions (lowers the indoor air quality), which both lower the heat comfort (Mahapatra & Gustavsson, 2008).

Besides that, it stands out that most studies which included these hassle system characteristics were performed in Nordic countries (Norway, Finland, and Sweden) where biomass is considered to be a sustainable and viable option for residential space heating (Bjørnstad, 2012; Kontu et al., 2015; Lillemo et al., 2013; Rouvinen & Matero, 2013; Ruokamo, 2016; Sopha et al., 2010). Likewise, reliability and security of fuel supply are also system characteristics which play a role in biomass RHS (Kontu, 2015; Lillemo et al., 2013).

Secondly, the above operational hassle characteristics are likely to play a much smaller role in the case of heat pumps, district heating, and green gas hybrid heat pumps. However, heat pumps are relatively large appliances due to the fact that a large hot water tank is needed. As a result, extra indoor space is required, which is another form operational hassle (Willis et al., 2011; Kontu et al., 2015). Willis et al. (2011) operationalised construction hassle as the need to dig up one's garden. They argue that this in an issue with heat pumps and district heating.

In conclusion, adding the hassle factor to the psychological view presented the opportunity to categorise different relevant characteristics which relate to hassle after the decision has been made to install a new RHS. Biomass RHS are a source of different primarily operational hassles, such as ease of operating and heat comfort. Other types of RHS suffer mostly from construction hassle during the installation of the system and from operational hassle due to extra space requirements.

Two system characteristics have not been categorised because they do not fit in one of the three attribute categories of section 3.1: CO_2 emissions and fine particle emissions. Many studies have included either or both of these characteristics (Achtnicht, 2011; Jansma et al., 2020; Kontu et al., 2015; Li et al., 2018; Lillemo et al., 2013; Mahapatra & Gustavsson, 2008; Michelsen & Madlener, 2013; Rouvinen & Matero, 2013; Ruokamo, 2016; Troiano et al., 2019). However, as explained in section 1.2, given the time frame of 2030-2050, the absolute differences between the substitute RHS in terms of CO_2 emissions will become neglectable. Besides that, the CO_2 emissions will decrease more and more towards 2050. Moreover, it is unlikely that biomass RHS (with their fine particle emissions) will play a substantial role in the future space heating system in the Netherlands (Kampman & Van der Niet, 2019). Therefore, CO_2 emissions and fine particle emissions are considered to be irrelevant characteristics for homeowners of Delft and are thus not included as attributes in this study.

3.2 Categorisation of previously included variables to capture and explain taste heterogeneity

People are different which means that it is important to consider taste heterogeneity (Li et al., 2018). This is done by extending the choice model with a latent class model (see section 2.3). A similar approach has been followed by Troiano et al. (2019) and Michelsen & Madlener (2013). Other studies have used a different approach to capture taste heterogeneity, for example, by including interaction effects (Achtnicht, 2011), using an ML model (Gu et al., 2019; Rouvinen & Matero, 2013; Ruokamo, 2016; Lillemo et al., 2013; Willis et al., 2011; Phillips, 2012), or by applying a k-means cluster analysis (Li et al., 2018). Other studies have not explained taste heterogeneity but have directly linked variables to RHS choices (Bjørnstad, 2012, Braun, 2010; Chen, 2021; Decker & Menrad, 2015; Jansma et al., 2020; Mahapatra & Gustavsson, 2008; Sopha et al., 2010; Van Middelkoop et al., 2017). In order to be able to explain class membership in this study, covariates are needed. These covariates are found using a similar three-step approach used in section 3.1. Previously included variables are reviewed using three categories: socio-demographic variables, dwelling variables, and attitudes. This review will serve as a starting point for choosing relevant covariates for the latent class model of this study (see section 3.4).

3.2.1 Socio-demographic variables

Table 3.4 provides an overview of all included socio-demographic variables in the reviewed studies. All variables (except household size and composition) concern individual characteristics of the respondent.

Table 3.4: included socio-demographic variables which are suitable to analyse taste heterogeneity for RHS attributes.

Variable	Count	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19
Age	15	X		X	X			X	X	X	X	X	X	X	X	X	X	X	
Income	15	X	X		X	X		X	X	X	X	X	X	X	X		X	X	X
Education	12	X	X	X	X		X	X		X		X		X	X	X			X
Gender	11	X	X	X		X	X			X		X	X	X		X			
Household size	7		X	X	X				X					X		X			X
Household composition	5	X			X		X											X	X
Ethnicity	1																	X	
Income source	1																	X	

Where: [1] Achtnicht (2011); [2] Bjørnstad (2012); [3] Chen (2021); [4] Decker & Menrad (2015); [5] Gu et al. (2019); [6] Jansma et al. (2020); [8] Phillips (2012); [9] Li et al. (2018); [10] Lillemo et al. (2013); [11] Mahapatra & Gustavsson (2008); [12] Michelsen & Madlener (2013); [13] Rouvinen & Matero (2013); [14] Ruokamo (2016); [15] Sopha et al. (2010); [16] Troiano et al. (2019); [17] Willis et al. (2011); [18] Van Middelkoop et al. (2017); [19] Braun (2010).

Observations

First of all, age and income are almost always included in previous studies and so are education and gender. This is as expected because these variables represent very generic socio-demographic characteristics which could be included in any research concerning people.

Secondly, the two next most included variables (household size and composition) are more specific for the case of RHS choices. For example, Braun (2010) used household composition (including the presence of children) as a proxy for higher comfort requirements and hypothesised that RHS with higher comfort levels would be chosen more often by households with young children. The same study argued that larger households prefer flexible RHS as these allow to choose which room is heated.

Lastly, ethnicity and income source are only included by Van Middelkoop et al. (2017). They found that people with a western background are more likely to adopt energy-saving measures. The sensitivity of ethnicity data could be a reason why only one study included this variable. Although the results for income source were significant, the results were too ambiguous to serve as an explanation for the adoption of energy-saving measures.

In short, socio-demographic variables are, as one can expect, often used to gain insights into the differences between respondents. All reviewed studies have included at least one socio-demographic variable, which indicates that this variable type is important to consider when choosing covariates. Some of the variables are generic and others are more specific for the case of RHS choices. Selvakkumaran & Ahlgren (2019) also observed the importance of socio-demographic variables in explaining taste heterogeneity.

3.2.2 Dwelling variables

This category of variables refers mainly to the characteristics of the dwelling in which respondents live. Table 3.5 shows which dwelling variables have been included in the reviewed studies.

Table 3.5: included dwelling variables which are suitable to analyse taste heterogeneity for RHS attributes.

Variables	Count	1	2	4	5	6	8	9	10	11	12	13	14	15	17	18	19
House type	7	X			X				X		X				X	X	X
Construction year	6	X					X		X		X					X	X
Living area	6		X	X	X				X		X	X					
Ownership type	4				X				X							X	X
Current RHS	3							X		X		X					
Dwelling location	3												X	X			X
Energy label	3					X	X				X						
Years in dwelling	2								X							X	
Property value	1															X	
Recent renovation	1																X
RHS neighbour	1			X													

Where: [1] Achtnicht (2011); [2] Bjørnstad (2012); [4] Decker & Menrad (2015); [5] Gu et al. (2019); [6] Jansma et al. (2020); [8] Phillips (2012); [9] Li et al. (2018); [10] Lillemo et al. (2013); [11] Mahapatra & Gustavsson (2008); [12] Michelsen & Madlener (2013); [13] Rouvinen & Matero (2013); [14] Ruokamo (2016); [15] Sopha et al. (2010); [17] Willis et al. (2011); [18] Van Middelkoop et al. (2017); [19] Braun (2010).

Observations

The first observation has to do with the fact that dwelling variables are much less often included than socio-demographic variables. Age and income were included fifteen times, while house type is only included seven times. Nevertheless, sixteen studies have included at least one dwelling variable.

Secondly, house type, construction year, and living area are relatively often included variables. As covariates, these variables present clear possible influences on the tastes of respondents. In the case of construction year, the older the dwelling, the more likely it is that the construction and/ or operational costs of the substitute RHS are high. People in such dwellings are likely to allocate more importance to these attributes which increases the performance of RHS that perform well on these attributes.

Finally, a wide variety of other dwelling variables has been included in previous studies albeit only occasionally. There is no unambiguous explanation why this is the case. One reason could be that researcher indirectly assume that these variables play an insignificant role in explaining taste heterogeneity.

To conclude, dwelling variables are compared to socio-demographic variables infrequently included in previous studies. Within this category, numerous variables were included of which house type, construction year and living area are most often included.

3.2.3 Attitude variables

The last set of included variables can be categorised as attitudes, which is also one of the determinants in the theory of planned behaviour. An attitude is further defined as a *'psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor.'* (Eagly & Chaiken, 1993, p.1). Other studies have also investigated taste heterogeneity by including the motives of households for doing an investment in their RHS (Lillemo et al., 2013; Van Middelkoop et al., 2017). However, the present study will not investigate those motives because the focus lies on the early majority and late majority of which is assumed that they see the Climate Agreement as the primary motive for having to invest in their RHS. The entities which were evaluated by respondents in previous studies by which they expressed various attitudes are shown in table 3.6.

Table 3.6: included attitude variables which are suitable to analyse taste heterogeneity for RHS attributes.

Variables	Count	2	4	6	7	8	9	10	16	18
Environmental consciousness	7	X	X	X	X			X	X	X
Technical interest	5	X		X		X	X			X
Attitude towards energy carriers and sources	2		X						X	
Attitude to natural gas-free	1			X						
Policy knowledge	1			X						

Where: [2] Bjørnstad (2012); [4] Decker & Menrad (2015); [6] Jansma et al. (2020); [7] Kontu et al. (2015); [8] Phillips (2012); [9] Li et al. (2018); [10] Lillemo et al. (2013); [16] Troiano et al. (2019); [18] Van Middelkoop et al. (2017).

Observations

Firstly, and similar to the dwelling variables, attitudes are much less often included in studies than socio-demographic variables. This observation is supported by the fact that the most often included variable is used in only seven studies and that only nine out of nineteen reviewed studies have included at least one attitude variable.

Secondly, environmental consciousness and technical interest (including knowledge about substitute RHS and insulation) are most often included to explain RHS taste heterogeneity. The inclusion of these variables is intuitively comprehensible since they represent the extent to which someone is interested in the heat transition. To illustrate, respondents who are concerned about the environment and have already some knowledge about the substitute RHS could be, for example, less sensitive to costs since they find it important to switch to a new RHS. The attitude to becoming natural gas-free and policy knowledge are also variables which indicate the degree of interest of someone in the energy transition.

Finally, the attitude towards energy carriers and sources was included twice. It is important to mention that respondents in both the studies of Decker & Menrad (2015) and Troiano et al. (2019) were asked to evaluate relatively familiar and comprehensible energy carriers and heat sources, such as fossil fuels, solar energy, and wood.

To summarise, attitudes are the least often included variables that could potentially explain taste heterogeneity among respondents. It is argued that four variables indicate the extent to which someone is interested in the heat transition. Only familiar energy carriers and sources were evaluated in two studies.

3.3 Life events

The present study will estimate a LC DCM to investigate the tastes and preferences of different classes of homeowners. Apart from that, the present study will also examine the impact of a life event on the tastes of homeowners by including it as a context in the choice experiment (see section 2.3). This section explains what a life event is, why including it in the choice experiment is a theoretical contribution, and why and how relocation is further examined.

A life event is here defined as *'a major event in a personal life that will trigger a process of reconsidering current behaviour'* (Van der Waerden et al., 2003, p.2). Behaviour is more likely to be reconsidered during life events because the change of context disrupts the habits of individuals, which opens a window of opportunity. This is dynamic view on human behaviour is called the habit discontinuity hypothesis (Verplanken et al., 2008; Verplanken & Roy, 2016). In choice experiment terminology, life events cause windows of opportunity for people to change their tastes for attributes in such a way that they would otherwise not have done. Examples of such events include transition to secondary school, post-secondary school education, work related changes, marriage, parenthood, retirement, and relocation. The idea for including a life event in this study stems from the research field of travel behaviour. Larouche et al. (2020) have conducted an extensive literature review regarding the way that life events affect travel behaviour. They found that relocation was by far the most often included life event. Furthermore, relocation is especially bound to cause behavioural change if the relocation results in changes in built environment variables, such as shorter commute distance, better walkability, and shorter distance to the city centre.

People relocating to such places are found to increase their use of sustainable travel modes and decrease their car use (Larouche et al., 2020). These built environment variables must not be confused with the dwelling attributes of section 3.2.2. Contrary to the travel behaviour field, little research has been conducted regarding the effects of life events within the field of RHS choices. Such specific scientific literature is, to the best of the author's knowledge, absent. However, Schäfer et al. (2012) have provided some insights into how relocation can cause changes to energy efficiency behaviour. They showed that people who moved were more aware of their future energy consumption. This is exemplified by the fact that they considered energy labels when buying new appliances and by installing low-energy light bulbs. Yet, these changes towards a more sustainable lifestyle were primarily driven by comfort and money saving motives rather than environmental concerns (Schäfer et al., 2012). Furthermore, grey literature hints that relocation is the only natural moment for homeowners to change the RHS of a house (Council for the Environment and Infrastructure, 2018; Schilder & Van Der Staak, 2020). However, in-depth findings about how and why relocation is such an opportunity for change are missing. It even seems that relocation is only beneficial to the adoption rate of substitute RHS and that it has no downsides or conditions.

As the number of choice sets increase rapidly with the number of contexts, it is necessary to choose which context is included in this study. The present study will focus on relocation for two reasons. Firstly, since context dependent studies have not been conducted yet within the field of RHS choices it is logical to start with the context that is most often included in the field of travel behaviour. Secondly, given the focus and attributes of this study (see section 3.4), clear and imaginable hypotheses can be formulated for the context of relocation. Other contexts are assumed to be irrelevant in the case of RHS choices (secondary school and post-secondary school education) or the effect of these contexts are presumed to be less influential on RHS choices (work related changes, marriage, parenthood, and retirement).

Two hypotheses are drawn regarding the effect of relocation on RHS attributes. In this way, more in-depth knowledge is acquired about how and when relocation might cause a window of opportunity. The hypotheses are in line with the habit discontinuity hypothesis in the sense that relocation already implies that people need to adapt their behaviour and that this could serve as a starting point for further behavioural change, namely the adaption of a new RHS. The first hypothesis is that construction hassle is less important in the decision-making process of homeowners who are in the midst of a relocation compared to those who are not. The idea behind this is that relocation already brings some degree of construction hassle to people which means that extra construction work resulting from insulation work or the installation of a substitute RHS is perceived as less inconvenient. Secondly, relocation causes homeowners to pay less attention to investment costs. Relocation is often accompanied with high costs indicating that people are already willing to spend more money. Furthermore, homeowners can increase their mortgage relatively easily and against an attractive interest rate via a building fund account which they can use to insulate their new house and install a substitute RHS. The additional costs of insulation or a new RHS are therefore hypothesised to be perceived as less important compared to someone who is not relocating. In other words, both parameter estimates for the context interaction effects are hypothesised to be positive.

3.4 Conceptual model

Section 3.1 and section 3.2 have provided an extensive categorisation of previously included RHS characteristics and covariates. These were the first two diverging steps in finding relevant and important attributes and covariates to include in this study in such a way that the bias of the researcher is minimised and that a wide range of attributes is ensured. In this section, the final converging step is performed by choosing attributes and covariates with the help of experts and literature. Not all system characteristics from section 3.1 can namely be selected to include as attributes in this study because choice sets would otherwise be too difficult to understand for respondents. Similarly, not all covariates of section 3.2 are relevant for this study. Three experts were interviewed. Firstly, an employee of research institute CE Delft was interviewed. This institute supports and advises the municipality of Delft during the heat transition. The interviewed employee leads this project for CE Delft. With this interview, in-depth technical knowledge was acquired. The second interviewee is a civil servant of the municipality of Delft who is member of the team that leads the heat transition. This interview provided the municipal view on what are relevant and important attributes and covariates.

Finally, a board member of Platform Energietransitie Delft, which is a platform for and founded by inhabitants of Delft. The essential household perspective was ensured via this interview. All in all, a variety of actors was interviewed which reduces the chance that the attribute and covariate choices are too biased to the beliefs of one interviewee and its problem perception. The resulting conceptual model is visualised in figure 3.1 and is explained below including all scientific contributions of this study.

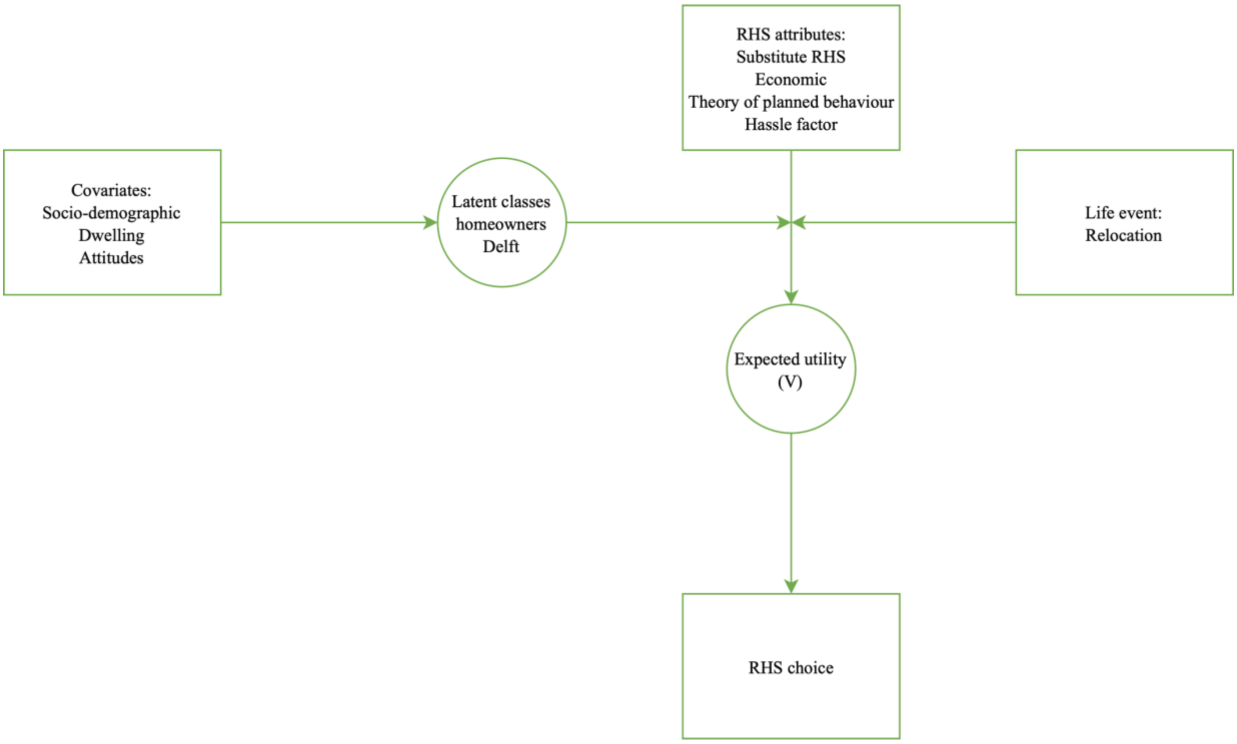

Figure 3.1: conceptual model with the results of the literature review and expert interviews.

3.4.1 Selected RHS attributes

The first scientific contributions of this research result from section 3.1. By using the structured three-step approach with clear theoretical foundations in the categorisation step, a well-founded choice can be made with regard to which attributes are included in the choice experiment of this study. Such a theoretically driven approach has not been used in previous studies. The selected attributes resemble both the economic as well as the two-sided psychological view on what drives people's choices. The contribution of the categorisation lies in the fact that it allows the researcher to examine the extent to which each category of attributes (and thus each underlying theory) plays a role in the trade-offs of homeowners. The last contributions of section 3.1 are the addition of a third system characteristic category (extension of the psychological view) and the extension of the definition of the hassle factor by De Vries et al. (2020). The present study added two more phases of hassle: construction hassle and operational hassle.

Substitute RHS

A more general scientific contribution is that the present study focusses on the Netherlands and on the substitute RHS which are relevant for the Dutch context. Li et al. (2018) stress the importance of country-specific research since influential factors vary considerably among countries. Only one of the nineteen reviewed scientific studies was conducted in the Netherlands. However, that study focussed on the broader notion of the transition towards natural gas-free dwellings by analysing the policy acceptance, preferred household engagement, and knowledge about the transition (Jansma et al., 2020). Little specific insights are provided with respect to the trade-offs between attributes of heating alternatives. Outside the jurisdiction of scientific papers, research institutes TNO and Motivaction have provided some insights into the drivers, barriers, and clusters of Dutch citizens in the context of becoming natural gas-free (Tigchelaar et al., 2019; De Koning et al., 2020; Thijssen et al., 2020). The present study distinguishes itself compared to those in the applied methodology. Differences and similarities between this and other the studies will be discussed in section 6.3.

Apart from the fact that almost all reviewed studies were performed outside the Netherlands, none of the studies reviewed solely the RHS which are relevant for the Dutch and Delft context, namely all-electric heat pumps, district heating, and hybrid heat pump using green gas (Kruit et al, 2021; PBL Netherlands Environmental Assessment Agency, 2020; CE Delft, personal communication, February 22, 2021; Municipality of Delft, personal communication, February 18, 2021; Platform Energietransitie Delft, personal communication, February 11, 2021). The reviewed studies included, for example, fossil based and/ or biomass based RHS which means that they provide insights into trade-offs which cannot be made by homeowners in Delft when choosing a substitute RHS. The present study will only focus on relevant RHS for the context of Delft. By including the substitute RHS as an attribute, it can be determined whether people have a preference for a certain RHS which is not explained by the other attributes.

Investment costs and operational costs

The two selected attributes which trace back to the economic viewpoint are investment costs and yearly operational costs. Based on section 3.1.1, it can be concluded that these system characteristics are the most relevant economic attributes. All three experts agree that this is also the case for the context of Delft (CE Delft, personal communication, February 22, 2021; Municipality of Delft, personal communication, February 18, 2021; Platform Energietransitie Delft, personal communication, February 11, 2021). By including investment and operational costs, it can be determined to what extent the choices of individuals are driven by cost factors.

Popularity in the neighbourhood

This attribute stems from the subjective norm category of the theory of planned behaviour. More specifically, it is a descriptive norm which is better suited to include as an attribute in a choice experiment than an injunctive norm. The subjective norms determinant is meant to be perceived as societal pressure to perform particular behaviour. The popularity operationalisation is therefore better suited than the opinion of someone else operationalisation because the latter can also be perceived as help for the lack of knowledge of the decision-maker about RHS. The communality operationalisation is not selected as this is only linked to district heating and not to heat pumps. From section 3.1.2, it can be derived that the subjective norm determinant is most often included in previous studies. Both CE Delft and the municipality agree that this determinant is also relevant for this study and is more relevant than perceived behavioural control, which was according to section 3.1.2 another possible determinant to include (CE Delft, personal communication, February 22, 2021; Municipality of Delft, personal communication, February 18, 2021). Popularity is further specified as popularity in the neighbourhood because a homeowner’s neighbourhood is most likely the relevant scale to consider. Put differently, a homeowner is probably not influenced by the fact that homeowners at the other side of the city have switched to a substitute RHS. The municipality of Delft is subdivided in various neighbourhoods (‘wijken’ in Dutch), such as ‘Binnenstad’, ‘Voorhof’, and ‘Vrijenban’. These are the neighbourhoods that are referred to in the popularity in the neighbourhood. By including this attribute, the extent to which the choices of people are individually determined or socially determined can be investigated. In other words, it can be analysed whether the determinant subjective norms of the theory of planned behaviour plays a role in RHS choices. In the realm of the diffusion of innovations theory, the attribute popularity in the neighbourhood is also especially relevant for the early majority and late majority, which are the focus groups of this study. People in these categories are theorised to be, namely, heavily influenced by other people’s behaviour and are likely to follow a ‘staying with the herd’-approach (Bjørnstad, 2012; Moore, 2014).

Required inside space and construction time

These two attributes are both part of the hassle factor category. More specifically, they resemble hassle during the operation and installation of the substitute RHS. As argued in section 3.1.3, these system characteristics are especially relevant for the substitute RHS which are most likely to play a large role in Delft. All three experts agree that required inside space and construction time are the most relevant hassle attributes for the context of Delft (CE Delft, personal communication, February 22, 2021; Municipality of Delft, personal communication, February 18, 2021; Platform Energietransitie Delft, personal communication, February 11, 2021). The inclusion of these two attributes allow to examine the extent to which people find construction and operational hassle important when choosing a substitute RHS. The civil servant of the municipality also recommended to add noise pollution (also a type of operational hassle) as an attribute since this is especially relevant for all-electric heat pumps.

However, this is not done due to the fact that the choice experiment already has six attributes and because noise pollution is subjective and hard to operationalise (e.g., the same number of decibels is perceived differently and outside or inside noise).

3.4.2 Selected covariates

The scientific contribution resulting from section 3.2 is that this study will explain taste heterogeneity among respondents using a latent class choice model of which the covariates are found using a three-step approach similar to that of finding the attributes. A wide range of covariates (socio-demographic, dwelling, and attitudes) will be used to form classes. It is crucial to have a variety of covariates because class specific recommendations will differ depending on what covariates are statistically significant. The approach of the municipality should target certain types of persons if socio-demographic or attitude covariates form the classes, while certain types of dwellings could better be targeted if dwelling covariates are more important. Classes could, of course, also be formed by covariates from different categories. In short, the contribution lies in the fact that this study will include numerous covariates from different categories, which enables the researcher to make precise classes. In the end, this allows for formulating more tailor-made policy recommendations. Answering covariate questions consumes relatively little time (compared to choice sets), which means that a substantial number of covariates can be included.

Socio-demographic covariates

The following socio-demographic covariates of found to be relevant for the context of this study: gender, age, education, income, household composition, and household size. Compared to table 3.4, only the variables ethnicity and income source are not included as covariates. During the interview with CE Delft, it was determined that no additional useful insights can be gathered by asking the ethnicity of someone. Furthermore, ethnicity could be considered to be sensitive data which after the recent child benefits scandal in the Netherlands is especially relevant to consider. The data of income source are found to be also incapable of delivering new information which is not gathered yet using the other covariates. No additional socio-demographic covariates have to be added specifically for the context of Delft.

Dwelling covariates

Seven dwelling covariates are included in this study: house type, construction year, living area, dwelling location, energy label, current RHS, and monumental status. Five variables from table 3.5 are not included in this study. Firstly, ownership type is irrelevant since the present study focusses on homeowners. Secondly, years in dwelling was only included in two studies in section 3.2.2, which indicates the irrelevancy of including this variable. Thirdly, property value is considered to be sensitive information and the insights from this variable are already collected by the covariates income and living area. Fourthly, whether a homeowner has recently renovated his/ her home is only relevant if the renovation was for insulation or a new RHS. This information is already gathered via the covariates energy label and current RHS. Lastly, the RHS of the homeowner's neighbour is considered to be unknown for most homeowners. Furthermore, the last three excluded variables are only used in one study, which again illustrates their irrelevance. The monumental status covariate is added because the municipality of Delft consist of numerous monumental dwellings which are subjected to projected city view (CE Delft, personal communication, February 22, 2021). This means that the original character of the exterior of these houses must remain the same. If the owner of a house with monumental status wants to insulate or install a heat pump, he/ she has to make additional costs to comply with the protected city view, which is discouraging.

Attitude covariates

Section 3.2.3 argued that four attitudes resemble the interest of someone in the heat transition: environmental consciousness, technical interest, attitude to becoming natural gas-free, and policy knowledge. However, as explained in section 1.2, the present study assumes that the decision to invest in a new RHS is already made (either by the municipality or by the homeowner in cooperation with the municipality) and that the absolute differences in CO_2 emissions are neglectable. Therefore, there is nothing that people who are interested in the heat transition can trade off. In the choice experiment of this study, these people cannot, for example, trade off investment costs with lower CO_2 emissions. As a result, the attitudes environmental consciousness, technical interest, attitude to natural gas-free, and policy knowledge are irrelevant in the context of this study.

The attitude towards energy carriers and sources is also not included in this study because it is assumed that most homeowners are currently unfamiliar with the relevant heat sources for natural gas-free RHS, such as geothermal energy, residual industrial heat, biomass, and aqua thermal energy (Kruit et al., 2021). This would have otherwise provided invalid results. The present study will include two attitudes: community feeling and the influence of others in one's decision. The attitude community feeling is important to measure because it allows testing whether someone who feels part of a community is also more likely to prefer district heating as substitute RHS (via the latent classes). In this way, this attitude is comparable to the system characteristic communality used by Jansma et al. (2020), which was an operationalisation of the determinant subjective norms of the TPB. The second attitude also has a clear link to the subjective norms category of the TPB. The goal is to check whether people who are, generally speaking, influenced by others during their decisions are also influenced by others during the choice of an RHS.

As mentioned earlier, the present study examines choices that will be made in about 10-20 years from now using the current of covariates. Some of these covariates are linked to individuals and can thus change over time, while others are linked to dwellings which will stay constant over time. Depending on which covariates are statistically significant, it could be that the latent classes are primarily characterised by personal covariates. The findings of the LC DCM are then still relevant in the future albeit that the sizes of each class will be different. If dwelling covariates prove to be relevant, the latent classes will roughly stay constant over time. The above is conditional on the fact that the effect of a covariate remains the same over time. This can only be validated by performing the choice experiment again in the future (see section 8.3).

3.4.3 Relocation

The primary scientific contribution of the present study results from section 3.3. The latent class discrete choice model is extended by making it dependent on the context of relocation. It is theorised that relocation opens up a window of opportunity for a new RHS because it causes people to have different taste parameters compared to people who are not moving. The effect of this life event on the tastes of people choosing a new RHS has not yet been investigated before. If relocation proves to play a significant role, this could serve as another starting point for policy recommendations for the municipality of Delft.

3.5 Conclusion

This section has provided insights into what previous studies presumed to be influential factors in the choice of homeowners for an RHS. The system characteristics were categorised using three theoretically founded categories, i.e., economic, theory of planned behaviour, and the hassle factor. All three categories fit within the assumption that people are rational decision-makers. These insights were used to select six RHS attributes for the choice experiment of this study. Numerous covariates have also been selected, which will be used to explain taste heterogeneity across respondents. The exact operationalisations of the attributes and covariates are discussed in sections 4.1 and 4.2. This research will also examine the effect of relocation on two attribute parameters of homeowners using two hypotheses. The first hypothesis is that homeowners become less sensitive to construction time as a consequence of relocation. The second one states that relocation causes homeowners to be less influenced by investment costs.

4 Survey design: operationalisation

This section describes the operationalisation of the stated preference survey. The selected attribute levels are explained in section 4.1. In section 4.2, it is explained how the covariates are measured. Other experimental design choices are depicted in section 4.3. The resulting survey outline is shown in section 4.4. The changes to the survey after the test phase are discussed in section 4.5. Finally, the conclusion of this section is provided in section 4.6.

4.1 Selected attribute levels

The attributes for the choice experiment of this study were selected in section 3.4. This section explains how the attribute levels are selected. Table 4.1 provides an overview of all attribute levels.

Table 4.1: selected attribute levels for this study.

Attribute category	Attribute	Level 1	Level 2	Level 3
	Substitute RHS	All-electric heat pump	District heating	Hybrid heat pump with green gas
Economic	Investment costs	€5,000	€27,500	€50,000
	Operational costs	€500	€1,500	€2,500
Theory of planned behaviour (subjective norm)	Popularity in the neighbourhood	15 out of 100 people (15%)	50 out of 100 people (50%)	85 out of 100 people (85%)
Hassle factor	Required inside space	As much as a conventional central heating boiler	2 times as much as a conventional central heating boiler	3 times as much as a conventional central heating boiler
	Construction time	1 day	1 month	3 months

Substitute RHS

As already mentioned in section 3.4, the present study focusses on the three main categories of substitute RHS which are most likely to play the largest roles in Delft: all-electric heat pumps, district heating, and hybrid heat pumps using green gas. It is chosen on purpose to not further specify what type of green gas (biogas or hydrogen gas) is used by the hybrid heat pumps, because this is irrelevant for the context of this study.

Investment and operational costs

Investment costs include the costs for the RHS itself, installation, insulation, and taxes. The operational costs consist of variable energy costs, fixed delivery costs, taxes, maintenance and if applicable rent. The exact investment and operational costs depend on various factors, among which the considered substitute RHS, the current insulation level of a dwelling, dwelling type, temperature setting, and dwelling size. The attribute levels have been selected in such a way that they encompass numerous combinations of the factors above. To do this, various studies have been consulted, e.g., by CE Delft, Berenschot, Economisch Instituut voor de Bouw, and PBL Netherlands Environmental Assessment Agency. As a result of having unlabelled alternatives (see section 4.3), two combinations of substitute RHS and operational costs are less likely to occur, i.e., high temperature district heating costing €500 per year and an all-electric heat pump that costs €2,500 per year. More about this and the full explanation of the selected attribute levels (including all sources) can be found in Appendix A.

The attribute level of €5,000 refers to the minimum investment requirement. This is a realistic number in case that a hybrid heat pump or district heating is installed in an already well insulated dwelling, such as label A or B. On the contrary, the upper limit of €50,000 refers to a situation in which much more insulation is needed (e.g., a house with label E or worse) and/ or when an all-electric heat pump is installed. The middle attribute level (€27,500) is applicable for dwellings that require a few energy label improvements in order to be able to install, for example, an all-electric heat pump. This level also preserves equidistance, which reduces the correlation between attributes (Molin, 2019c). The lower limit of operational costs (€500) corresponds to small dwellings or to a situation where dwellings are well insulated. By contrast, operational costs of €2,500 are applicable for large or poorly insulated dwellings.

The level of €1,500 again preserves equidistance and is appropriate for, for example, medium insulated dwellings.

Popularity in the neighbourhood

The selected attribute levels are closely linked to the theoretical diffusion rate of the innovation (the RHS in this case) across the different adopter categories from the diffusion of innovations theory. The first attribute level corresponds to the moment when the early majority just starts adopting the innovation. The diffusion of innovations theory states that this happens when 16% of the people have already adopted the new innovation. However, 15% is selected in this study because this is easier for respondents to interpret. The second level (50%) is the exact point when the late majority starts adopting the innovation. The last level of 85% refers to the moment when the late majority have all adopted the innovation and the laggards have just started. The theoretical value of 84% is again slightly altered for easier interpretation.

Required inside space and construction time

The attribute levels of required inside space are relative to the space that a conventional natural gas fired central heating boiler takes up. In consultation with CE Delft, this is argued to be better imaginable than length, width, and height dimensions. District heating at least requires a unit inside a dwelling which in terms of size is comparable to that of a conventional gas boiler (level 1). The second level refers to a hybrid heat pump, which is also conveniently in the middle for equidistance reasons. All-electric heat pump are large appliances which also require a large hot water tank, which combined refers to the third attribute level. The exact required space varies for each RHS because it also depends on other factors, such as the required capacity (CE Delft, personal communication, February 22, 2021).

The attribute levels of construction time have also been determined in consultation with CE Delft (personal communication, February 22, 2021). The level of 1 day refers to a situation where only the RHS has to be installed and only limited insulation work is needed. However, the construction time can rise substantially if more insulation is required and the current insulation level is low. The upper level of 3 months is relevant in the case that poorly insulated (label E and worse) houses have to be insulated to for example level B in order to be able to install an all-electric heat pump.

4.2 Covariates

This section explains how the in section 3.4 selected covariates are measured. The answer options and the answer scale of the socio-demographic and the dwelling covariates are shown in table 4.2. Income is measured as household income (not as the income of respondents), because it is assumed that, in the case of multiple earners, the investment in an RHS comes from the entire household budget. The answer option district heating is used as a synonym for a variety of Dutch RHS: district heating ('warmtenet' in Dutch), block heating ('blokverwarming' in Dutch), and city heating ('stadsverwarming' in Dutch).

Table 4.2: answer options and scale of the socio-demographic and dwelling covariates.

Covariate	Answer options	Scale
Gender	Female, male, I prefer not to answer	Nominal
Age	Open question: year of birth	Ratio
Education	Primary school, VMBO-b, VMBO-k, MBO-1, VMBO-g, VMBO-t (MAVO), HAVO-, VWO-first half, MBO-2, MBO-3, MBO-4, HAVO, VWO completed, HBO-, WO-bachelor, WO-master, doctor, I prefer not to answer	Ordinal
Household income	Less than €20,000, €20,000-€39,999, €40,000-€59,999, €60,000-€79,999, €80,000-€99,999, €100,000-€149,999, €150,000-€199,999, €200,000 or more, I prefer not to answer	Ordinal
Household composition	Alone, single parent with children, living together, living together with children	Nominal
Household size	1 person, 2 persons, 3 persons, 4 persons, 5 persons or more	Ordinal
House type	Flat/ apartment/ gallery apartment house/ maisonette/ staircase-access flat/ upstairs apartment, Corner house, Terraced house, Semidetached house, Detached house	Nominal
Construction year	Before 1850, 1850-1904, 1905-1924, 1925-1944, 1945-1964, 1965-1984, 1985-2004, 2005-2021, I do not know	Ordinal
Living area	Less than 50 square metres (m^2), 50-74 square metres (m^2), 75-99 square metres (m^2), 100-149 square metres (m^2), 150-249 square metres (m^2), 250 square metres (m^2) or more	Ordinal
Dwelling location	Open question: four digits of zip code	Nominal
Energy label	A^{++++}, A^{+++}, A^{++}, A^{+}, A, B, C, D, E, F, G, I do not know	Ordinal
Current RHS	Natural gas fired central heating boiler, district heating, gas heater, wood fired heating, heat pump, different namely	Nominal
Monumental status	Yes (municipal or national), no, I do not know	Nominal

Table 4.3 presents the operationalisations of the two attitude covariates. The statements that operationalise the community feeling attitude are taken from the study of Kalkbrenner & Roosen (2016) and are slightly altered (community is changed into neighbourhood). Respondents are also asked whether they are member of an energy collective or cooperation. This will also reveal information about the community feeling of a respondent. The statements for measuring the second attitude have been made by the researcher. The five-point Likert scale ranges from completely disagree to completely agree and is assumed to be an interval variable. A factor analysis will be carried out in order to check whether the statements indeed measure the same underlying attitude.

Table 4.3: operationalisations, answer options, and scale of the attitude covariates (Kalkbrenner & Roosen, 2016).

Attitude covariates	Operationalisation	Answer options	Scale
Community feeling	I feel strongly attached to the neighbourhood I live in.	Five-point Likert scale	Interval
	There are many people in my neighbourhood whom I think of as good friends.	Five-point Likert scale	Interval
	I often talk about my neighbourhood as being a great place to live.	Five-point Likert scale	Interval
	Are you a member of an energy collective or cooperation?	Yes, no, I do not know	Nominal
Influence of others in one's decision	The opinion of someone else is important when I make a decision.	Five-point Likert scale	Interval
	During important decisions, I ask people around me what to do.	Five-point Likert scale	Interval
	I find it important to know what other people would do if they were in the same situation.	Five-point Likert scale	Interval

4.3 Experimental design

With the selection of attributes (and their levels) and covariates, the first steps of making the SP survey are completed. This section explains the remaining steps and presents the utility function of the context dependent LC DCM.

Construction of alternatives: efficient design

Having established the attributes and attribute levels, these have to be combined into alternatives. There are two main methods for doing this: full-factorial and fractional factorial. Full-factorial designs include all possible combinations of attribute levels, which results in too many alternatives and choice sets. A more suitable method for this study is, therefore, fractional factorial designs. There are three types of fractional factorial designs: random, efficient, and orthogonal. Random designs randomly draw a sample of the full-factorial designs. However, this leads to correlations between attributes, which results into high standard errors and less reliable parameters. In orthogonal designs, the alternatives are constructed in such a way that the correlations between attributes are zero. This results in more reliable parameters than random designs. A potential problem of orthogonal designs is that dominant alternatives can occur. An alternative is dominant if it performs better than all other alternatives with respect to at least one attribute and as well as the other alternatives for the other attributes. Dominant alternatives are undesirable because they provide no insights into the trade-offs of respondents if every respondent chooses the same alternative. Efficient designs will be used to remedy this problem by balancing the utilities of alternatives. By doing so, the information acquired by alternatives is maximised and the standard errors of the parameters are minimised. The utilities of the alternatives can only be balanced if prior estimates of the attribute parameters are available. These can be obtained by conducting a small scale pre-survey. Given the time constraints of this study, it is determined that this is not possible. However, efficient designs will also perform better than orthogonal designs if the sign of the parameters is known. One can then include a small positive or negative prior value in the efficient design (ChoiceMetrics, 2018). Four attributes have a negative expected sign (investment costs, operational costs, required inside space, and construction time). The substitute RHS attribute has no clear expected sign, which is why a prior of 0 will be used for its parameters. Popularity in the neighbourhood is expected to have a positive sign since the adopter categories of early majority and late majority are likely to follow the behaviour of the herd.

Construction of context descriptions: two descriptions

As argued in section 3.3, the present study will include relocation as a context. In order to minimise the growth of the size of the choice experiment, two context descriptions are used in this study. In the first context description respondents have to imagine that they stay living in their current house and that the RHS of that house will be replaced. Contrary to that, the second context description asks people to assume that they will be moving towards a new house and that the RHS of that house will be replaced. The context descriptions are deliberately kept rather short. Context descriptions which are too elaborate might influence the choices of respondents too much which makes their responses invalid.

Construction of choice sets: Modified Federov algorithm

Choice sets are created by combining the constructed alternatives. The choice sets in this study include three alternatives. The alternatives can be labelled or unlabelled. The label of a labelled alternative denotes a certain characteristic. Unlabelled alternatives do not express a characteristic and are mostly called option A, option B, etc. The presents study assumes that there are no differences with respect to the taste parameters across the different RHS. In other words, the attributes are generic and as a result the attribute levels are also generic. If one would like to examine whether the taste parameters are alternative specific, which would be possible in labelled alternatives, more parameters need to be estimated. As a result, more choice sets would be needed and thus more respondents in order to obtain significant results. Given the fact that the number of choice sets already doubles because of the relocation context and that various attributes are effects coded (this adds even more choice sets), labelled alternatives are considered to produce an undesirable number of choice sets.

In order to still be able to examine whether there is preference for a substitute RHS, the substitute RHS is included as an attribute. As a consequence of using unlabelled alternatives, certain in-depth nuances cannot be expressed by the experiment and some alternatives are less likely to occur. This might have some impact on the validity of the results. For example, one of the constructed choice sets includes an alternative in which district heating requires and investment of €50,000 and results in operational costs of €2,500. Generally speaking, high investment costs (due to insulation) result in low operational costs. Yet, this could still be an imaginable alternative in the case that a household sets the room temperature to, for example, 25 °C. Although some of the alternatives are less likely to occur, the alternatives are still imaginable, which is most important (Molin, 2019a). By choosing unlabelled alternatives, the risk of losing parameter significancy weights heavier than the risk of losing some validity. This is considered to be a fair trade-off given the assumption that collecting respondents for this survey might be hard during COVID-19 and the fact that the alternatives are still imaginable.

Typically, attribute level balance is preserved in efficient designs. This means that every attribute level appears an equal number of times across all alternatives. As a result, each attribute has the same number of observations which means that every parameter has an equal probability of becoming statistically significant.

The choice sets are constructed using Ngene. Appendix B includes the Ngene syntax and the necessary coding of the categorical variables. Investment and operational costs are specified as continuous variables, while the other four (categorical) attributes are effects coded. Ngene uses the D-error to determine the efficiency of an experimental design. The lower the D-error the more efficient a design is. In principle, Ngene could determine the D-error of every possible design coming from the full factorial design. However, this would result in very long computation times. Therefore, Ngene uses an algorithm to find the most efficient design as possible. By default, Ngene uses the swapping algorithm which maximises attribute level balance and minimises the D-error. However, Ngene could not find a design without dominant alternatives for the given syntax. Therefore, the Modified Federov algorithm is used instead (ChoiceMetrics, 2018; Bliemer et al., 2017; Federov, 1972; Cook & Nachtrheim, 1980). This algorithm does not guarantee attribute level balance by default. Attribute level balance is imposed on the continuous variables in order to ensure that the respondents are presented with the variety in costs attribute levels. This is not necessary for the effects coded variables, because the D-error ensures a sufficient degree of attribute level balance. Too little balance would result in a high D-error, which causes the design not to be selected (Bliemer, 2009). Even though the efficient design could theoretically be made with 6 choice sets, it is specified that Ngene constructs 12 choice sets. Together with the two context descriptions, this will result in eight choice tasks, which is a good amount for one respondent. As expected, none of the constructed choice sets contains a dominant alternative based on the expected utility signs.

Nesting the choice sets under the context descriptions

The last step of constructing a choice task is nesting the choice sets under the context descriptions. Contexts can be varied within respondents and between respondents. The present study uses the former option. One risk of within subject context variation is that respondents learn what the researcher is after with the contexts and that they change their choices accordingly. However, this risk is considered to be neglectable given the fact that the relocation context descriptions are short and generic.

In total, 24 different choice sets are constructed (12 choice sets under two context descriptions). Completing all 24 choice tasks would require too much time and effort from respondents. Therefore, blocking is used. Three blocks were constructed in Ngene consisting each of four choice sets. Each block was placed under each context description. The SP preference survey has three versions. In each version, one non-relocation block and one relocation block is presented to the respondent. The combination of non-relocation blocks and relocation blocks in done in such a way that every respondent sees eight different choice tasks, e.g., non-relocation block 1 is combined with relocation block 2. An example choice set is shown in figure 4.1.

Imagine that you stay living in your current home and that is has been decided to change to one of the below sustainable residential heating systems.

	Option A	Option B	Option C
Substitute RHS	All-electric heat pump	District heating	Hybrid heat pump with green gas
Investment costs	€ 27,500	€ 27,500	€ 50,000
Operational costs	€ 1,500	€ 1,500	€ 500
Popularity in the neighbourhood	15 out of 100 people (15 %)	15 out of 100 people (15 %)	50 out of 100 people (50%)
Required inside space	As much as a conventional central heating boiler	As much as a conventional central heating boiler	2 times as much as a conventional central heating boiler
Construction time	1 month	1 day	1 month

Which option do you prefer?

- Option A
- Option B
- Option C

Figure 4.1: third choice task in the first version of the survey.

Utility function of the context dependent LC DCM

As explained in section 2.3.1, the context dependent LC DCM is based on RUM. The utility function of the model must be formulated before the model can be estimated on the SP survey data. The systematic part (V_i) of the utility function is shown in equation 5.1. Since the alternatives in the SP survey are unlabelled, the utility function applies to all three alternatives (*i* = 1, 2, 3) and the parameters and attribute levels are generic. Effects coding is used for the categorical variables (substitute RHS, popularity in the neighbourhood, required inside space, and construction time) in order to be able to interpret the parameters as utility differences from the average utility of the attribute levels. Dummy coding is applied to the relocation context in which non-relocation represents the reference level. Appendix B shows the utilised coding schemes. The two hypotheses of the relocation context with respect to the attributes investment costs and construction time were explained in section 3.3. The hypotheses are represented as interaction effects in the utility function.

$$V_i = \beta_{SRHS1} \times SRHS1 + \beta_{SRHS2} \times SRHS2 + \beta_{IC} \times IC + \beta_{OC} \times OC + \beta_{POP1} \times POP1 + \beta_{POP2} \times POP2 + \beta_{SPA1} \times SPA1 + \beta_{SPA2} \times SPA2 + \beta_{CON1} \times CON1 + \beta_{CON2} \times CON2 + \beta_{ICR} \times IC \times REL + \beta_{CON1R} \times CON1 \times REL + \beta_{CON2R} \times CON2 \times REL \quad \text{(Equation 5.1)}$$

In which:

- V_i = Systematic utility of alternative i
- β_{SRHS1} = Parameter for the first part of the effects coded attribute substitute RHS (SRHS1)
- β_{SRHS2} = Parameter for the second part of the effects coded attribute substitute RHS (SRHS2)
- β_{IC} = Parameter for the attribute investment costs (IC)
- β_{OC} = Parameter for the attribute operational costs (OC)
- β_{POP1} = Parameter for the first part of the effects coded attribute popularity in the neighbourhood (POP1)
- β_{POP2} = Parameter for the second part of the effects coded attribute popularity in the neighbourhood (POP2)
- β_{SPA1} = Parameter for the first part of the effects coded attribute required inside space (SPA1)
- β_{SPA2} = Parameter for the second part of the effects coded attribute required inside space (SPA2)
- β_{CON1} = Parameter for the first part of the effects coded attribute construction time (CON1)
- β_{CON2} = Parameter for the second part of the effects coded attribute construction time (CON2)
- β_{ICR} = Parameter for the interaction effect between IC and the context relocation (REL)
- β_{CON1R} = Parameter for the interaction effect between CON1 and REL
- β_{CON2R} = Parameter for the interaction effect between CON2 and REL

Survey distribution

The population of this research are homeowners in Delft who also live in the house that they own. Thus, landlords and tenants are excluded. It is considered to be hard to collect respondents for the survey of this study given the current pandemic. In order to reach as many potential respondents as efficiently as possible, various citizen organisations were approached that could distribute the survey among their members. There are numerous neighbourhood associations in Delft which protect the interests of their members for a wide variety of subjects. These associations are also part of the formulation process of the transition vision for heat in cooperation with the municipality of Delft and CE Delft (more about this in section 7.2). Four neighbourhood associations have distributed the survey among their members, namely Belangenvereniging Olofsbuurt-Westerkwartier (via Facebook, 238 members), Belangenvereniging Voorhof II West (via e-mail, 180 members), Buurtvereniging Delftzicht (via website and WhatsApp, 126 participants), and Belangenvereniging de Oude en de Nieuwe Delf (via e-mail, 200 members). Furthermore, the survey has also been distributed via a mailing list to the citizens of the neighbourhood Indische Buurt Zuid (90 members). Besides, Platform Energietransitie Delft has sent the survey to their 389 members via e-mail and posted a news item on their website. Lastly, the survey has been distributed on social media via the Facebook account of Delft wordt groen (4,669 followers) and the LinkedIn account of City Deal Kennis Maken Delft (141 followers).

The risk of using the above citizen organisations is that the respondents are biased. It could be that members of these organisations are, for example, more engaged into the heat transition and are more positive towards the transition. Even though the direct trade-offs between climate and costs are not possible in this study, it is still possible that environmentally consciousness biases other results (see section 3.4.2). To check the extent to which the sample is biased, two questions and two statements are taken from a recent representative study by Citisens (2020). By asking the exact same questions, the scores on all questions and statements can be compared, which indicates whether the sample is biased in terms of environmentally consciousness (see section 5.2.3). Each question or statement relates to a different aspect of a respondent's perception about the heat transition (see table 4.4).

Table 4.4: statements and questions to check the sample bias (Citisens, 2020).

Aspect	Question/ statement	Answer options
Knowledge	The government wants that more dwellings are disconnected from the natural gas grid. Did you know this?	Yes, no
Attitude towards natural gas-free	I find it important that all Dutch dwellings become natural gas-free.	7-point Likert scale
Behaviour	Do you want your dwelling to be disconnected from natural gas?	Yes, no, I do not know
Attitude towards climate neutrality	I find it important that the Netherlands become climate neutral.	7-point Likert scale

4.4 Survey outline

The constructed SP survey is distributed using the software Qualtrics (Qualtrics, 2021). This section describes the outline of the survey. The full survey can be found in Appendix C (in Dutch).

Part 1: introduction

This part welcomes the respondents to the survey and explains the topic and goal of this study. Furthermore, an overview of the different parts of the survey is provided including an estimation of the response time. Moreover, the contact details of the researcher are stated to make the survey personal and to provide the opportunity to ask questions. Lastly, two bias mitigation strategies from Haghani (2021b) are included. The cheap talk strategy is operationalised by stressing the fact that the quality of the results will be increased if respondents answer the questions as honest as possible. The perceived consequentiality strategy is included by stating that the results of the study will be sent to the municipality of Delft.

Part 2: choice experiment

The choice experiment is first explained in order to ensure that the respondents understand what they have to do and understand what is meant with the six attributes. Subsequently, one of the three survey versions is presented to the respondent. This process is randomised in such a way that all versions have an equal chance of being presented. In each choice set, it is also stressed that one has to assume that the decision to invest is already made. The verb ‘is’ is chosen on purpose because in this way it is not necessary to further specify whether the choice is made by the homeowners herself/ himself or by the municipality. Even though the choice tasks are the hardest for respondents to answer, it is chosen to start the survey with the choice experiment in order to increase the chance that the choice data is gathered before a respondent decided to leave the survey.

Part 3: personal characteristics

The third part includes the questions of the socio-demographic covariates. These questions are relatively easy to answer.

Part 4: dwelling characteristics

The questions of the dwelling covariates are asked in the fourth part of the survey and are also considered to be easy to answer.

Part 5: attitudes

In the final part, respondents are presented with six statements belonging to two attitude covariates: community feeling and influence of others in one’s decision. Moreover, the questions and statements needed to check for the sample bias are also included in this part.

Part 6: expression of gratitude

In the last part of the survey, respondents are thanked for their participation.

4.5 Changes according to pilot survey

A pilot survey was distributed among board members of neighbourhood associations, friends, and family members. The aim of this survey was to collect feedback and improve the survey. In the survey, a constant trade-off has to be made between the brevity and the clarity of all questions and introduction texts. Based on the feedback, too much attention was paid to the brevity of the survey. Therefore, additional information about the attributes was provided in the explanation of the choice experiment. A number of smaller changes have also been made, which are listed below per survey part:

- Part 1
    - The goal of the study is formulated more comprehensibly.
    - Respondents are told that the results of this survey are also shared with their neighbourhood association. Furthermore, respondents are referred to the TU Delft Repository for the entire study.
- Part 2
    - People who have already switched to a natural gas-free RHS are asked to imagine that they still live in a dwelling with a natural gas fired central heating boiler. This partly decreases the validity of their answers. If enough respondents are collected, these respondents can be removed from the sample.
    - The explanation of the six attributes is presented below on every page with four choice tasks in the survey in the case that respondents want to read the explanation again. This is done this way because the survey software does not allow respondents to go back to the explanation page due to the randomisation.
- Part 3, part 4, and part 5
    - The formulation of several questions was altered.

4.6 Conclusion

In this section, the conceptual findings of section 3 are operationalised into the SP survey. To do this, attribute levels and covariate answer options were selected. An efficient design with the Modified Federov algorithm is used to construct the choice sets. These choice sets are nested under the context descriptions in order to arrive at three versions of the SP survey. The survey is distributed among several citizen organisations, which could result in a biased sample. Therefore, various questions and statements from a recent representative study are included in the survey, which provides the ability to check the bias of the sample.

5 Data preparation and descriptive statistics

This section provides an overview of the collected data which will be used to estimate the different choice models. Section 5.1 provides the response statistics and the data preparation steps. The characteristics of the sample are presented and compared to proxy population data in section 5.2. In section 5.3, both the representativeness of the sample and the implications on the interpretation are discussed. Section 5.4 contains the conclusion.

5.1 Response statistics and data preparation

First, the response statistics are described. Subsequently, the data cleaning and data treatment steps are explained which prepares the data for the model estimation in section 6.

5.1.1 Response statistics

As discussed in section 4.3, the survey was distributed by numerous citizen organisations. The data was collected between April 5th, 2021, and April 21st, 2021. In total, the survey reached 6,033 people of which 304 opened the survey and 168 finished it. Thus, the response rate is 2.8% and the dropout rate equals 44.7%. The response rate is rather low, because the majority of the people was reached via the two social media platforms (4810 people). Such platforms are, generally, effective in reaching many people but ineffective in obtaining respondents. Furthermore, not all followers of the two social media accounts are in the population of interest of the present study. It must also be said that the number of 6,033 is an indication since the survey has also been posted on multiple websites and it is unknown how many people have been reached in this way. Almost all dropouts did not go further than the introduction. This could indicate that most dropouts are either landlords or tenants who only realised that the survey was not meant for them after having opened the survey. The median response time of finished responses was 12 minutes and 25 seconds. The respondents took on average 109 minutes to complete the entire survey. This number is very high due to the fact that 7 respondents took more than two hours to complete the survey. These 7 respondents have probably filled in the survey in two sessions, which results in high response times. The average completion time without these respondents was 14 minutes and 35 seconds.

5.1.2 Data cleaning

The dataset consisting of 168 complete responses was cleaned by evaluating three aspects: completion time, straight lining, and dominant alternatives. First of all, no respondent completed the survey within five minutes. This is considered to be the minimum completion time in order to be able to respond seriously and carefully. Secondly, straight lining or non-trading behaviour concerns the phenomenon that a respondent chooses the same answer option again and again due to, e.g., fatigue, boredom or misunderstanding the survey. This negatively impacts the parameter estimates, which is why such respondents should be removed from the dataset (Hess et al., 2010). In this study, a respondent is considered to be straight lining when he/ she chooses the same choice alternative in seven out of eight times. One respondent has been removed as a consequence of straight lining. Lastly, although an efficient design is used and dominance is checked for, it is still possible that an alternative is dominant in practice. An alternative is considered to be dominant if it is chosen by 90% of the respondents. However, and in contrast to common believe, a dominant alternative still contains information which could be useful for the model estimation if the alternative is not chosen by all respondents (Bliemer et al., 2017). Therefore, dominant alternatives may still be used in the model estimation as long as the number of dominant alternatives is relatively low. Figure 5.1 shows the provided answers of all choice sets across all three survey versions. This figure shows that option C is dominant in choice set 3 of the second version of the survey (92.5% of the respondents chose option C). Figure 5.2 shows this choice set. Apparently, respondents are, in this choice set, willing to accept higher operational costs and a construction time of one month in return for a high popularity in the neighbourhood and a low required inside space. Since 7.5% of the respondents chose option B in the choice set of figure 5.2, this choice set is kept in the data set. No dominant alternatives have, thus, been removed.

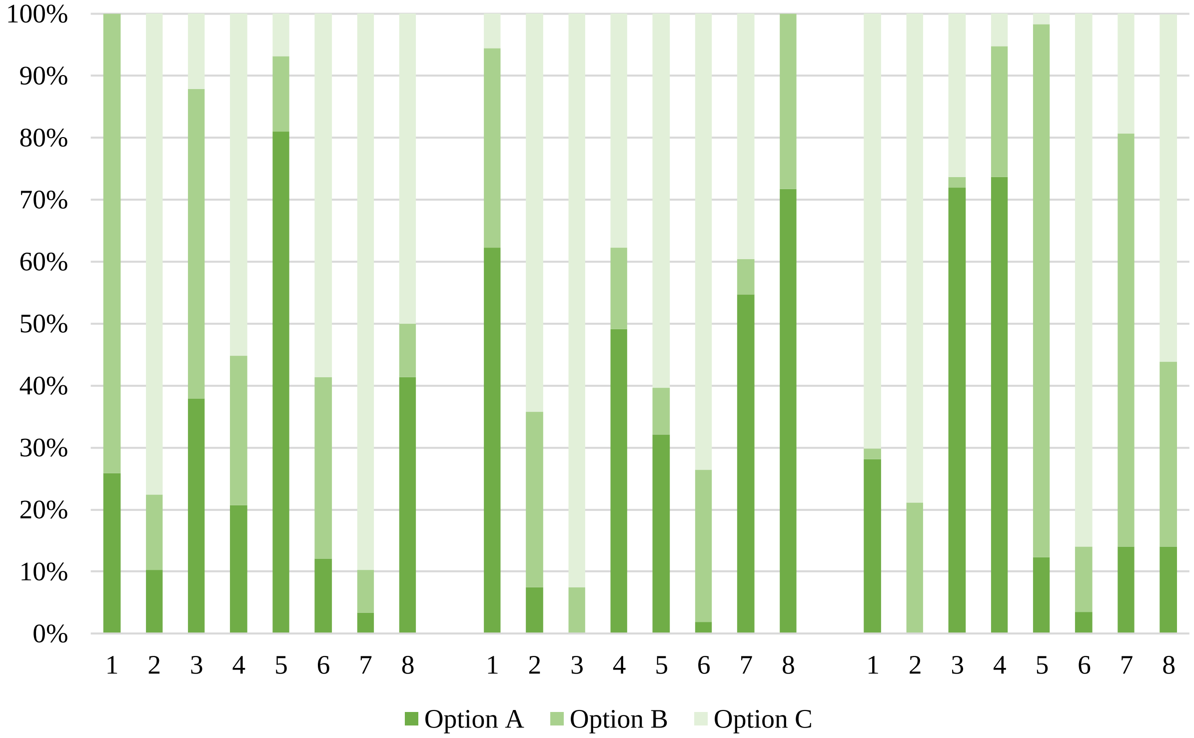

Figure 5.1: answer distribution of all choice sets.

	Option A	Option B	Option C
Substitute RHS	All-electric heat pump	All-electric heat pump	All-electric heat pump
Investment costs	€ 50,000	€ 27,500	€ 27,500
Operational costs	€ 1,500	€ 1,500	€ 2,500
Popularity in the neighbourhood	15 out of 100 people (15 %)	15 out of 100 people (15 %)	85 out of 100 people (85%)
Required inside space	3 times as much as a conventional central heating boiler	3 times as much as a conventional central heating boiler	As much as a conventional central heating boiler
Construction time	1 month	1 day	1 month

Which option do you prefer?

- Option A
- Option B
- Option C

Figure 5.2: choice set in which option C turned out to be dominant.

5.1.3 Data treatment

Before the dataset can be used for the estimation of the context dependent LC DCM, six restructuring actions have been executed. Firstly, the year of birth of respondents has been recoded into age for which seven ordinal categories have been created. Secondly, the entered text in the ‘other, namely’ category of current RHS of ten respondents has been recoded. Three answers were synonyms for district heating (‘blokverwarming’ in Dutch). One respondent didn’t know what his/ her current RHS is. However, this respondent lives in a flat, which is why it is assumed that this respondent is connected to district heating. Three respondents had a form of electric heating (infrared heating and/ or electric underfloor heating) for which a new answer category has been created. Another three respondents have a combination of two of the existing answer categories, which has been accounted for by entering two current RHS. Thirdly, the investment costs categories (€5,000, €27,500, and €50,000) have been divided by 10,000 (0.5, 2.75, and 5) and the operational costs (€500, €1,500, and €2,500) by 1,000 (0.5, 1.5, and 2.5) in order to ensure that the estimated parameters are in the same order of magnitude of the other parameters, which facilitates an easier interpretation. Fourthly, all provided answers to the covariate questions which correspond to ‘I prefer not to say’ and ‘I do not know’ have been recoded into a missing value.

This in combination with including all cases with missing values (this is a setting in the utilised model estimation software Latent GOLD 5.1 Choice) ensures that the parameters are estimated correctly and are based on all available information. Missing values on numeric covariates are replaced by the mean of that covariate, while a zero is used by the software in case of missing values on nominal variables. Fifthly, in order to be able to examine the effect of relocation, two interaction effects have been added. The first is between the context (non-relocation or relocation) and investment costs and the second between the context and construction time. Latent GOLD 5.1 Choice can only facilitate one type of coding (dummy or effects). Given the fact that effects coding is most applicable for most attributes and covariates, effects coding is used. Finally, a factor analysis has been conducted in order to verify whether the attitude statements could be merged into two new attitude variables. The suitability of the data for the factor analysis is shown by the value of 0.646 for the Kaiser-Meyer-Olkin Measure of Sampling Adequacy and by a p-value <0.001 for Bartlett's test of sphericity. Using Principal Axis Factoring and orthogonal rotation (varimax), the simple structure was reached after one iteration. The rotation sums of squared loading cumulative percentage is 44.2%. The internal consistency of the statements is checked with Cronbach's alpha. The alpha of factor 1 (community feeling) is 0.706 and factor 2 (influence of others in one's decision) has an alpha of 0.673. Although the alpha of the second factor is lower than the preferable level of 0.7 (due to the fact that these statements were formulated by the researcher), the level is still considered to be sufficient for the purpose of this study. In short, the factor analysis has shown that the statements can be considered to be measuring the underlying attitudes. Therefore, two new variables are computed which are the summations of the provided answers for each of the three statements per attitude. The two new variables represent two attitudes which will be used as covariates in the LC DCM. The in-depth results of the factor analysis are shown in Appendix D.

5.2 Characteristics of respondents in comparison with a proxy population

The characteristics of the respondents are discussed by means of both the socio-demographic and dwellings characteristics as well as the sample bias questions which were earlier discussed in section 4.3. The six data restructuring actions have not been performed yet on the provided characteristics data. So, for example, the new current RHS infrared heating and/ or electric underfloor heating is not included yet. The population of this study is defined as Delft homeowners who also live in the house that they own. Unfortunately, such specific population data is not available. In order to still get some idea about the representativeness of the sample, a comparison is made with data from all Delft citizens (including tenants) and dwellings (including rental properties). This is also why some of the characteristics have been recategorised (e.g., age, education, and household income). The percentage point (pp) deviations from the sample compared to the proxy population are shown in all tables in this section. It can sometimes be argued that these deviations are the result of the proxy population data, while in other cases it shows that the sample is biased. Furthermore, it is important to mention that the percentages are solely based on valid observations, i.e., the answers 'I prefer not to say' and 'I do not know' are excluded. Due to rounding off, the total percentage per characteristic could exceed 100%.

5.2.1 Socio-demographic characteristics

Table 5.1 shows the distribution of the sample in terms of the socio-demographic characteristics. Males are strongly overrepresented in the sample. Since the survey is only filled in by one household member, it is conceivable that males were primarily responsible for this. This is supported by the fact that 76.6% of the households consist of a couple, which will largely be a male and female together. The focus of the survey was on homeowners, which is why it is not surprising that no children (0.0%) and very little young adults (0.7%) have responded. Usually, one first rents a house before one buys a house. Yet, this argument cannot be used to explain that there is a 24.4% point deviation in the age category of 65-74 (year of birth has been recoded to age). This is most likely the result of the survey distribution method via civil organisations. Considering education, a very large share is highly educated (90.8%). It is likely that this is partially the result of focussing on homeowners and largely due to the distribution method and the subject of this survey. The sample is also biased towards high income households, which is a logical consequence of highly educated people. Moreover, low income households are more likely to rent a dwelling, which causes them to be absent in the survey.

As one can expect, household composition and household size show similar results. 1-person (alone) households are underrepresented, while households consisting of a couple and possible children (2 persons and 3 persons or more) are overrepresented.

Table 5.1: socio-demographic characteristics of the respondents and proxy population.

Characteristic	Merged categories	Sample distribution	Proxy Delft population distribution	Difference in pp
Gender (n=160)				
Male		78.8%	52.8%	26.0%
Female		21.3%	47.2%	-25.9%
Age (n=150)				
0-17 years		0.0%	14.7%	-14.7%
18-26 years		0.7%	22.4%	-21.7%
27-39 years		5.4%	19.1%	-13.7%
40-54 years		25.9%	15.9%	10.0%
55-64 years		24.0%	11.7%	12.3%
65-74 years		34.0%	9.6%	24.4%
75+ years		10.0%	6.5%	3.5%
Education (n=162)				
Low	Primary school, VMBO-b, VMBO-k, VMBO-g, VMBO-t , HAVO- & VWO-first half, MBO-1	2.4%	20.4%	-18.0%
Middle	MBO-2, MBO-3, MBO-4, HAVO & VWO completed	6.8%	35.6%	-28.8%
High	HBO-, WO-bachelor, WO-master, doctor	90.8%	44.0%	46.8%
Household income (n=138)				
0-19%	Less than €20,000	0.7%	25.7%	-25.0%
20-39%	€20,000-€39,999	8.7%	22.8%	-14.1%
40-59%	€40,000-€59,999	23.2%	18.6%	4.6%
60-79%	€60,000-€79,999, €80,000-€99,999	36.2%	15.6%	20.6%
80-100%	€100,000-€149,999, €150,000-€199,000, €200,000 or more	31.2%	17.2%	14.0%
Household composition (n=167)				
Alone		19.8%	58.7%	-38.9%
Single parent with children		3.6%	6.0%	-2.4%
Living together		46.1%	21.0%	25.1%
Living together with children		30.5%	14.4%	16.1%
Household size (n=167)				
1 person		19.2%	58.7%	-39.5%
2 persons		48.5%	24.1%	24.4%
3 persons or more persons	3 persons, 4 persons, 5 persons or more	32.4%	17.2%	15.2%

5.2.2 Dwelling characteristics

The characteristics of the dwellings in which the respondents live in are presented in table 5.2. A large share of the dwellings in Delft are from the type of flat and similar types of dwellings (75.1%). Such dwellings are usually rented and not for sale, which explains why these dwelling types are strongly underrepresented (-54.7% points). The last observation in 5.2.1 could be explained by this finding since this type of dwelling is also, frequently, smaller and thus more likely to be the home of someone who lives alone (1 person household). Corner and terraced houses are overrepresented in the sample (55.4 % points). There is no clear explanation for this. It could be that the members of civil organisations predominantly live in such dwellings. With respect to the construction year, the sample and proxy population are more comparable to each other. Nevertheless, old dwellings (<1904) are somewhat overrepresented (10.9% points). Such dwellings are mostly located in the city centre (zip code 2611), which is also a little disproportionally present in the sample (7.1% points). The construction year category of 1945-1964 is largely absent in the sample, which is likely the period in which most flats were built.

Small dwellings (living areas of 2-49 m^2, 50-74 m^2, and 75-99 m^2) are expected to be most likely flats/ apartments, which explains why these dwelling sizes are underrepresented (-16.2% points, -22.3% points, and -16.8% points). Apart from the fact that owner-occupied homes are often larger than rented dwellings, the overrepresentation of large dwellings (> 100 m^2) can also be caused by the fact that the sample consists of relatively many high income homeowners (see table 5.1).

As mention earlier, the zip code 2611 is more present in the sample than in the proxy population. This could indicate that members from Belangenvereniging de Oude en Nieuwe Delf have participated relatively often and/ or that the part of the city centre represented by this organisation has many owner-occupied homes. 2614, i.e., the neighbourhood of Voordijkshoorn, is a little underrepresented (-6.9% points). This neighbourhood has no association, which means that these homeowners were only reached if they are a member of Platform Energietransitie Delft or Facebook group Delft wordt groen or are following the LinkedIn account City Deal Kennis Maken Delft. The survey has also been distributed by the neighbourhood association of Voorhof (zip code 2624), which explains the observation that this zip code is overrepresented (7.9% points). The zip code 2625 (Buitenhof) is probably underrepresented for the same reason as zip code 2614. Zip code 2628, i.e., Wippolder, is most likely underrepresented (-10.9% points) as a consequence of how the population distribution was calculated. The distribution was calculated using the total number of addresses per neighbourhood. This is considered to be a good method when most addresses belong to homes. However, the Wippolder is characterised by the presence of Delft University of Technology, which accounts for many addresses. Another reason for the difference between the sample and proxy population in the case of zip code 2628 is the same as mentioned for zip code 2614. Relatively very little dwellings are located in three zip code areas (2616, 2626, and 2629) which is why these areas are added to neighbouring areas (respectively 2616, 2622, and 2627).

The observation that well insulated dwellings (labels A and B) are disproportionally present in the sample (10.7% points and 10.8% points) could either be explained by the fact that the population data stems from 2019 or that respondents are relatively environmentally conscious (see section 5.2.3). One reason for the low amount of medium insulated dwellings (-7.2% points, -19.0% points, and -6.9% points) in the sample could be that respondents living in such dwellings did not know that this was their energy label. 65 respondents (38.9%), namely, did not know the energy label of their house. The current RHS of the sample is compared with data from both Delft and Westland due to the absence of more specific data. Very little homeowners use wood fired heating which is why this type of RHS is added to the heat pump category. Moreover, respondents who indicated that they use multiple RHS (e.g., a central heating boiler and a gas heater) are placed in the different category for the purpose of this section. This explains the 9.8% point deviation from the proxy population. In both the sample as well as the proxy population, the natural gas fired central heating boiler is the most often used RHS. 86.1% of the respondents live in a dwelling which is not subject to protected city view. Unfortunately, no population data is available for the monumental status, which is why no comparison can be made.

Table 5.2: dwelling characteristics of the respondents and proxy population.

Covariate	Merged categories	Sample distribution	Proxy Delft population distribution	Difference in pp
House type (n=167)				
Flat/ gallery apartment house/ maisonette/ staircase-access flat	Flat/ apartment/ gallery apartment house/ maisonette/ staircase-access flat/ upstairs apartment	20.4%	75.1%	-54.7%
Terraced	Corner house, terraced house	73.7%	18.3%	55.4%
Semidetached and detached	Semidetached, detached	6.0%	6.7%	-0.7%
Construction year (n=167)				
<1904	Before 1850, 1850-1904	19.2%	8.3%	10.9%
1905-1924		4.2%	6.6%	-2.4.%
1925-1944		17.4%	7.5%	9.9%
1945-1964		1.8%	12.1%	-10.3%
1965-1984		32.9%	35.7%	-2.8%
1985-2004		18.6%	17.3%	1.3%
2005-2021		6.0%	12.6%	-6.6%
Living area (n=163)				
2-49 m^2		0.6%	16.8%	-16.2%
50-74 m^2		3.1%	25.4%	-22.3%
75-99 m^2		11.0%	27.8%	-16.8%
100-149 m^2		47.2%	22.8%	24.4%
150-249 m^2		32.5%	6.1%	26.4%
250 m^2 or more		5.5%	1.3%	4.2%
Dwelling location (n=121)				
2611		21.5%	14.4%	7.1%
2612 and 2616	2612, 2616	12.4%	8.5%	3.9%
2613		9.1%	11.4%	-2.3%
2614		3.3%	10.2%	-6.9%
2622 and 2626	2622, 2626	10.7%	6.7%	3.0%
2623		7.4%	5.4%	2.0%
2624		22.3%	14.4%	7.9%
2625		4.1%	13.0%	-8.9%
2627 and 2629	2627, 2629	6.6%	2.6%	4.0%
2628		2.5%	13.4%	-10.9%
Energy label (n=102)				
Label A	A^{++++}, A^{+++}, A^{++}, A^{+}, A	24.5%	13.8%	10.7%
Label B		19.6%	8.8%	10.8%
Label C		16.7%	23.9%	-7.2%
Label D		8.8%	27.8%	-19.0%
Label E		7.8%	14.7%	-6.9%
Label F		8.8%	7.2%	1.6%
Label G		13.7%	3.9%	9.8%
Current RHS (n=165) proxy population Delft and Westland				
Natural gas fired central heating boiler		82.4%	79.6%	2.8%
District heating		3.0%	15.8%	-12.8%
Gas heater		0.6%	3.1%	-2.5%
Wood fired heating and heat pump	Wood fired heating, heat pump	3.0%	4.6%	-1.6%
Different		10.9%	1.1%	9.8%
Monumental status (n=166)				
Yes		13.9%		
No		86.1%		

5.2.3 Sample bias questions

The extent to which the sample is biased in terms of energy transition engagement is measured by means of various questions and statements which were taken from the study of Citisens (2020). The answers to these questions and statements are depicted in table 5.3 and table 5.4. Be aware of the fact that a different population is meant in these tables. The study of Citisens is representative for the Netherlands and is thus not necessarily focussed on Delft.

The sample is slightly more aware (3.4% points) of the national goal to remove dwellings from the natural gas grid, yet it seems comparable to the population. Moreover, the sample is marginally more willing to be disconnected from the grid (3.7% points) and an almost equal share of people does not know yet (0.2% points). In terms of the importance allocated to becoming natural gas-free, the sample is more neutral (8.4% points) and less extremely positive (-4.4% points). With respect to the larger overall goal of becoming climate neutral, the sample is more positive than the Dutch population (10.3% points and 9.1% points). In terms of the various adopter categories of Rogers (1983), it seems that the sample contains a wide range of categories.

Table 5.3: answers to knowledge and behaviour sample bias question of the respondents and population.

Aspect	Sample distribution	Citisens population distribution	Difference in pp
Knowledge (n=167)			
Yes	99.4%	96%	3.4%
No	0.6%	4%	-3.4%
Behaviour (n=167)			
Yes	40.7%	37%	3.7%
No	40.1%	44%	-3.9%
I do not know	19.2%	19%	0.2%

Table 5.4: answers to attitudes sample bias question of the respondents and population.

Statement (n=167)		1	2	3	4	5	6	7	Mean	Standard deviation
I find it important that all Dutch dwellings become natural gas-free.	Sample	12.6%	8.4%	12.6%	17.4%	21.0%	18.6%	9.6%	4.20	1.836
	Citisens population distribution	14%	11%	13%	9%	20%	18%	14%		
	Difference in pp	-1.4%	-2.6%	-0.4%	8.4%	1.0%	0.6%	-4.4%		
I find it important that the Netherlands become climate neutral.	Sample	1.8%	3.6%	1.8%	7.8%	15.6%	29.3%	40.1%	5.80	1.420
	Citisens population distribution	6%	5%	10%	9%	21%	19%	31%		
	Difference in pp	-4.2%	-1.4%	-8.2%	-1.2%	-5.4%	10.3%	9.1%		

5.3 Representativeness of the sample

Unfortunately, it is not possible to check whether the sample properly reflects the population of Delft homeowners since data thereof is missing. In order to still be able to reflect on the representativeness of the sample, the best alternative data is selected, which includes data of tenants and rental properties. The representativeness is checked for by means of chi-square tests for the following characteristics: gender, age, education, household income, household composition, household size, house type, construction year, living area, dwelling location, energy label, current RHS, energy transition knowledge and behaviour, and the two attitude statements about the national goals of becoming natural gas-free and climate neutral.

The in-depth results of all chi-square tests can be found in Appendix E. Based on the differences in percentage points between the sample and proxy population (see section 5.2), one can expect that the sample is not representative for the proxy population. This is indeed the case. The chi-square tests show that the sample is only representative for the entire Dutch population in terms of the willingness to be disconnected from the natural gas grid (behaviour). It is assumed that it also representative for the population of Delft homeowners. Although some differences can be explained due to comparing the sample to a proxy population (e.g., house type), the overall conclusion is that the sample of this research cannot be considered as representative for the population of Delft homeowners who live in the house they own.

The absence of a general representative sample means that the model results should be interpreted with care. In principle, dependent variables (choices in this case) can be properly predicted by estimated parameters if the variation in independent variables is captured in the sample. One can, for example, argue that the variation in energy labels of dwellings is captured. However, the variation in education level is not captured in the sample. In such cases, two aspects must be kept in mind. First of all, and in the case that a non-representative covariate turns out to be significantly explaining class membership, one must keep in mind that this effect is biased and will likely be less extreme in the population. Secondly, choice behaviour in the sample might not be a correct representation of choice behaviour in the population. That is, the estimated parameters for the attributes will differ in the population compared to a biased sample. For example, lower educated people are likely to be more price sensitive. However, since the sample is biased towards higher educated people, this effect is not captured, which could result in (too) low parameter estimates for investment costs and or operational costs.

5.4 Conclusion

The sample in this research consists of 167 respondents, which is generally speaking not representative for the population of interest in this study. The sample is only representative for the entire Dutch population in terms of the willingness to be disconnected from the natural gas grid. The non-representativeness is both the result of comparing the sample to a proxy population and due to bias in the sample as a result of the survey distribution method and the subject of this study. For example, the house type flat (and comparable types) is heavily underrepresented in the sample, but this is most likely the result of the fact that such dwelling are mostly rented dwellings. However, the sample is highly educated, which is a consequence of the distribution via neighbourhood associations. When interpreting the model results, one must keep in mind that the effects of covariates and attribute parameters can be biased. Even though covariates can be not representative for the population of Delft homeowners, the estimated parameters can still be valid if the variation in the answer categories is captured in the sample.

6 Model results

The estimation results of the various models are discussed in this section. Section 6.1 first describes what the attitudes of the respondents are. Next, section 6.2 elaborates on the results of the base MNL model. Section 6.3 extensively explains the results of the context dependent latent class discrete choice model and compares these results with previous scientific and non-scientific research. Finally, section 6.4 provides the conclusion.

6.1 Attitudes of respondents

In general, the sample responds positively to the community feeling statements (see table 6.1 and figure 6.1). However, although people feel attached to their neighbourhood and find it pleasant to live there, they do not necessarily have many friends in their surroundings. A more normal and less extreme distribution can be observed with the next three statements which indicate the extent to which respondents are influenced by others when they make a decision. The first of these three statements is more skewed to the right, while the third is skewed to the left. Generally speaking, somewhat equal shares of people state that they are and are not influenced by others when making a decision. Only 12.6% of the respondents is a member of an energy collective or cooperation, e.g., Deelstroom Delft (see table 6.2). Given that such collectives are mostly only a few years old, this result is not surprising.

Table 6.1: responses to attitude statements by the respondents.

Statement (n=167)	Completely disagree	Disagree	Neutral	Agree	Completely agree	Mean	Standard deviation
I feel strongly attached to the neighbourhood I live in.	1.2%	3.6%	27.5%	49.1%	18.6%	3.80	0.821
There are many people in my neighbourhood whom I think of as good friends.	2.4%	21.0%	38.8%	28.1%	9.6%	3.22	0.961
I often talk about my neighbourhood as being a great place to live.	0.6%	1.8%	7.8%	51.5%	38.3%	4.25	0.724
The opinion of someone else is important when I make a decision.	11.4%	29.9%	36.5%	21.6%	0.6%	2.70	0.951
During important decisions, I ask people around me what to do.	3.6%	28.1%	39.5%	27.5%	1.2%	2.95	0.864
I find it important to know what other people would do if they were in the same situation.	4.8%	19.2%	34.1%	40.7%	1.2%	3.14	0.905

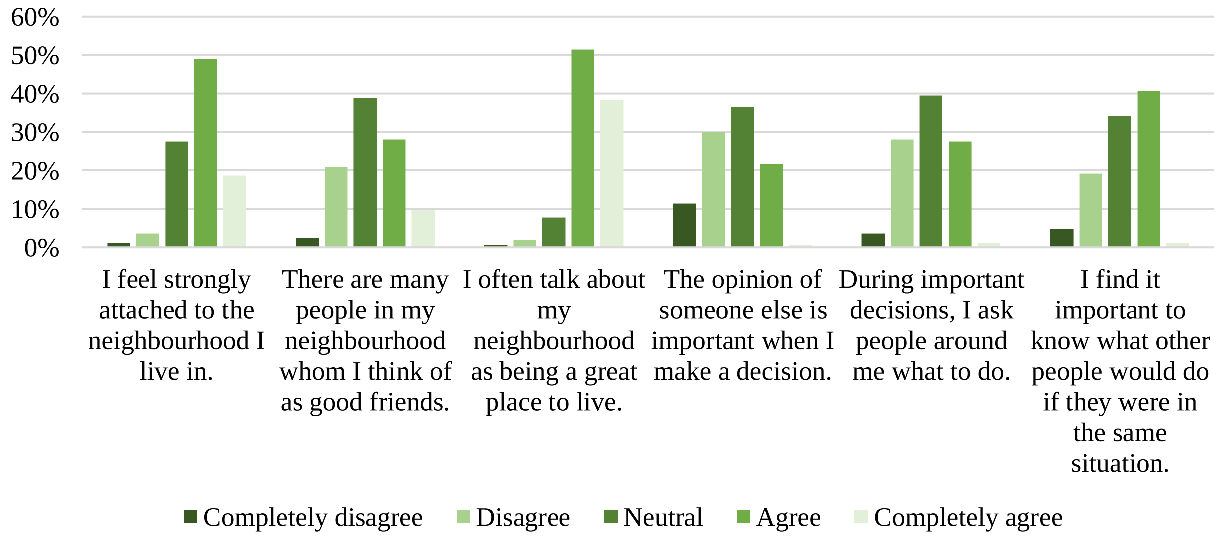

Figure 6.1: answer distribution attitude statements.

Table 6.2: energy collective or cooperation membership in the sample.

Member of energy collective (n=167)	Sample distribution
Yes	12.6%
No	87.4%

6.2 Base MNL model results

The base MNL model only includes the six attributes. In other words, the relocation context and latent classes are not accounted for. The MNL model is estimated in Latent GOLD 5.1 Choice and the results are presented in table 6.3. The R^2 of this model equals 0.3196, the $\rho^2$is 0.3179, and the BIC is 2,043.1152. The p-value shows that all parameters are highly significant (p-value <.001). Put differently, it is very unlikely that the attribute effects are equal to 0 in the population. To reiterate, the observed respondent's choice behaviour is the dependent variable in the choice model.

All attributes were first estimated as nominal variables. In case of equidistance between the first and second attribute level and the second and third level, the attribute was recoded into a numeric variable. Compared to the utility formula and coding discussed in section 4.3, this has resulted in changing construction time from an effects coded categorical variable into a numeric variable. Since the attribute levels have a rising distance between them (1 day, 1 month, and 3 months), this effect can thus be considered to be non-linear and concave (decreasing marginal utility). This seems natural as people generally find an extra construction day less annoying if the total number of construction days is already large.

In the first instance, the popularity in the neighbourhood parameter estimate for the attribute level 50 out of 100 (50%) was more negative than that of the first level (-0.2142 vs. -0.1270). A similar counterintuitive curvilinear relationship between social surrounding and choice behaviour was found by Araghi et al. (2014). Their provided potential explanation for this finding is that people want to be controversial (either being the first one in something or the last) instead of that people want to be someone in the middle. This explanation could also be applied in this case. However, given that the parameter estimates of the more elaborate model do provide the intuitive linear relationship, it becomes more likely that the found effect is due to a sampling error (see table 6.5) (Statistical Innovations, n.d.). Another potential reason could be that the attribute popularity in the neighbourhood is relatively strongly correlated with negatively valued other attributes, e.g., investment costs. Although such correlations are not available in Latent GOLD 5.1, the attribute level 50 out of 100 (50%) is relatively often accompanied in the alternatives with investment costs of €50.000. This might suggest that respondents do not necessarily have something against a popularity of 50% but do not choose an alternative which contains a popularity of 50% due to the high investment costs. However, the correlation between the parameter estimates of popularity in the neighbourhood and investment costs have to be checked in order to verify this. Given the above, it was determined to be more adequate to put an ascending order restriction on the popularity in the neighbourhood attribute. Since the base MNL model is estimated to gain a first understanding of the tastes and preferences and acts as a comparison to the context dependent LC DCM, only a brief interpretation of the attributes parameters is provided.

Table 6.3: results base MNL model.

Attribute	Parameter estimate	Wald statistic	p-value	Relative importance
Substitute RHS		23.0011	<.001	0.0714
All-electric heat pump	0.0704			
District heating	0.2235			
Hybrid heat pump with green gas	-0.2939			
Investment costs	-0.5724	130.5636	<.001	0.3553
Operational costs	-1.0064	256.8941	<.001	0.2776
Popularity in the neighbourhood		21.4327	<.001	0.0718
15 out of 100 (15%)	-0.1736			
50 out of 100 (50%)	-0.1736			
85 out of 100 (85%)	0.3472			
Required inside space		91.0105	<.001	0.1566
As much as a conventional central heating boiler	0.4435			
2 times as much as a conventional central heating boiler	0.2487			
3 times as much as a conventional central heating boiler	-0.6923			
Construction time	-0.2441	13.4156	<.001	0.0673

Substitute RHS

The estimates show that the sample has a preference for district heating, dislikes hybrid heat pumps with green gas, and is somewhat indifferent regarding all-electric heat pumps. Even though respondents have preferences regarding the specific type of RHS, this is only of little importance in their decision compared to the other attributes (relative importance of 0.0714).

Investment costs

As expected, the parameter estimate of investment costs has a negative sign, which indicates that an alternative with high costs results in a lower utility and thus has a lower chance of being chosen. Generally speaking, this is the most important attribute for respondents on which they base their choice (relative importance of 0.3553).

Operational costs

In accordance with expectations and the obtained results for investment costs, operational costs are also negatively valued. Although it might seem that respondents are more sensitive to operational costs than investment costs based on the parameter estimate (-1.0064 versus -0.5724), the relative importance shows that operational costs are slightly less impactful (0.2776 versus 0.35563). The economic attribute category to which both cost attributes belong is by far the most important category on which respondents base their substitute RHS choice (total relative importance of 0.6329).

Popularity in the neighbourhood

A rising popularity in the neighbourhood is associated with a higher utility, which is in line with expectations. The parameter estimates for the first two attribute levels are similar due to the fact that Latent Gold fits the data as best as possible given the ascending order restriction. Similar to the first attribute, this attribute plays only a small role in the decision of respondents (relative importance of 0.0718). Popularity in the neighbourhood seems to be only of little importance, which is contradictory to what the TPB states about subjective norms. Subjective norms are, according to the TPB, an important determinant in the choices of people. The absent importance could also be due to the operationalisation of the subjective norms determinant in this study and its potentially limited relation to the TPB.

Required inside space

If the required inside space is equal to that of a conventional central heating boiler, respondents value this positively. Respondents also seem to be accepting a substitute RHS which requires 2 times as much space than that. However, a negative taste parameter is associated with the highest attribute level which indicates that respondents are not willing to adopt an RHS that requires 3 times as much space. After the two cost attributes, this attribute is most important to respondents (relative importance of 0.1566). This signifies that hassle during the operation of the substitute RHS is important to respondents.

Construction time

The negative sign of the parameter estimate for construction time is as expected. However, is could be argued that it is somewhat surprising to find that respondents consider construction time as the least important attribute when making a decision. This hints that hassle experienced during construction work is not crucial in the decision of respondents.

6.3 Context dependent latent class discrete choice model results

Having established the tastes and preferences of respondents without accounting for taste heterogeneity and the impact of relocation, this section describes the results of the context dependent LC DCM which does take these two aspects into account. The optimal number of latent classes is first determined before the model can be interpreted. Subsequently, the estimated parameters are interpreted and discussed by comparing them to the results of previous scientific and grey studies.

6.3.1 Class determination

As argued in section 2.3.2, the optimal number of classes is determined by means of the BIC. The R^2, namely, does not consider model parsimony, which is shown by the fact that the R^2 is always higher by increasing the number of latent classes (see table 6.4). In line with the previous and expectations, the ρ^2 also increases with a rising number of classes. In the class determination, the two interaction variables (referring to the relocation context) are included as attributes and no covariates are added yet. Covariates do not namely have influence on the optimal number of classes and the choices of respondents. This also explains why model fit statistics of the 1-class model in table 6.4 are different from those stated in section 6.2. For the purpose of this study, it suffices to consider five latent classes (see table 6.4). The degrees of freedom are equal to the number of respondents (167 in this case) minus the number of estimated parameters within the model. From table 6.4 it can be concluded that the optimal number of latent classes is 2 since the BIC is lowest for this number. Therefore, it can also be concluded that there exists taste heterogeneity among respondents.

Table 6.4: model fit statistics with different number of classes.

Classes	R^2	ρ^2	Parameters	df	BIC
1	0.3228	0.3210	11	156	2,049.57
2	0.4162	0.3651	23	144	1,981.34
3	0.4877	0.3807	35	132	1,997.21
4	0.5313	0.3956	47	120	2,014.69
5	0.5431	0.4093	59	108	2,035.92

6.3.2 Model estimation process and results

The base MNL model used in section 6.2 is extended in three ways. First of all, the number of classes is increased from 1 to 2 to account for taste heterogeneity among respondents. Secondly, the two interaction effects are added as attributes and are also treated as numeric variables. The combination of using 0 for the relocation variable in case of non-relocation and treating the interaction effect as numeric allows for a correct interpretation of the effect of relocation on investment costs and construction time. Lastly, the covariates are iteratively removed and added to the class membership model in order to arrive at significant covariate effects which are interesting and useful to interpret. The complete iterative model estimation process is described in Appendix F.

The following covariates are treated as numeric variables in Latent GOLD 5.1 Choice since they represent some ordinal, interval, or ratio variable: age, education, household income, household size, construction year, living area, energy label, community feeling, and influence of others in one's decision. These covariates are nominal: gender, household composition, house type, dwelling location, current RHS central heating boiler, current RHS district heating, current RHS gas heater, current RHS wood fired heating, current RHS heat pump, current RHS infrared heating and/ or electric underfloor heating, monumental status, and energy collective membership. The reasons for putting various restrictions on attributes are also discussed in Appendix F.

In short, a descending order restriction has been put on the required inside space attribute. This was done due to the fact the second attribute level estimate was higher than that of the first in class 2 (0.2640 vs. 0.0121). This counterintuitive result could be caused by the same principle as discussed for the attribute popularity in the neighbourhood in section 6.2. Again, although the correlation between required inside space and investment costs have not been checked, the observation that the second attribute level is relatively often accompanied with low investment costs suggests that the counterintuitive result is not correct. Furthermore, four effects (popularity in the neighbourhood, construction time, and both interaction effects) are treated as class independent effects, which means that both latent classes have the same parameter(s) for a specific attribute. The class independent restriction is installed if the Wald(=) statistic turned out to be insignificant (p-value >.05).

The resulting model has an overall R^2 of 0.4077, the ρ^2 is 0.3702, and a BIC of 1,951.1539. These numbers are different compared to those stated for the 2-class model in table 6.4 due to the addition of model restrictions. The R^2 of class 1 is equal to 0.4420 and that of class 2 to 0.1832. The R^2 of class 2 is rather low compared to that of class 1, which might indicate that people in this class have responded more quickly and were less focussed. In other words, people in class 2 were probably less familiar with the subject and have filled in the survey more randomly. Given that people did this, it becomes even more likely that the counterintuitive result (i.e., the estimate without descending order restriction) of required inside space is incorrect and that the order restriction is adequate (also note the low relative importance of this attribute in class 2).

The model results are depicted in table 6.5. The relative importance of each attribute is shown per latent class and per context level. To do this, the relative importance of all attributes in class 1 and class 2 in the non-relocation context have been rescaled to exclude the interaction effects since these effects are equal to zero in this case. Below, the estimated parameters are interpreted, it is argued whether these estimations are biased, and the separate results are compared to existing studies. Section 6.3.6 provides a summary of the model results for each of the two latent classes.

Table 6.5: results context dependent latent class discrete choice model.

Parameter	Parameter estimate class 1	Parameter estimate class 2	Wald statistic	p-value	Wald(=) statistic	p-value	Relative importance class 1 non-relocation	Relative importance class 2 non-relocation	Relative importance class 1 relocation	Relative importance class 2 relocation
Attributes										
Substitute RHS			78.6272	<.001	54.5192	<.001	0.1173	0.2967	0.1012	0.2149
All-electric heat pump	0.0598	0.4865								
District heating	0.6579	-0.9639								
Hybrid heat pump with green gas	-0.7177	0.4774								
Investment costs	-1.0677	-0.2368	98.7060	<.001	55.2880	<.001	0.4097	0.2180	0.4249	0.3018
Operational costs	-1.3533	-0.3981	193.3937	<.001	27.0142	<.001	0.2308	0.1629	0.1991	0.1180
Popularity in the neighbourhood			33.3352	<.001	0.0000		0.0760	0.1825	0.0656	0.1322
15 out of 100 (15%)	-0.3911	-0.3911								
50 out of 100 (50%)	-0.1104	-0.1104								
85 out of 100 (85%)	0.5015	0.5015								
Required inside space			94.1221	<.001	35.7420	<.001	0.1441	0.0857	0.1243	0.0621
As much as a conventional central heating boiler	0.7530	0.1397								
2 times as much as a conventional central heating boiler	0.1842	0.1397								
3 times as much as a conventional central heating boiler	-0.9373	-0.2795								
Construction time	-0.1322	-0.1322	1.8801	.17	0.0000		0.0226	0.0541	0.0850	0.1711
Interaction effect investment costs and relocation	0.1943	0.1943	7.6380	0.0057	0.0000					
Interaction effect construction time and relocation	-0.2968	-0.2968	5.8220	0.016	0.0000					
Covariates										
Energy label	0.2440	-0.2440	8.7181	0.0032						
Current RHS gas heater	-0.6455	0.6455	4.2925	0.038						
Household income	0.2738	-0.2738	6.3272	0.012						

6.3.3 Attribute parameter interpretation

Substitute RHS

Class 1 shows similar results compared to the base MNL model with respect to this attribute, i.e., a significant preference for district heating, an aversion to hybrid heat pumps, and a neutral position to all-electric heat pumps. However, the substitute RHS itself plays a larger role in the choice of respondents compared to section 6.2 (relative importance of 0.1173 and 0.1012 versus 0.0714). It can be argued that this attribute captures all non-observed utility associated with the three different substitute RHS. It is therefore not clear why this preference exists. One possible explanation could be that respondents have a negative association with green gas and favour district heating because they are more familiar with it or assume that this is a relatively cheap and/ or hassle-free alternative. A clear and significant contradiction to class 1 can be observed in class 2. This class has a relatively strong distaste for district heating, while both types of heat pumps are positively valued. Moreover, the substitute RHS is the most important determinant for the choice of respondents in this class in the non-relocation context and the second most important in the relocation context. Apparently, other unobserved attributes also play a role in this class. As mentioned, the relatively low R^2 of class 2 could be the result of respondents filling in the survey more randomly. This could also be an explanation why the relative importance of this attribute is large in this class.

Ruokamo (2016) found that most people prefer a heat pump and after that district heating. The results of the present study are somewhat contradictory to this because district heating is preferred by most respondents (class 1 size is 0.7943). The results of Ruokamo (2016) are, however, applicable to class 2. This difference could be either the result of the geographical focus and the inherent change in preferences (Finland versus the Netherlands), as Li et al. (2018) have argued, or due to the fact that a different and more elaborate mix of substitute RHS was used in Ruokamo (2016). By only comparing electric heating and district heating, Braun (2010) shows similar results as this study. Furthermore, both Rouvinen & Matero (2013) and Mahapatra & Gustavsson (2008) have also found the general preference for district heating over electric substitute RHS.

Investment costs

Class 1 has a strong and significant dislike for investment costs which is illustrated by the fact that this is the most influential attribute regardless of non-relocation or relocation. This is similar to the base MNL model and in line with general expectations. Since the investments costs for a substitute RHS can be substantial (in this study €5,000, €27,500 or €50,000), respondents are likely to allocate much importance to this attribute. This is however much less the case for class 2 in the non-relocation context. The attribute parameter is much lower in this class and the relative importance is much lower (0.2180). Although investment costs are still the second most important attribute, the absolute level is lower within this class. This significantly changes in the relocation context (see section 6.3.4).

The results of Troiano et al. (2019) and Michelsen & Madlener (2013) are with respect to the investment costs very similar to this study. They have also found one latent class (called 'Green and cost conscious' and 'Consequences-aware RHS adopter') that is very sensitive for investment costs and one class that is less sensitive for these costs (called 'Wood heaters lovers' and 'Convenience-oriented RHS adopter'). One must, however, keep in mind that different system characteristics were taken into account in these studies which limits the extent to which those results are comparable to the results of this study. Solely based on cost consciousness, it could be argued that class 1 is comparable to the 'dutiful' profile ('plichtsgetrouwen' in Dutch) as defined by Thijssen et al. (2020). Tigchelaar et al. (2019) also made the more general (irrespective of taste heterogeneity) observation that high investment costs form (one of) the most important barriers for homeowners towards transitioning to a natural gas-free RHS. Selvakkumaran & Ahlgren (2019) also note that costs (both investment as well as operational) are very important attributes on which people base their choice.

Operational costs

The attribute parameter of class 1 for this attribute shows a similar result as in the base MNL model and the previous attribute. Members of class 1 also allocate much importance to operational costs, although less than investment costs. Operational costs are after investment costs the most important attribute for respondents in this class irrespectively of the context level.

As expected, class 2 also has a negative parameter for operational costs. Moreover, operational costs are also for members in this class less influential on their decision than investment costs. However, it is interesting to observe that the difference between the relative importance of investments costs and operational costs is much smaller in class 2 than in class 1 when looking at the non-relocation context (0.0551 versus 0.1789). This indicates that class 2 considers both types of costs more evenly. With respect to the importance of the economic attribute category, both classes find this category most important in both contexts. Yet, class 1 is heavily influenced by cost parameters, while class 2 is less extremely affected by costs and shows a more evenly spread out importance allocation across all attributes. Given that the sample is biased towards high income homeowners, the parameter estimates for investment costs and operational costs are likely to be underestimated. Low income homeowners, which are less present in the sample, are namely likely to be more price sensitive.

Contrary to the findings of this study, Mahapatra & Gustavsson (2008) and Ruokamo (2016) have found that operational costs are more influential than investment costs for the relevant substitute RHS. This can again be the result of the different geographical focus or due to the exact definitions and the mix of system characteristics and included substitute RHS. The influence of the exact definitions of substitute RHS on the importance of investment costs and operational costs is shown by Rouvinen & Matero (2013). They found that people are more sensitive to operational costs (compared to investment costs) in the case of ground heating and district heating and that the reversed is true for electricity based substitute RHS.

Popularity in the neighbourhood

The effect of this attribute is considered equal in both classes as a consequence of an insignificant Wald(=) statistic. The effect itself is, however, significantly different from 0. Both classes find it negative when a substitute RHS is only adopted by 15% or 50% of the people in their neighbourhood. Although the parameter estimates are the same for both classes, the relative importance does differ. The popularity in the neighbourhood is only of little importance to class 1, while it is one of the more influential factors in class 2. Therefore, the tastes of class 1 are contrary to what the TPB states about subjective norms, while those of class 2 are in line with the TPB. This nuance was not captured in the base MNL model. Purely based on these observations, one could argue that the expectation that the sample was following the 'staying with the herd'-approach is indeed shown by this (see section 3.4.1). This is also contrary to the non-constrained parameter estimates for this attribute in the base MNL model, which suggests that the non-constrained estimates were incorrect. In line with this, one could also argue that class 2 belongs to the late majority adopter category. However, this is only an explorative observation and no conclusions can be drawn about the adopter category based on only this attribute. As mentioned in section 6.2, the lacking importance of the popularity in the neighbourhood (as in class 1) could also be due to the operationalisation of the subjective norms determinant in this study and its potentially limited relation to the TPB. The influence of others in one's decision is assumed to be the most important determinant of the taste parameters of this attribute. Since the sample is relatively balanced in terms of this attitude (i.e., the variation across the answer categories is captured in the sample), the parameter estimates can be considered unbiased. Other socio-demographic and dwelling characteristics, which are biased in the sample, are considered to be not substantially affecting the parameter estimates of this attribute.

The relatively small effect of the popularity in the neighbourhood on the choices of people (as in class 1) was also found by Kontu et al. (2015) and Van Middelkoop et al. (2017). Unfortunately, these studies have not explained taste heterogeneity in such a way that it allows to compare their results to the finding that class 2 is more influenced by the popularity in the neighbourhood. The findings of Sopha et al. (2010) do allow for such a comparison. They have also found that people who are likely to choose a heat pump (i.e., class 2 in this study) are more influenced by their social environment. Sopha et al. (2010) explain that heat pumps are new RHS which is why many people do not have experience with these RHS. This uncertainty causes people to be more influenced by their social surroundings. In contrast to the results of this study, Kalkbrenner & Roosen (2016) have found that social norms are important influencing factors for sustainable behaviour. This difference could be due to the focus on the willingness to participate in local renewable energy projects (the present study is focussed specifically on homeowners' RHS) or due to the different operationalisation of the determinant social norms. As Selvakkumaran & Ahlgren (2019) adequately formulated in their literature review, there is no conclusive finding with regard to the influence of the social surrounding of people on their substitute RHS choice.

Merely founded upon the finding that class 2 is relatively heavily influenced by the popularity in the neighbourhood, it could be argued that class 2 is similar to the 'structure seeker' profile of Thijssen et al. (2020). Structure seekers are, namely, likely to do what their neighbours do. This confirmatory behaviour is comparable to the positive (and relatively heavy) influence of the popularity in the neighbourhood in class 2.

Required inside space

Class 1 has a rather strong and significant preference for a substitute RHS which is comparable in size to that of a conventional central heating boiler. The utility decreases sharply with increasing required inside space. The strong preference is also shown by the fact that the relative importance of this attribute for class 1 is equal to 0.1441 (non-relocation) and 0.1243 (relocation), which is next to the costs parameters the most influential attribute. In contrast, class 2 has a significantly less strong preference for small RHS. The descending order restriction has been put on this attribute which causes the parameter estimates for the first two attribute levels to be the same. Although class 2 shows the same signs for the various attribute levels, the estimates are more centred around 0, which indicates that respondents in class 2 have a less extreme taste for a certain RHS size. This is also exemplified by the low relative importance of 0.0857 and 0.0621. Thus, operational hassle is an important attribute category for class 1, while it is far less important for members of class 2. Since the sample is biased towards dwellings with large living areas (partially due to comparing the sample to a proxy population and partially due to the sampling distribution method), it could be argued that the attribute parameter estimates are somewhat underestimated.

Kontu et al. (2015) have found that required inside space is of little importance across a wide range of different substitute RHS among which are those used in this study. The obtained results of this study for class 2 are in line with these findings. Willis et al. (2011) also found that required inside space negatively impacts the choice probability of an alternative but has not reflected upon the relative importance of this attribute.

Construction time

The effect of this attribute is, similar to the popularity in the neighbourhood, class independent, but more importantly also not significant at the 5% level. This means that the effect of construction time cannot be generalised to the population in the non-relocation context and therefore it has to be assumed that this effect is 0 in the population. Within the sample, and as expected, a rising construction time is related to a rising negative utility. Furthermore, in both class 1 and 2, this attribute is the least important that is taken into consideration. Therefore, construction hassle is not an important attribute category for respondents in the sample in case of non-relocation. The bias of the sample is argued to be unimportant for the parameter estimates for construction time.

Meles et al. (2019) have also found that installation hassle (i.e., construction hassle in this study) does not significantly influence the choice of respondents. Although De Vries & Kooger (2020) have not quantified their finding, they have also found that construction hassle is not of importance to people. This is in contrast to the effect of the operationalisation of construction hassle in Willis et al. (2011). In that study, the need to dig up one's garden had a significant negative impact on the choice of respondents. This contrast could be due to the different operationalisation of construction hassle.

6.3.4 Effect of relocation on attributes

Effect of relocation on investment costs

In section 3.3, the hypothesis was formulated that relocation causes people to be less sensitive to investment costs. The positive and significant parameter estimate of 0.1943 confirms this hypothesis. The most logical explanation for this effect is that relocation already brings high costs, which causes the substitute RHS costs to be relatively lower. Since the Wald(=) was insignificant for this effect, both classes have an equal reaction to the context of relocation. However, by combining both the main effect and interaction effect, the resulting sensitivity to investment costs is different between the classes (see table 6.6). Although class 1 is less sensitive to investment costs during relocation, the overall parameter is still -0.8734, which is rather large. In contrast, relocation has a much larger influence on the sensitivity to investment costs of class 2 (relative importance grows by 0.0839 and in class 1 by 0.0152).

It can be counterintuitive that the relative importance of investment costs grows, while the attribute parameter is smaller. This is due to the fact that the relative importance of the other attributes also changes because it is not rescaled in the relocation context. The importance of the other attributes decreases which is why the importance of investment costs increases. In the relocation context, investment costs become the most important attribute for respondents in class 2. The earlier mentioned large difference between the relative importance of investment costs and operational costs across classes is much smaller in the relocation context (difference in class 1 is 0.2258 and in class 2 0.1838). So, class 2 considers investment costs much more than operational costs during relocation, while it more or less equally considers investment costs and operational costs in the non-relocation context. All in all, relocation serves as a starting point for behavioural change with respect to the sensitivity to investment costs.

Table 6.6: investment costs parameter estimates without and with relocation.

Attribute	Parameter estimate class 1	Relative importance class 1	Parameter estimate class 2	Relative importance class 2
Investment costs without relocation	-1.0677	0.4097	-0.2368	0.2180
Investment costs with relocation	-0.8734	0.4249	-0.0425	0.3018

Effect of relocation on construction time

Contrary to the hypothesis in this study, relocation causes respondents to be more sensitive to construction time (parameter estimate of -0.2968). This is a surprising result, especially since the main effect of both classes was only -0.1322, although this could also be the result of multicollinearity between the main and interaction effect. The effect of relocation on construction time is also equal for both classes, which causes the sensitivity to construction time in the relocation context to be equal to -0.4290 (see table 6.7). The Wald statistic of the interaction effect is significant, which shows that people are only significantly influenced by construction time in a relocation context. Given the utility contributions of all other attributes, the relative importance rises more in class 2 than in class 1 as a consequence of relocation. Construction time is one of the most influential attributes in class 2 in the relocation context (only substitute RHS and investment costs have more influence). The present study assumed that additional construction time for a substitute RHS during relocation was perceived as less hassle, while the results show that this causes in fact more hassle (especially in class 2). Therefore, construction hassle is argued to play a role during relocation and not when someone is not moving.

Table 6.7: construction time parameter estimates without and with relocation.

Attribute	Parameter estimate class 1	Relative importance class 1	Parameter estimate class 2	Relative importance class 2
Construction time without relocation	-0.1322	0.0226	-0.1322	0.0541
Construction time with relocation	-0.4290	0.0850	-0.4290	0.1711

Due to the fact that the effect of relocation has not been studied yet before in the scientific research field of RHS choice behaviour, a comparison to existing scientific literature is not possible. However, the PBL Netherlands Environmental Assessment Agency has provided some insights into this effect. Contrary to the findings of this study but in line with the hypothesis, Schilder & Van Der Staak (2020) state that people become less and less sensitive to construction hassle in a relocation context as the construction time grows. This common belief is, based on the results of this study, misplaced. It is surprising to find that other grey literature stress the importance of relocation as a natural moment for change, but that more in-depth reasons why this is the case, e.g., that people become less sensitive to investment costs, are absent. Any conditions when relocation is a moment for change are also missing. The present study has shown that such in-depth knowledge is crucial because relocation is only a window of opportunity for change if the increased sensitivity for construction time is taken into account. In short, relocation does not only have positive effects on the behaviour of homeowners. Even though this study has not researched this, the increased sensitivity for construction time as a result of relocation could be due the current overheated housing market in the Netherlands and Delft.

As a consequence of the soar in house prices, homeowners are less willing to relocate and are staying in their current houses (Obbink, 2021; Municipality of Delft, 2020e). One would assume that homeowners want to sale their house now given the high prices. However, these homeowners cannot find a new home, which causes them to stay in their current house. Given this, it is plausible that these homeowners are more willing to renovate their house and also to change their current RHS. As a result, sensitivity for construction time is low during non-relocation. If homeowners do find a new house, which they have bought for a high price, it is conceivable that they want a house that is immediately ready to move in, which increases the sensitivity for construction time.

6.3.5 Covariate parameter interpretation

Energy label

Based on the significant effect of energy label the better insulated one's house is the larger the probability that one belongs to class 2 if everything else is kept constant. Similarly, people living in poorer insulated dwelling are more likely to belong to class 1. Since class 2 prefers heat pumps (which require more personal effort) and class 1 favours districts heating (low personal effort), this seems to be a logical result since high insulation levels currently also require personal effort. Table 6.8 provides a more in-depth overview of the class membership probabilities. As argued in section 5.2.2, it is likely that respondents living in dwellings with label C do not know what the energy label of their house is. This partially explains the relative low class 1 membership probability for label C. Another explanation could be that medium insulated dwellings are smaller dwellings (possibly flats) in which people live with relatively low income levels (see also the interpretation of household income). Despite that a better energy label increases the probability to belonging to class 2, all respondents have the largest probability to belonging to class 1 across all energy labels. This makes sense because most respondents will by definition belong to class 1 (class 1 size is 0.7943). People living in very poorly insulated dwellings (label F and G) are very likely to belong to class 1. This is in line with the observations made for household income, because poorly insulated dwellings are often owned by relatively rich households (such dwellings are, for example, often located in the city centre of Delft). Even though the sample data for energy label is not representative for the proxy population (possibly because due to the environmentally conscious sample), it can be argued that the variety of energy labels is present in the sample. Therefore, the covariate effect of energy labels is most likely not biased.

Table 6.8: class membership probability given a certain energy label.

Energy label	Class 1 membership probability	Class 2 membership probability
A^{++++}, A^{+++}, A^{++}, A^{+}, A	0.6631	0.3669
B	0.7315	0.2685
C	0.6999	0.3001
D, E	0.8767	0.1233
F, G	0.9414	0.0586

The result that homeowners living in well-insulated homes are more likely to be less cost sensitive is in line with what Michelsen & Madlener (2013) have found. They explain their finding by stating that people in well-insulated dwellings are likely to have lower energy requirements, which results in lower costs. If the possible range of investment and/ or operational costs is lower, it is imaginable that people are less sensitive to these attributes. Even though each respondent was presented with the same imaginative cost attribute levels in this study, it could be that respondents have interpreted the costs differently depending on their situation.

Current RHS gas heater

The second significant covariate explaining class membership is current RHS gas heater. This is a rather surprising result, especially because only four respondents in the sample have such an RHS. Three of these respondents are men (the other preferred not to answer), all four are highly educated, all four live in a terraced house, and none of them are a member of an energy collective. Although these are the shared factors among the respondents with a gas heater, they cannot explain why people with a gas heater are more likely to belong to class 2 (covariate effect of class 2 is 0.6455). In addition, table 6.9 shows that the class 2 membership probability of people with a gas heater is more than 50%, while people who do not have such an RHS are very likely to belong to class 1 (80.21%).

The attribute estimates for class 2 do not seem to be incompatible with the result that people in this class are more likely to have a gas heater. Although caution is appropriate with only four respondents, one could for example argue that the found covariate effect is in line with the result that class 2 is less sensitive to required inside space. Gas heaters, namely, require additional inside space on top of the space needed for the primary RHS. Given that only four respondents have a gas heater in the sample and that this is relatively little compared to the proxy population, the covariate effect could be underestimated.

Table 6.9: class membership probability given having a gas heater or not.

Current RHS gas heater	Class 1 membership probability	Class 2 membership probability
Yes	0.4766	0.5234
No	0.8021	0.1979

Regarding the result that people with gas heaters are more likely to be in class 2 and are therefore less cost sensitive, Michelsen & Madlener (2013) found a similar result. Furthermore, people in the same class in that study are also relatively little influenced by the fact that they know other people with a similar RHS. Although one could argue that is contrary to the finding of this study that the popularity in the neighbourhood is a relatively important attribute, this is likely the result of different definitions.

Household income

The significant effect of income on class membership shows that households with a higher income are more likely to belong to class 1 (covariate effect of class 1 is 0.2738) and vice versa that class 2 is more likely to consist of households with a lower income (covariate effect of class 2 is -0.2738). In a sense, this is a surprising result, because people with well insulated dwellings are also in class 2. Given that well insulated dwellings currently often require a lot of effort and investments, one would expect that high income homeowners would be more represented in class 2. From table 6.10 it can be deduced that across the entire range of income levels, people are most likely to belong to class 1. Nevertheless, high income households (>€80,000) are very likely to fit in class 1, while low income households (<€80,000) are somewhat likely to belong to class 2. This insight has three important implications. First of foremost, the fact that people with lower incomes are more likely to be in class 2 could be a reason for the relatively low R^2 of class 2. It is namely conceivable that at this stage in time, people with lower incomes (and with that often lower education) are less likely to be interested in the subject of the heat transition. As a consequence, these people are more likely to answer the survey more randomly, which causes the R^2 to decrease, the relative importance of all attributes to be more evenly spread out, and the relative importance of the substitute RHS to be relatively large. Secondly, since the effect of household income is significantly explaining class membership it becomes very likely that the parameter estimates for investment costs and operational cost are underestimated. This is especially the case for class 2, because low income households are more likely to be in this class. As a result, the cost parameter estimates are in reality probably larger, which causes class 2 to be more similar to class 1. Lastly, as mentioned in section 6.3.3 the parameter estimates of required inside space could also be underestimated since smaller dwellings are underrepresented in the sample. This covariate forms the link between these two variables since low income households also frequently live in smaller dwellings. Therefore, it is likely that the parameter estimates for the attribute required inside space for class 2 are underestimated. Similar to the cost parameters, this causes class 2 to be more equal to class 1.

The results of household income and the popularity in the neighbourhood parameter estimates are also in line with the adopter categories defined by Rogers (1983). Section 5.2.3 showed that the sample seems to be consisting of various adopter categories based on the sample bias questions results. High income homeowners are more likely to be in class 1. This class allocates a lower relative importance to popularity in the neighbourhood than class 2. Therefore, purely based on this, one could argue that the earlier adopter categories are in class 1 and that later adopter categories are in class 2. The higher relative importance of the cost parameters in class 1 seems to contradict this statement, but this could be due to the underestimation of the relative importance of these parameters in class 2. The sample is more positive towards the goal of becoming climate neutral than the Dutch population (see table 5.4). One could argue that people with a positive climate neutrality attitude are more likely to be in one of the earlier adopter categories. Therefore, it could be that the class 1 size of 0.7943 is overestimated.

Table 6.10: class membership probability given a household income level.

Household income	Class 1 membership probability	Class 2 membership probability
Less than €20,000, €20,000-€39,999	0.6881	0.3119
€40,000-€59,999	0.6613	0.3387
€60,000-€79,999	0.7219	0.2781
€80,000-€99,999, €100,000-€149,999	0.9003	0.0997
€150,000-€199,999, €200,000 or more	0.9623	0.0377

The observation that people with higher incomes (class 1 in this study) are more likely to consider both investment as well as operational costs relatively heavily is also made by Michelsen & Madlener (2013). Similarly, Ruokamo (2016) also found that people with higher incomes are more likely to be relatively sensitive to investment and operational costs. However, it is important to stress that in the research of Ruokamo (2016) people with a higher income were likely to choose a substitute RHS which was relatively expensive to acquire. In line with the argument made in the section about the covariate energy label, if the investment costs range is relatively high to begin with, it is likely that people are more sensitive to investment costs. The study of Willis et al. (2011) is both in line and in conflict with the results of this study. They also found that people with low incomes are less likely to be cost sensitive, but also found that people with a high income are less cost sensitive. At first sight, it could be surprising to find that people with a high income are more cost sensitive. However, this is likely to be the result of the fact that such people live in very poorly insulated dwellings (see effect of covariate energy label) and that these people are aware that their investment costs range is likely to be relatively high. Therefore, these findings are in line with those of Ruokamo (2016). Contradictory to the results of the present study, but in line with more general expectations, low income homeowners are relatively sensitive to costs in Willis et al. (2011). That this result is not found in this study is most likely the result of the above explained relevant investment costs range of high income homeowners. Another reason for the counterintuitive finding that high income households are cost sensitive could be that class membership for these households is based on the parameter estimates for the other attributes and less for the cost attributes. To reiterate, the found class dependent effects of investment costs, operational costs, and required inside space could be underestimated due to the bias in the sample. As a result, unbiased class 2 attribute parameters are likely to be more equal to those of class 1. It could even be the case that in a completely representative sample, no taste heterogeneity exists anymore. However, this is solely based on speculation and requires future research to confirm.

Non-significant covariates

It is no surprise that only three covariates significantly explain class membership, however when looking at which covariates are significant (and more importantly which are not) various interesting observations can be made. Firstly, and as already explained, it is rather surprising that current RHS gas heater significantly explains class membership. No clear reason has been found for this effect. Secondly, various covariates are likely to be mutually correlated, which causes multiple covariates not to be significant if one of the correlated covariates is already significant. Household income is significant, which is why it is likely that the following covariates are not: education, living area, dwelling location, construction year, monumental status, and house type. The fact that gender and age can also be significant in some combinations of added covariates is also caused by correlations. Another reason why covariates are not significant is due to the missing variation within the sample. A clear example of this is education (90.8% is highly educated in the sample). Fourthly, irrespective of the selected combination of significant covariates, the attitude covariates (community feeling and influence of others in one's decision) are not significant. This is a rather unexpected result. One possible reason for this could be that the attitudes only explain the variance in popularity in the neighbourhood and partially explain the preference for district heating. Put differently, if covariates are specifically targeted to a few attributes and are not generic covariates, it is hard to become statistically significant. Another reason, naturally, could be that the expected link between attitudes and choice behaviour is not existing or that the link is reversed, i.e., choice behaviour influences attitudes (Kroesen et al., 2017). With respect to the various current RHS, it might seem unexpected that current RHS heat pump is not significantly explaining class membership. One could, namely, formulate clear expected effects, such as a high preference for an all-electric heat pump and a low sensitivity for costs, required inside space, and popularity in the neighbourhood. However, the scope of this study is very likely to be the reason for the absence of this effect.

Respondent who were already natural gas-free were namely asked to imagine that they would still have a conventional central heating boiler. Moreover, and as mentioned in section 3.4.2, the scope of this study causes current trade-offs (CO_2 emissions versus price) to be impossible.

6.3.6 Class summary

Based on all of the above, the two latent classes can be summarised as either 'cost conscious homeowners' or as 'relocation sensitive homeowners'.

Class 1: 'cost conscious homeowners'

It can be expected that by far most homeowners are members of this class (79%). Therefore, this class is characterised by a wide range of homeowners in terms of their household income and the energy label of their house. Yet, high income homeowners living in poorly insulated houses are very likely to be in this class. Figure 6.2 shows that homeowners in this class are predominantly driven by investment costs and operational costs in their decision for a substitute RHS. Apart from the economic attributes, members of this class also find the required inside space an important characteristic of the substitute RHS, albeit much less important than costs. Operational hassle is, thus, of some importance. Even though homeowners have a preference for district heating, they find the type of substitute RHS itself relatively unimportant while choosing a substitute RHS. Likewise, it helps al little if a specific RHS is already adopted by a large proportion of the homeowners in the neighbourhood. Construction time (i.e., construction hassle) is of no importance when homeowners stay living in their current house but becomes somewhat important if homeowners are relocating to a new house. The effect of relocation is less apparent in the other characteristics. Investment costs become relatively a little more important (the attribute parameter is smaller in the relocation context), while the other four characteristics become slightly less important.

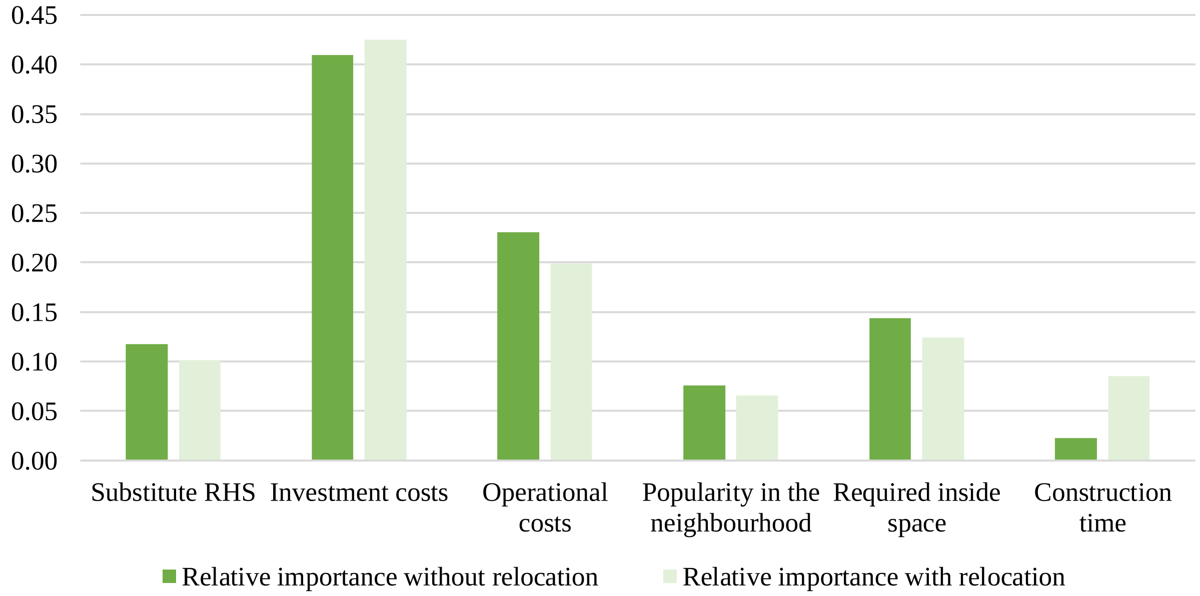

Figure 6.2: relative importance of all attributes in class 1 in both contexts.

Class 2: 'the relocation sensitive homeowners'

About one-fifth of the Delft homeowners are member of class 2. Contrary to class 1, this class is more likely to consist of homeowners with lower incomes and who live in relatively well insulated dwellings. Furthermore, homeowners with a gas heater are also likely to belong to class 2. This class can be best characterised as relocation sensitive. The context has namely a profound impact on the relative importance of various attributes (see figure 6.3). When homeowners in this class are not moving, they base their choice mostly on the type of substitute RHS with a preference for both all-electric heat pumps as well as hybrid heat pumps with green gas. However, the combined effects of investment costs and operational costs are most influential for the choice of homeowners. Although economic attributes are also leading in this class, they are much less influential than in class 1. Another clear contradiction to class 1 can be seen when looking at the relative importance of popularity in the neighbourhood and required inside space.

Class 2 homeowners find the former characteristic much more important than the latter. This suggests that homeowners in this class might be part of the late majority adopter category of Rogers (1983). The popularity in the neighbourhood is, thus, more relevant than operational hassle for homeowners in this class. Similar to class 1, homeowners in class 2 are also only influenced by construction time (i.e., construction hassle) when they are relocating. However, in contrast to class 1, the influence of relocation is much larger in this class. Similar to construction time, investment costs become much more important in a relocation context in terms of the relative importance (not in terms of the attribute parameter). The specific substitute RHS, operational costs, popularity in the neighbourhood, and required inside space are in the relocation context substantially less influential.

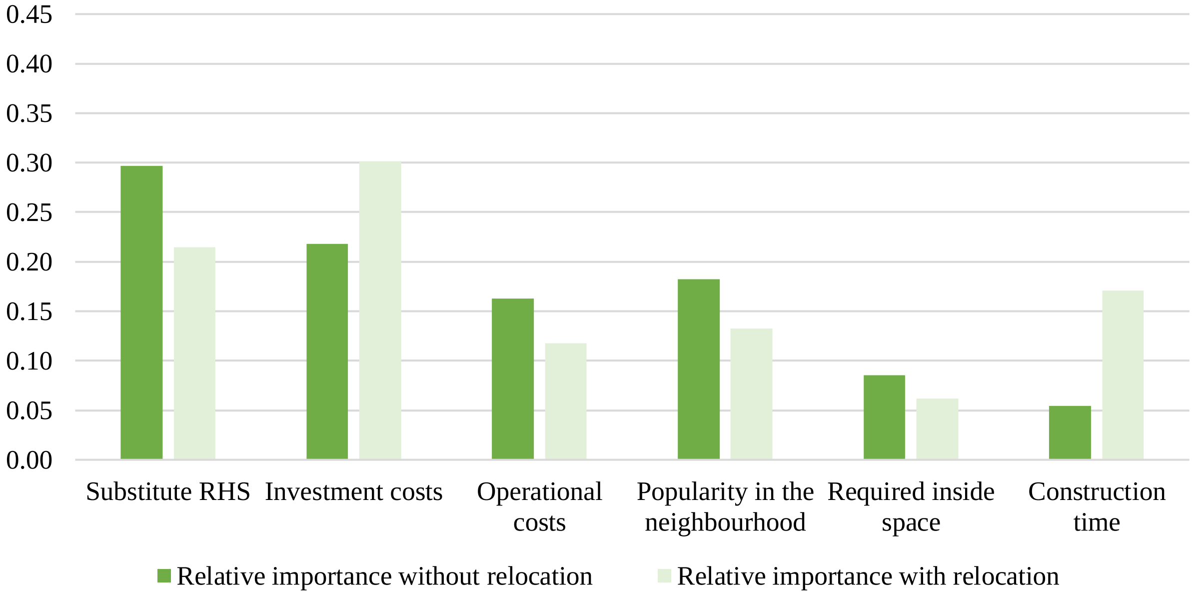

Figure 6.3: relative importance of all attributes in class 2 in both contexts.

6.4 Conclusion

In this section, the results of a base MNL model and a context dependent latent class discrete choice model have been interpreted. The latter model has shown that there exists taste heterogeneity among respondents. The largest group of homeowners primarily bases their choice on investment costs, operational costs, and required inside space. The smaller second group is also influenced by economic attributes as well as the substitute RHS and popularity in the neighbourhood. The, scientifically speaking, most interesting result is that a life event (relocation in this study) makes homeowners less sensitive to investment costs and more sensitive to construction time (i.e., construction hassle). The latter finding is contrary to common belief, which exemplifies the necessity and scientific contribution of including relocation as a context in the RHS choice behaviour research field. The inclusion enables researchers to analyse the effect of relocation more in-depth and has shown in this study that relocation does not only have positive consequences for the behaviour of homeowners. Relocation is only a window of opportunity if the increased sensitivity for construction time is taken into account.

7 Improving the Delft heat transition

In this section, the model results and interpretation are used to formulate policy recommendations. Section 7.1 describes both the goal of the policy recommendations as well as which experts have been interviewed and why. Subsequently, section 7.2 analyses the decision-making process of the Delft heat transition. Section 7.3 provides three sets of policy recommendations which are based on the results of this study and the decision-making process analysis insights. The conclusion is provided in section 7.4.

7.1 Goal of policy recommendations and consulted experts

As argued in section 2.4, the societal contribution of this study lies primarily in the policy recommendations. The goal of these recommendations is to increase the adoption rate of natural gas-free RHS. The adoption rate is, understandably, low as of now with 6.8% (Statistics Netherlands, 2021). In December 2020, a survey among Delft citizens revealed that 33% of the Delft homeowners find the goal of becoming natural gas-free unrealistic and that 8% completely disagrees with the goal (Municipality of Delft, 2021a). This indicates that the adoption rate will not increase as much as wanted voluntarily and that additional measured are needed. Most recommendations are directed to the municipality of Delft as this is the facilitator of the heat transition in Delft. The method for achieving the increased adoption rate can be best summarised as to govern is to foresee (translated from the Dutch proverb 'regeren is vooruitzien').

To gain a more in-depth understanding of the decision-making process policy documents have been reviewed. Furthermore, in order to ensure that the recommendations are feasible in practice, three expert interviews have been conducted. A civil servant from the municipality of Delft and an employee of research institute CE Delft have been interviewed. Both experts were already introduced in section 3.4. The third expert is a heat transition advisor for consultancy firm Over Morgen. This expert has helped numerous municipalities with the formulation of their transition vision. Together, these experts provide both in-depth municipal knowledge as well as inter-municipal knowledge from which the municipality of Delft can learn.

7.2 Heat transition in Delft: decision-making process analysis

The heat transition is a complex and long-term challenge. Therefore, the municipality of Delft is currently in the midst of the decision-making process of how this transition will take place in Delft. As a result, numerous policies have been made, are being made, and have to be made. This analysis serves two goals. First, the analysis shows which policies can still be influenced by policy recommendations. Trying to improve definitive policies is, namely, redundant. Secondly, the extent to which the municipality is already taking into account the various substitute RHS attributes is revealed by the decision-making process analysis. For example, it shows what measures are already in place to help homeowners with investment and operational costs.

What has already been decided?

Before the national Climate Agreement, the municipality of Delft already decided in 2011 that it wants to be energy neutral in 2050 (Municipality of Delft, 2013). Moreover, the municipality aims to reduce its energy use and CO_2 emissions by 50% in 2030 compared to the emissions of 1990. Due to the fact that the CO_2 emissions of 1990 are not exactly known, a recalibration to 2014 is used to measure the CO_2 reductions. Compared to 2014, the municipality of Delft is aiming to reduce its CO_2 emissions by 43% in 2030 and 100% in 2050 (Platform Energietransitie Delft, 2021a). These goals cannot be changed anymore. With respect to the CO_2 emissions by inhabitants in 2017, a reduction of 9.7% has been achieved (Platform Energietransitie Delft, 2021b).

In a sense, the municipality Delft was already committed to the 2019 Climate Agreement goals before the agreement was reached. However, the Climate Agreement did impose a certain policy-making process towards the 2050 goal. All municipalities, namely, have to have formulated a transition vision for heat at the end of 2021. The transition vision has two goals: indicate when each neighbourhood will be made natural gas-free and which neighbourhoods which will be made natural gas-free before 2030. The first policy-making step of the municipality was taken in 2018.

A participation process with inhabitants, entrepreneurs, and organisations was held in order to formulate starting points for a good heat transition. The central question during this process was: How should the municipality tackle the heat transition from the perspective of inhabitants, entrepreneurs, and organisations? In short, the starting points relate to the participation process, information provision, financial consequences, importance of a sustainable, safe, and reliable heat provision, and compatibility with other laws and regulations. One of the most important starting points in the context of this study is that participation is centralised during the formulation of the transition vision for heat. To facilitate the participation, Platform Energietransitie Delft was founded by a group of citizens to form the bridge between the municipality and citizens. In 2019 and with the input from the first participation process, the municipality formulated an action plan in which is stated how the transition vision for heat will be made (Municipality of Delft, 2019a). The most relevant steps are explained below including the moments when citizens are asked to participate. This explanation will also illustrate how this study is a useful addition to the current participation process.

What is currently being decided?

The municipality is currently in the decision-making process of the transition vision for heat. This process is subdivided into four phases with each their own participation process. Only the participation steps relevant to homeowners are discussed below.

First of all, phase 0 was the official kick-off which took place in September 2020. Various actors were represented in different teams and groups, which each had their own role in the decision-making process. Homeowners were represented in the focus group via Platform Energietransitie Delft and multiple neighbourhood associations, such as those of TU Noord and Tanthof (CE Delft, 2020). These citizens organisations are, therefore, a crucial link between homeowners and the municipality. Another organisation participating in the focus group is Energieloket Delft. This organisation, as well as 015 Duurzaam, guide homeowners through the process of becoming natural gas-free, for example by advising them about required insulation and suitable RHS for their house. 015 Duurzaam does this, for example, using their generic construction plans on how to make different types of houses natural gas-free. In short, Energieloket Delft and 015 Duurzaam form an essential link between municipal plans and real-life execution. Homeowners also had the opportunity to participate in a survey in December 2020, which was part of a broader communication campaign to inform citizens about the start of the decision-making process. The survey has provided insights into the current living situation of citizens, insulation of dwellings, and the attitudes regarding becoming natural gas-free (Municipality of Delft, 2021a).

Secondly, phase 1 (October 2020 – January 2021) was meant to find a preliminary high-level RHS design per neighbourhood based on the lowest national (societal) costs. This design was made by enriching the start analysis (provided by the PBL Netherlands Environmental Assessment Agency) with local insights from CE Delft's model CEGOIA (CE Delft, 2020). This phase coincides with the technical-economic perspective on the heat transition (explained in section 1.2) and the first goal of the transition vision for heat. Given a range of assumptions about the availability of green gas (hydrogen gas and biogas) and heat sources, the analysis showed that the city centre of Delft should change to hybrid heat pumps. Furthermore, neighbourhoods with dense housing (e.g., flats) should switch to district heating, while less concentrated neighbourhoods should switch to all-electric heat pumps (Kruit et al., 2021). No attention was paid to differences between homeowners with respect to their sensitivity to attributes of RHS in the preliminary high-level RHS design. Another communication campaign was held to inform the citizens of Delft about these findings. In addition, two city talks were organised during which the results of the analysis were explained and citizens could ask questions about the results. A substantial part of these questions were related to costs, which indicates the importance of cost attributes (Municipality of Delft, 2021b). The municipality of Delft already has several subsidies and loans in place to help homeowners with their concern for costs (see section 1.2). However, these measures are insufficient and focus primarily on investments costs and only indirectly on operational costs, namely through lower energy requirements due to insulation (Dignum et al., 2021; Municipality of Delft, personal communication, May 25, 2021; CE Delft, personal communication, May 26, 2021; Over Morgen, personal communication, May 24, 2021).

Thirdly, phase 2 (January 2021 – April 2021) concerned the second goal of the transition vision for heat: selecting neighbourhoods which will be made natural gas-free before 2030 (CE Delft, 2020). The municipality of Delft contributes around 15,000 dwellings to the national goal of 1.5 million natural gas-free dwellings before 2030 (Municipality of Delft, 2013). The prioritisation was made using a variety of criteria which have been formulated in consultation with the focus group. The selected criteria are: affordability, robustness across different scenarios, CO_2 reduction potential, contractability (focus on social housing), compatibility with existing developments and construction plans, and feasibility. Each criterium is given a different weight in the decision. These criteria only include the cost attributes (via affordability) and none of the other attributes. Moreover, it is interesting to note that relocation is not one of the criteria. In the end, thirteen neighbourhoods were selected to be made natural gas-free before 2030. These neighbourhoods are mostly located in the western part of Delft where the housing density is high (Berkel et al., 2021). The results of the neighbourhood prioritisation were again communicated to citizens by a communication campaign and a second round of city talks.

Finally, all input from the previous phases was used to formulate a concept transition vision for heat in phase 3 (April 2021 – December 2021). Citizens are now able to react on this via the official consultation procedure, which is encouraged to do via a final communication campaign. Subsequently, the municipal council will approve the concept version around December 2021.

What has to be decided yet?

After the municipal council has approved the transition vision, the municipality will start formulating district-specific implementation plans. These plans (to be finished within two years) will also be made in cooperation with citizens and state the definitive substitute RHS for each neighbourhood (Government of the Netherlands, 2019). The first phase in making an implementation plan is the district analysis. This analysis examines relevant actors (and their wishes) and physical and social characteristics. These insights are used in the subsequent determinisation phase. The ambition (e.g., natural gas-free ready or natural gas-free), geographical boundaries, division of roles, and preconditions are set in this phase. The design phase is next during which the costs, substitute RHS, required construction work to homes, timeline, and risks are determined. The final phase (the so-called Go! phase) entails the formal approval by the municipal council, execution of the implementation plan, and commissioning of the new substitute RHS (Municipality of Delft, personal communication, February 18, 2021; Municipality of Delft, personal communication, May 26, 2021; Van Rees Vellinga & Bode, 2021). In short, an implementation plan is a more specific version of the transition vision in which is specified which dwellings will change when to what substitute RHS. The above decision-making process is visualised in figure 7.1. Although not specifically part of the municipal decision-making process, it is also interesting to mention that the Metropolitan Region Rotterdam The Hague acts as a regional connector of municipal transition visions for heat. The Metropolitan Region acts as a coordinator between the 23 municipalities in the region (together accounting for 2.4 million citizens) in order to make sure that the regional energy system is constructed as efficiently as possible. This is needed since district heating networks, electricity networks, and green gas networks are almost always inter-municipal. The Metropolitan Region Rotterdam The Hague has already started with analysing the energy system on a regional aggregation scale in the Regional Energy Strategy 1.0 (Metropolitan Region Rotterdam The Hague, 2021). This strategy is updated between 2022 and 2023 with all municipal transition visions and implementation plans, i.e., the Regional Energy Strategy 2.0 (Nationaal Programma Regionale Energie Strategieën, n.d.).

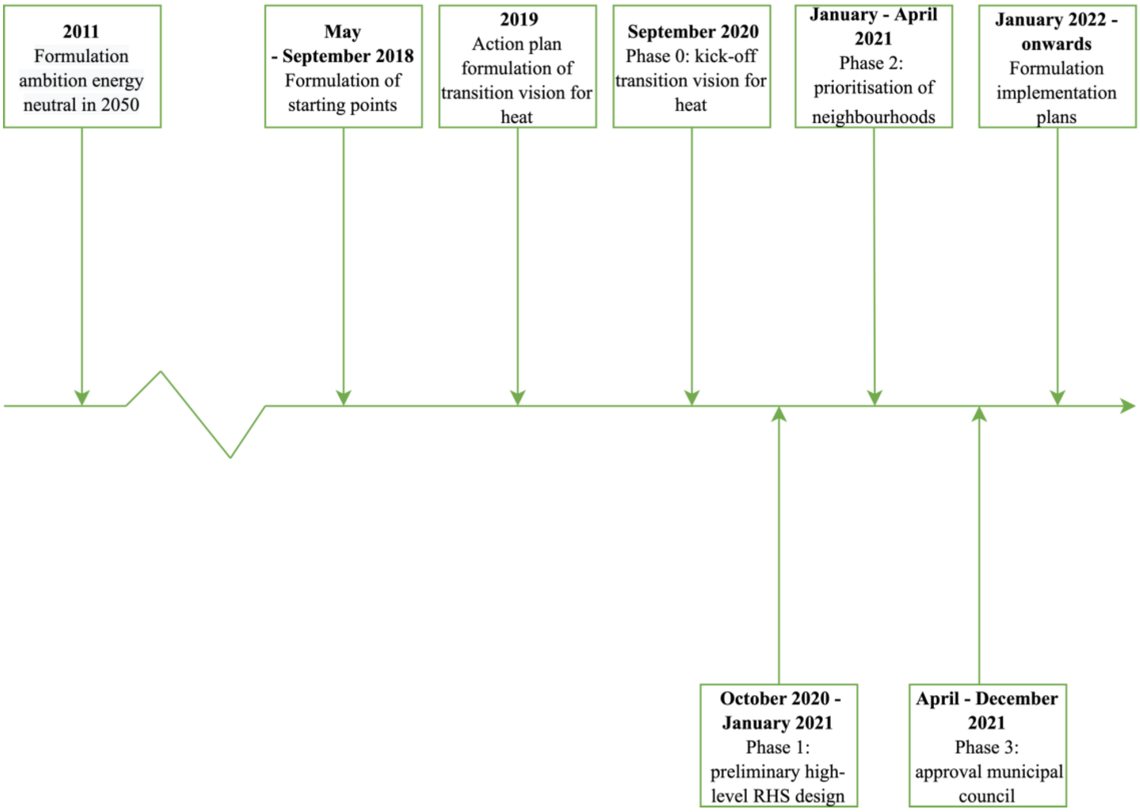

Figure 7.1: visualisation of the decision-making process heat transition in the municipality of Delft.

From the information above, it seems that cost attributes are important to homeowners and are sporadically taken into account by the municipality. However, there is no information yet from the participation process that can be used in the decision-making process regarding the importance of other attributes and the relative importance of all attributes. Furthermore, no attention has been paid in the decision-making process to taste heterogeneity across homeowners. Moreover, the effect of relocation on the tastes for attributes is also not investigated in the current process. The context dependent latent class discrete choice model from section 6.3 has provided this information and is therefore an interesting addition to the current participation process.

So, the results of this study could prove to be increasing the adoption rate of substitute RHS in the form of policy recommendations. But, before one can formulate these, one first needs to establish the policies to which the recommendations are aimed. Keeping in mind that various decisions have already been made by the municipality, the above analysis and expert interviews have revealed that the recommendations can be best targeted towards the concept version of the transition vision for heat and the district analyses of the implementation plans (Municipality of Delft, personal communication, February 18, 2021; Municipality of Delft, personal communication, May 26, 2021). More specifically, the results are used to improve the communication strategy towards citizens of the transition vision and the stakeholder part of the district analyses. The results of section 6.3 provide insights into the wishes of homeowners (one of the relevant actors), which cannot be obtained by directly asking homeowners since they cannot express their true trade-offs (see section 2.2). The decision-making process analysis has also shown that the current subsidies and loans of the municipality are insufficient for homeowners and that the municipality is not centralising cost attributes. Moreover, two links have been exposed that play a pivotal role in the heat transition of Delft. Citizen organisations (Platform Energietransitie Delft and neighbourhood associations) form a link between the municipality and homeowners. Energieloket Delft and 015 Duurzaam link municipal plans with the practical execution in real-life.

7.3 Policy recommendations

The below presented sets of policy recommendations are based on a synthesis of the model results of section 6.3 and the analysis of the decision-making process of the heat transition in Delft of section 7.2. The first recommendation set is focused on the communication strategy of the concept transition vision for heat and is based on the cost attribute results. The other two recommendation sets are targeted at the stakeholder part of the district analyses and are established from the results of the other attributes and the relocation results.

7.3.1 Acknowledge and prioritise the primary problem: affordability

Section 6.3 showed that homeowners base their substitute RHS mostly on investment costs and operational costs. Although investment costs are for both latent classes more important in their decision, one must keep in mind that operational costs follow closely. The decision-making process analysis has shown that the municipality of Delft has insufficient resources to help homeowners with both cost types. As stated in the national Climate Agreement, the national government is responsible to take care of the affordability of the heat transition for homeowners (Government of the Netherlands, 2019). Unfortunately, the national government has not done this yet (Over Morgen, personal communication, May 24, 2021). However, in order to avoid precious time and money and instead of trying to come up with own additional measures, the municipality should put pressure on the national government to present measures that help homeowners not only with investment costs, but also with operational costs. The latter costs are, namely, often neglected during public policy making (see the measures of the municipality of Delft). The recent national elections have provided a window of opportunity to address this issue to the new cabinet. The municipality of Delft should exert pressure in four ways. First and foremost, via the Association of Netherlands Municipalities. This association is a crucial and strong link between the municipality and the national government. Secondly, pressure can be exerted via the G40 city network. This organisation is similar to the previous one, but only consists of medium to large sized cities. The G40 city network has recently taken a first step in putting pressure on the national government via a letter to various relevant ministers (Dekker, 2021). Thirdly, the Metropolitan Region Rotterdam The Hague is a regional actor which plays a coordinating role in the heat transition. This and the fact that the region consists of 23 municipalities and 2.4 million citizens make the Metropolitan Region Rotterdam The Hague another interesting way to put pressure on the national government. Lastly, the municipality can take advantage of more informal inter-government layer lobby connections between municipal aldermen and national ministers of the same political party.

Apart from the little direct influence (own subsidies and loans) and indirect influence (via the national government) of the municipality concerning the affordability issue, the municipality should also align its communication campaign with the wishes and concerns of homeowners. Although the communication needs of homeowners are not directly investigated in this study, the results and current communication campaigns (e.g., city talks) show a discrepancy between the wishes of homeowners and the attention that the municipality is paying to these. Specifically, homeowners are mostly concerned about the affordability issue, while the municipality of Delft is not centralising this problem (see section 7.2). As a result, it seems that the municipality is 'punished' (in the form of citizen opposition) for not handling the affordability issue, even though this issue lies outside the responsibility of the municipality. The current strategy of not centralising the cost problem due to the limited influence seems to be not working. This shows the need for a clear information provision in which the discrepancy is taken away. The information can be best provided in the transition vision and should include five major points (Municipality of Delft, personal communication, May 25, 2021; CE Delft, personal communication, May 26, 2021; Over Morgen, personal communication, May 24, 2021). Firstly, the municipality should acknowledge that affordability is the main point of concern for homeowners and that it from now on will prioritise this issue. Secondly, homeowners should be informed about the fact that the national government is responsible for solving the issue of high costs and not the municipality. Thirdly, the municipality should explain how it is trying its best to influence the national government to address this issue (via the three earlier explains ways) and encourage homeowners also to influence the national government. Fourthly, the municipality should guarantee homeowners that no changes will be made to their houses before the cost issue is addressed, but that it is necessary to parallelly investigate other aspects (e.g., geographical possibilities) of the heat transition in order to be ready when the cost issue is solved.

Finally, perspective has to be provided when the affordability problem will be solved. It is most likely that it will be solved in time and during the formulation process of the implementation plans (Municipality of Delft, personal communication, May 25, 2021). Platform Energietransitie Delft, neighbourhood associations, and other citizens initiatives can help spreading this message from the transition vision towards homeowners. By addressing the most pressing issue to homeowners, the adoption rate is likely to increase.

7.3.2 Communication to homeowners: only focus on the relevant attributes

According to the city talks, clear and reliable information provision is the second most important aspect that would help to increase the adoption rate of substitute RHS. The municipality is going to communicate to its homeowners many more times in the (near) future about the various implementation plans. Consistent, structured, and reliable communication is crucial to keep homeowners involved in the formulation process of the implementation plans. The class specific trade-off findings of this study can provide useful additions to the district analysis in each implementation plan. Specifically, the results of the relative importance of the various attributes can help the municipality focussing on the most relevant concerns of homeowners in the stakeholder part of the district analysis. Section 7.3.1 has already shown that the municipality should primarily focus on cost related attributes. This section discusses how the findings of the other attributes can be utilised to further focus on the relevant concerns of homeowners and with that increase the adoption rate of substitute RHS.

Firstly, homeowners, especially high income homeowners in relatively poorly insulated dwellings, consider operational hassle (in terms of required inside space) as an important aspect when choosing a substitute RHS next to economic attributes. One way of efficiently taking into account this second most important concern is to group these people. For example, it is likely that homeowners living in houses with a monumental status are in this group of people. These homeowners often live in poorly insulated houses (resulting in high investment costs and sensitivity to these costs) and these houses are subjected to protected city view (making required changes to the house for a substitute RHS difficult). The required inside space concern of this group of people can be effectively mitigated with the help of Energieloket Delft and 015 Duurzaam. The analysis in section 7.2 has shown that these organisations are capable of doing this. It is likely that more and more homeowners will use the services of Energieloket Delft and 015 Duurzaam which is why it has to be ensured that ample advisors are available before the surge in demand starts. Another way to ensure that these initiatives stay approachable is by using the existing generic construction plans about how different types of houses can be made natural gas-free. It is, namely, easier to tweak a pre-made plan according to the specific needs of a dwelling instead of making a new plan each time.

Secondly, homeowners with a relatively low income living in relatively well insulated dwellings regard the popularity in the neighbourhood (of the substitute RHS) as an important driver in their choice for a new sustainable RHS. The municipality can use this finding to increase the adoption rate. This specific type of homeowner can be kept up-to-date regarding the progress of changing to a natural gas-free RHS in their neighbourhood and also about the rate of change. The popularity in the neighbourhood can act as evidence that changing to a new RHS is good and doable, which causes more people to transition. In this way, a new subjective norm is created that states that natural gas-free RHS are the default option. Section 7.2 argued that citizen organisations play a crucial role as link between the municipality and homeowners. The municipality should use this link by asking the organisations to both gather current RHS information from homeowners as well as to provide this information to the homeowners. It is better that these organisations do this as they will be perceived by homeowners as more locally involved and reliable than the municipality of Delft. In addition, this type of homeowners has a preference for heat pumps (either all-electric or hybrid) and their choice is fairly heavily influenced by the type of RHS. It is likely that low-income homeowners in relatively well insulated dwellings live in neighbourhoods where the housing density is high (e.g., flats). The decision-making analysis showed that district heating is the preferred alternative for such neighbourhoods based on societal costs and that these neighbourhoods are the first to be made natural gas-free. This causes a potential conflict of preferences. The municipality should take this conflict into account by focussing the conversations with homeowners on the RHS attributes and not on the alternative RHS itself.

Thirdly, this study has also shown that various aspects are not decisive in the choice of certain homeowners. In order to avoid overcomplicating the already complex subject of the heat transition, the municipality should express that these aspects are, for now, less pressing and should allocate much less attention to these aspects in the district analyses. Homeowners who are not relocating find construction time (construction hassle) relatively unimportant in their decision. In addition, most homeowners, especially high income homeowners in relatively poorly insulated dwellings, find the popularity of the substitute RHS of little importance. Moreover, low income homeowners in relatively well insulated dwellings pay little attention to the required inside space (operational hassle). Although these characteristics are of little importance now, this might change over time or when other issues have been solved, e.g., the cost problem. Therefore, the municipality should keep track that these characteristics stay unimportant.

7.3.3 Relocation as an opportunity for change if construction time is accounted for

Section 6.3.4 has shown that relocation causes homeowners to be less sensitive to investment costs and more sensitive to construction time compared to the situation in which homeowners stay living in their current house. The decision-making process analysis has shown that the municipality is currently not taking into account the opportunity that relocation could be providing. Since relocation is the only natural moment for homeowners to change the RHS of the new house, relocation is a rare and important opportunity for change, which is why from now on the municipality should consider relocation in the stakeholder part of the district analyses. In 2019, more than 900 houses were sold in Delft (Municipality of Delft, 2020e). Given that there are currently around 19,000 owner-occupied homes in Delft, relocation can have a substantial contribution to the heat transition (Statistics Netherlands, 2020c). Because changing to a new natural gas-free RHS possibly requires substantial investments and long construction work, it is crucial that homeowners looking for a new house are informed about this possibility as soon as possible. The best moment for this is when homeowners express their interest in a house for sale and want to plan a viewing (Municipality of Delft, personal communication, May 25, 2021; CE Delft, personal communication, May 26, 2021; Over Morgen, personal communication, May 24, 2021). In this way, homeowners can account for the extra required construction time and investment costs for a substitute RHS in their bid. The proposed moment to approach and inform homeowners about the opportunity to change the RHS in the new house requires that the municipality has strong ties with all real estate agents across the municipality. Such ties do not exist yet (Municipality of Delft, personal communication, May 25, 2021; CE Delft, personal communication, May 26, 2021). The primary recommendation based on the relocation results is, therefore, to start building a strong relation with all real estate offices in the municipality, starting with the largest ones.

Assuming that these relations are possible, the second recommendation is that the municipality and real estate agent invite an advisor from Energieloket Delft or 015 Duurzaam to the to-be-sold house before the house is on the market. The advisor should then make a plan in which is stated what the best substitute RHS is for that house, including an overview of the required investment costs and construction time. The advisor should consider increasing the investment costs in order to decrease the required construction time. The earlier discussed generic plans (see section 7.3.2) help to ensure that this is feasible in practice and that no delay is caused. The possibility of delay could, namely, be an important barrier for real estate agents to join the municipality in taking advantage of the opportunity for change that relocation causes. After the plan is made, the house can be placed on the housing market and the plan can be provided to those who are interested in buying the house. These steps should become a standard operating procedure for the municipality and real estate agents. The second recommendation is crucial in order to successfully take advantage of the opportunity for change. Without mitigating the negative effect of relocation, i.e., the increase in sensitivity for construction time, relocation will not be the window of opportunity for change to which is commonly referred to and with that will not increase the adoption rate of substitute RHS.

7.4 Conclusion

In this section, the model results have been translated into three sets of policy recommendations. These recommendations are directed to the municipality of Delft and aim to increase the adoption rate of substitute RHS. The current adoption rate is low and is likely to be not increasing without additional measures. By means of scrutinising the decision-making process of the Delft heat transition, the policies to which recommendations are formulated have been found. The first set of recommendations asks the municipality to acknowledge and prioritise the primary point of concern of homeowners: affordability. The next set of recommendations call the municipality to further focus only on the next most important attribute for homeowners in the stakeholder part of the district analyses and to pay little attention to relatively irrelevant attributes. The last set of recommendations is about how the municipality of Delft can successfully take advantage of the window of opportunity to change the RHS of a house that relocation causes.

8 Conclusion, discussion, and recommendations for future research

The overall conclusion of this study is provided in section 8.1. A discussion of this study and the resulting limitations are discussed in section 8.2. Finally, section 8.3 provides recommendations for future research.

8.1 Conclusion

The national Climate Agreement states the goal to have completely natural gas-free dwellings before 2050. Municipalities are responsible for the organisation and execution of this so-called heat transition. The present study has focussed on the municipality of Delft in order to maximise the societal contribution of the results and due to practical reasons. Moreover, the focus lied on homeowners and not on tenants or landlords. Homeowners must choose a substitute RHS for their current natural gas fired central heating boiler in the coming few decades. Although the municipality is involving its citizens heavily in the formulation processes of heat transition policies, the present study argued that a variety of insights cannot be obtained via these processes: trade-offs between substitute RHS attributes, variety in trade-offs, and the influence of relocation. Acquiring this information was useful because the insights have been used to formulate policy recommendations which can help to increase the adoption rate of substitute RHS. The current adoption rate is low (6.8%) and is likely to be not increasing without additional measures. Given all of this, the main research question of this study was as follows:

How do different classes of Delft homeowners make trade-offs between attributes of substitute residential heating systems and how do these trade-offs change due to relocation?

This main research question is answered by means of its five sub-questions. Each of these will be answered separately, apart from the second and third one. These will be answered combined.

1. *Which factors might influence the choice of homeowners of Delft for an RHS?*

This sub-question was answered in section 3 by means of a literature review of RHS choice behaviour studies. The aim of the review was to find attributes and covariates which could be relevant for this study. Given that a choice experiment was conducted, the economic theory of utility maximisation was inherently central in this research. Within the boundaries of the economic viewpoint, a two-sided psychological viewpoint on choice behaviour was added. This has resulted in three attribute categories: economic, theory of planned behaviour (subjective norm), and the hassle factor. The definition of the hassle factor by De Vries et al. (2020) was extended to hassle experienced during the construction work of a substitute RHS (construction hassle) and during the operation of a substitute RHS (operational hassle). The categorisation helped to ensure that a wide variety of relevant attributes was selected for this study (i.e., not only cost attributes) and allowed to reflect on the importance of the underlying theories to homeowners. With the help of experts, a final selection of relevant attributes was made: investment costs (economic), operational costs (economic), popularity in the neighbourhood (theory of planned behaviour), required inside space (operational hassle), and construction time (construction hassle). Furthermore, the substitute RHS itself was also added as an attribute, which allowed to check the extent to which homeowners prefer a particular RHS.

A similar approach was used for finding potentially relevant covariates. Covariates are variables which can explain taste heterogeneity among homeowners of Delft. Three covariate categories were created: socio-demographic, dwelling, and attitudes. Again, with the help of experts, the covariates of this study were selected. The selected socio-demographic covariates were: gender, age, education, household income, household composition, and household size. The dwelling covariates were: house type, construction year, living area, dwelling location, energy label, current RHS, and monumental status. Finally, community feeling and the influence of others in one's decision are the two selected attitudes.

2. *How do homeowners of Delft make trade-offs between attributes of substitute RHS?*
3. *Which homogeneous classes of Delft homeowners can be identified and what are the characteristics of these classes?*

These two sub-questions were answered with the context dependent latent class discrete choice model of section 6.3. This model has shown that Delft homeowners can be separated into two homogeneous classes, which are characterised by the household income level, dwelling energy label, and whether the house is (partially) heated by a gas heater. This means that socio-demographic and dwelling covariates are relevant covariate categories and that attitudes is not such a category. The largest class (79%) is characterised by a broad range of homeowners, but most likely consists of homeowners with a relatively high income, poor energy label, and without a gas heater. Homeowners in this class strongly base their choice on economic attributes (investment costs and operational costs) and to lesser extent also on required inside space (operational hassle). Popularity in the neighbourhood (i.e., the operationalisation of subjective norms from the TPB) and construction time (construction hassle) are relatively unimportant considerations for this class. Low income households living in relatively well insulated dwellings with possibly a gas heater are more likely to belong to the second class. Homeowners in this class base their choice on a wider variety of attributes, albeit that they are also mostly (although less than class 1) influenced by economic attributes. In contrast to the first class, this class is more influenced by the substitute RHS (preference for all-electric and hybrid heat pumps) itself and popularity in the neighbourhood. Both hassle types are of little importance to homeowners in this class.

It must be noted, however, that the sample is biased which might cause the effects of investment costs, operational costs, and required inside space to be underestimated in the second class. As a result, it is possible that the trade-offs of homeowners in this class are more comparable to that of class 1 if a more representative sample is acquired.

4. *What is the effect of relocation on the trade-offs that homeowners of Delft make?*

The effect of relocation has been examined by adding the context levels (non-relocation and relocation) as parameters to the latent class discrete choice model. Relocation has, as hypothesised, a positive effect on the sensitivity to investment costs. However, the change in relative importance of investment costs due to relocation is largest in class 2. The same difference between the reaction of relocation is found with respect to the sensitivity to construction time (construction hassle). However, the sensitivity to construction time increases as a consequence of relocation, which was not expected. In both classes, homeowners are only significantly influenced by construction time when they are moving to a new house. Given the above, class 1 consists of cost conscious homeowners and class 2 is characterised by relocation sensitive homeowners. The finding that relocation increases the sensitivity to construction time is contrary to common belief and exemplifies the necessity and scientific contribution of including relocation as a context in the RHS choice behaviour research field.

5. *How is the decision-making process of the Delft heat transition structured and how can it be improved given the obtained context dependent class specific trade-off information?*

The analysis of the Delft heat transition decision-making process served two goals: finding out to which policies the recommendations can be targeted and to check the extent to which the municipality is already taking into account the various substitute RHS attributes. In short, the policy recommendations are directed at the concept transition vision for heat and the stakeholder part of the district analyses of the to be made implementation plans. Furthermore, the analysis showed that municipal subsidies and loans are insufficient for homeowners and that the municipality is not centralising cost attributes. In addition, two crucial actor categories were found: citizens organisations (Platform Energietransitie Delft and neighbourhood associations) and the advisors of Energieloket Delft and 015 Duurzaam. Based on the results of the context dependent latent class discrete choice model and the results of the decision-making process analysis, various policy recommendations were made in order to increase the adoption rate of substitute RHS.

The first set of recommendations is based on the result that the economic attribute category (investment costs and operational costs) is most important to both latent classes. Firstly, the municipality of Delft should encourage the national government to solve the affordability issue soon.

It can do this via four channels: the Association of Netherlands Municipalities, the G40 city network, the Metropolitan Region Rotterdam The Hague, and via the inter-government layer lobby connections between municipal aldermen and national ministers of the same political party. Secondly, the municipality should inform its homeowners via the concept version of the transition vision about five points. The first point is that the municipality acknowledges that the affordability issue is the primary problem and that it will prioritise this issue from now on. Next, the national government and not the municipality is the responsible actor for solving the cost issue. Subsequently, citizens should be informed about how the municipality is trying to influence the national government and what the results are of these attempts. Moreover, the municipality should guarantee homeowners that no changes will be made to their houses before the cost issue is addressed, but that it is necessary to parallelly investigate other aspects (e.g., geographical possibilities) of the heat transition in order to be ready when the cost issue is solved. The fifth point is that the municipality should provide the perspective to homeowners that the affordability issue will most likely be solved in time and during the formulation process of the implementation plans

The second recommendation set is based on the results of the other attributes. The primary recommendation based on the class 1 sensitivity for required inside space is that the municipality uses Energieloket Delft and 015 Duurzaam to mitigate the concerns of homeowners about the inside space requirements of substitute RHS. In order to make this work, the municipality should also ensure that both organisations have ample advisors available and that the already existing generic construction plans on how to make different types of houses natural gas-free are used. This will increase the efficiency of the advisors from Energieloket Delft and 015 Duurzaam. With respect to the class 2 sensitivity for popularity in the neighbourhood, the municipality should have citizen organisations (Platform Energietransitie Delft and neighbourhood associations) to gather and spread information about the popularity in the neighbourhood. Moreover, assuming that class 2 homeowners live in neighbourhoods with a high housing density, the municipality should focus the conversations with these homeowners on the attributes of RHS and not on the substitute RHS itself. This is needed because class 2 homeowners prefer heat pumps (either all-electric or hybrid), while the transition vision states that neighbourhoods with a high housing density should be equipped with district heating. The third and final recommendation of this set is that the municipality should allocate less attention to relatively irrelevant attributes in the stakeholder analysis of the district analyses. So, in a non-relocation context, construction time should receive little attention. Furthermore, required inside space should play a small role in the analyses of low income homeowners living in relatively well insulated dwellings. Moreover, popularity in the neighbourhood should receive little attention in case of a neighbourhood with relatively many high income households living in poorly insulated houses. Naturally, the municipality should regularly check that the attributes stay relatively irrelevant in the future.

The relocation results are the basis for the third and final set of recommendations. The primary recommendation is that the municipality should start a partnership with all real estate offices, starting with the largest ones. Such a partnership enables the municipality to provide homeowners who are interested in buying a house with information about changing to a natural gas-free RHS before the first viewing. In this way, homeowners can account for the extra required construction time and investment costs for a substitute RHS in their bid. The second recommendation concerns the timing and method for acquiring the to be provided information. The municipality and real estate agent should have an advisor from Energieloket Delft or 015 Duurzaam to formulate a plan in which is stated what the best substitute RHS is for that house, including an overview of the required investment costs and construction time. The advisor should consider increasing the investment costs in order to decrease the required construction time. The earlier discussed generic plans help to ensure that this is feasible in practice and that no delay is caused. After the plan is made, the house can be placed on the housing market and the plan can be provided to those who are interested in buying a house.

8.2 Discussion and limitations of this study

In this section, the three main limitations resulting from the selected scope and research methods are discussed.

8.2.1 Selected time frame and resulting hypothetical bias

The time frame of interest of this study was set to 2030-2050, because the majority of houses will be made natural gas-free in this period of time. As a consequence, homeowners were now asked what they would do 10 years or more from now. Bases on feedback from respondents, this was considered to be hard. Respondents found the subject of the heat transition in combination with the context dependent choice experiment also hard. Therefore, the main limitation of the study is the hypothetical bias and thus the validity of the results. To reiterate, choice experiments based on stated preference data are inherently susceptible to hypothetical bias, but the bias is increased in this study due to the future time frame and the combination of the subject and the employed method. As a result, homeowner choices could be different in real-life, which causes the attribute parameter estimates to be different in reality. Furthermore, even if the hypothetical bias is small or absent, the present study links current socio-demographic and dwelling characteristics and attitudes to future choices. It is likely that these characteristics and attitudes change in the coming few decades. Depending on the size of change, this could cause the covariate parameters to be different.

8.2.2 Missing link between alternatives and respondent’s house

The stated preference survey presented the same alternatives to every respondent, regardless of the dwelling characteristics of the respondent’s house. Take for example a typical house in the city centre of Delft. Such dwellings lie on narrow canals and are often poorly insulated and subjected to protected city view. The required investment to change to a substitute RHS will be much higher for such dwellings than for a fairly well-insulated apartment. As a consequence, some of the presented alternatives (e.g., with investment costs of €5,000) are not realistic for city centre dwellings. This was also the primary reason for neighbourhood association Binnenstad Noord to not participate in this study. By making the alternatives more realistic for a particular neighbourhood or house type, more realistic trade-off data can be obtained. For example, it is likely that people are more sensitive to investment costs if the investment costs range in the various alternatives is relatively high to begin with.

8.2.3 Focus on Delft and the generalisability

The present study has focussed on the municipality of Delft in order to maximise the societal contribution of this study and due to practical reasons. This raises the following question: To what extent can the results be generalised? Although this study did not investigate whether certain characteristics of Delft limit the generalisability of the results, the significant covariates (energy label, current RHS gas heater, and household income) are not unique for Delft. This hints that the results are generalisable to other Dutch cities as well. Other cities often also have a mix of both well insulated as well as poorly insulated dwellings and a wide range in household income level. However, it is likely that the results are not generalisable to villages and rural areas. Villages and rural areas, for example, tend to be homogeneous in terms of the insulation level and household income, e.g., you either have a wealthy village or a poor village. Moreover, the relevant mix of substitute RHS is different in villages and rural areas compared to that of cities because district heating is not an option in villages and rural areas. This makes the trade-offs of homeowners in this study between heat pumps and district heating irrelevant.

8.3 Recommendations for future research

The recommendations for future research are meant to either improve the validity of this study or to extend this study.

8.3.1 Recommendations for improving the validity of this study

It is recommended to perform this study again every five years with a representative sample of Delft homeowners. By doing this study again, four aspects are improved which all contribute to more valid results.

Firstly, the risk of hypothetical bias is reduced as the moment between stating a choice and actually choosing is shortened. As mentioned in section 8.2, both the parameter estimates for the attributes as well as for the covariates could be different. Secondly, the relevant attribute levels are better known in the future because more will be known about technological advances of substitute RHS (reduction of costs, inside space requirements, etc.) and about the measures from the national government to solve the affordability issue. Thirdly, by conducting the context dependent choice experiment again, it can be determined whether the increased sensitivity for construction time is a temporary effect (e.g., due to the overheated housing market) or not. Finally, it allows to check whether the irrelevant attributes of this study are also irrelevant in the future. It could be, for example, that homeowners will also be significantly influenced by construction time in a non-relocation context whenever the cost issue is solved. When the choice experiment is performed again, it has to be ensured that a representative sample of Delft homeowners is used. This enables the researcher to verify whether taste heterogeneity is indeed present in the population or not. As mentioned in section 6.3.5, it could be that the effects of investment costs, operational costs, and required inside space are underestimated in class 2 and that these effects are similar to class 1 with a representative sample.

The second recommendation on how to improve this study is to specify the choice experiment for smaller groups of homeowners, for example for those of particular house types or in a particular neighbourhood. By making the population smaller, a more realistic choice experiment can be presented to the respondents that allows for nuances such as that the investment costs in city centre houses are higher than in apartments in the West of Delft. As a result, the found sensitivity for investment costs could vary considerably between these two neighbourhoods. The ideal moment to conduct this specified choice experiment is during the stakeholder part of the district analysis of the implementation plan of a neighbourhood.

8.3.2 Recommendations for extending this study

The present study has shown that a life event, relocation in this case, provides a window of opportunity to change the substitute RHS of a house and with that increase the adoption rate of natural gas-free RHS. Since life events have not been included yet in RHS choice behaviour studies, it is recommended that future studies investigate which other life events influence the choice behaviour of homeowners in such a way that policy-makers can use it to increase the adoption rate of substitute RHS. Examples of possible relevant life events are work related changes, marriage, parenthood, and retirement.

Furthermore, a choice experiment based on revealed preference data should be conducted. This is currently not possible due to the low adoption rate but will be possible later in the heat transition. Revealed preference data is based on actual choices (no hypothetical bias), which increases the validity of the estimated parameters.

Another way to extend this study is to centralise the psychological viewpoint and to analyse RHS choice behaviour by means of structural equation modelling. The present study centralised the economic viewpoint on RHS choice behaviour by conducting a choice experiment, which was only partially capable of including the theory of planned behaviour (only the subjective norm). The influence of the entire theory of planned behaviour (including attitudes and perceived behaviour control) on RHS choices can be investigated with a structural equation model.

Moreover, as mentioned in section 3.4.1, noise pollution is not included in this study due to its ambiguity. Yet, it is likely to be an important consideration in the case of all-electric heat pumps. Therefore, it is recommended to operationalise noise pollution as perceived noise pollution. In this way, noise is treated as a complex variable and can be included in the choice experiment. To do this, a rating experiment should be conducted apart from the choice experiment in which noise is the dependent variable.

Finally, it is recommended to conduct the choice experiment in cities that are substantially smaller than Delft (e.g., less than 50,000 inhabitants) and in rural areas. This allows to check whether the trade-offs observed for Delft homeowners can also be generalised to these areas or not. If different trade-offs are made, different cluster specific policy recommendations will be needed in order to increase the adoption rate of substitute RHS.

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Appendix A: attribute level selection investment and operational costs

This appendix delineates how the attribute levels of the attributes investment and operational costs are selected. The total investment costs depend on a variety of cost items, such as appliance, insulation, installation, and taxes (such as VAT). Operational costs consist of variable energy costs, fixed delivery costs, taxes, maintenance, and sometimes rent. The exact values of these cost items can differ considerably depending on the substitute RHS, the current insulation level of a dwelling, dwelling type, temperature setting, and dwelling size. The present study focusses on the entire municipality of Delft. Therefore, the three attribute levels have to be applicable to a wide variety of situations and for all three considered substitute RHS. The applicable situations for all attribute levels are illustrated below. Numerous sources have been used since the cost estimates vary considerably between studies. This is the result of, for example, underlying assumptions regarding the price developments of appliance and heat source costs.

Investment costs

Attribute level: €5,000

This level refers to the investments required for a green gas RHS (e.g., a hybrid heat pump) in already relatively well insulated and/ or small dwellings (Hers et al., 2018; Berenschot, 2018; CE Delft, n.d.a). If one assumes that additional subsidies or tax deduction options will be made available (worth a few thousands of euros), this level is, according to Berenschot (2018), also applicable to high temperature (HT) district heating in both poorly and well insulated dwellings of all types (apartment, terraced, corner, semi-detached, detached, etc.). From the findings of Tigchelaar et al. (2019) and CE Delft (n.d.b), it also becomes clear that this level is applicable for HT district heating. This level is only relevant for low temperature (LT) district heating in the case of a small well insulated dwelling (CE Delft, n.d.c). A small all-electric heat pump also requires an investment of about €5,000 if no additional insulation is required and additional subsidies or tax deduction options will be made available (CE Delft, n.d.d; CE Delft, n.d.e).

Attribute level: €27,500

This level applies to a homeowner who decides to switch to a hybrid heat pump or HT district heating and to also improve the insulation level voluntarily with a few energy labels. Berenschot (2018) calculated that an investment of about €27,500 is needed for LT district heating in poorly insulated corner or semi-detached dwellings. An all-electric heat pump in the same dwelling types, yet with a better energy label, also requires an investment of around €27,500 (Hers et al., 2018; Arnoldussen et al., 2021).

Attribute level: €50,000

Similar to the previous level, this level can refer to a hybrid heat pump or HT district heating, but in this case the homeowners could be living in a large poorly insulated dwelling which he/ she decides to insulate with numerous energy labels improvement as a consequence. The required investments of an all-electric heat pump for an average dwelling in combination with insulation to energy label A are also around €50,000 (Arnoldussen et al., 2021; Tigchelaar et al., 2019).

In theory, the investment costs could exceed €50,000 and could be as high as €100,000. However, this level is considered to be too exceptional to include in the choice experiment. The selected range of investment costs is applicable to almost all dwellings in Delft (CE Delft, personal communication, February 22, 2021).

Operational costs

Attribute level: €500

If one assumes that the energy cost of green gas (either hydrogen or biogas) will be subsidised (by a few hundred euros per year) in the time frame of interest of this study, hybrid heat pumps cost a little over €500 per year in apartments (Berenschot, 2018; CE Delft, n.d.a). District heating is generally speaking more expensive than €500 per year. This number will only be applicable for homeowners who are exceptionally cost conscious. When considering all-electric heat pumps, the level of €500 applies for a wide variety of dwellings in terms of their type (thus size) and current insulation level (Van Polen, 2021; Berenschot, 2018). All-electric heat pumps bring high insulation standards, which result in low yearly costs.

Attribute level: €1,500

Assuming that green gas will cost in the future as much as natural gas costs now, Berenschot (2018) found that this level is realistic for terraced, corner, semi-detached and detached houses with both low and high insulation levels. According to Schepers et al. (2018) and Berenschot (2018), these operational costs are also appropriate for HT district heating in apartments and terraced dwellings with already good or mediocre energy labels. Berenschot (2018) also showed that this number is applicable for LT district heating in both poor as well as well insulated apartments, terraced, corner, and semi-detached dwellings. Schepers et al. (2018) estimate higher yearly costs for all-electric heat pumps than Berenschot (2018). They argue that a level is €1,500 per year is applicable for a wide variety of dwellings in terms of their type (thus size) and current insulation level.

Attribute level: €2,500

The highest attribute level approximately refers to the operational costs of a hybrid heat pump with green gas in a range of dwelling types (from apartment to detached) with various insulation levels (Schepers, 2018). This is in contrast to what Berenschot (2018) estimated. In the case of HT district heating, it costs about €2,500 to heat up a poorly (energy label F) insulated terraced or corner dwelling. A semi-detached house (label D) or a detached house (label A or D) also costs around €2,500 per year (Berenschot, 2018). Given the current insights and future price development estimates, it is unlikely that all-electric heat pumps will cost around €2,500. Yet, this number could turn out to be realistic in case of large dwellings with a high temperature setting and an unfavourable electricity contract.

The operational costs of HT district heating could be even higher than €2,500 due to the fact that this type of substitute RHS has no to limited insulation requirements. It is unlikely that owners of poorly insulated dwellings choose HT district heating without (partly) insulating their house. Therefore, and given that this only applicable to HT district heating, the present study does not include operational costs over €2,500.

Appendix B: experimental design

The experimental design of the stated preference survey is made in Ngene. The exact syntax for doing this is shown below. With the asterisk (*) in the alts property, it is prevented that Ngene constructs a design with repeating alternatives within a choice set, strict attribute level dominance, and repeating choice tasks (ChoiceMetrics, 2018). Table B.1 shows the coding scheme that is used in Ngene for the levels of the categorical attributes. The effects coding schemes for the categorical attributes which are needed for the utility function are provided in tables B.2, B.3, B.4, and B.5. The dummy coding scheme the relocation context for the utility function is shown in table B.6. The constructed (blocked) choice sets are depicted in table B.7.

```
design
;alts = alt1*, alt2*, alt3*
;rows=12
;eff = (mnl,d)
;alg = mfederov
;block=3, minsum
;model:
U(alt1) = b1.effects[0.0|0.0]*heat[1,2,3]+ b2[-0.001]*investment[5000,27500,50000](4,4,4) + b3[-0.001]*operational[500,1500,2500](4,4,4) + b4.effects[0.001|0.001]*popularity[15,50,85] + b5.effects[-0.001|-0.001]*space[1,2,3] + b6.effects[-0.001|-0.001]*construction[1,2,3]/
U(alt2) = b1*heat+ b2*investment + b3*operational + b4*popularity+ b5*space + b6*construction/
U(alt3) =b1*heat+ b2*investment + b3*operational + b4*popularity+ b5*space + b6*construction
$
```

Table B.1: coding scheme used in Ngene of the categorical attributes.

Attribute level	Coding
All-electric heat pump	Heat 1
District heating	Heat 2
Hybrid heat pump using green gas	Heat 3
15 out of 100 (15%)	Popularity 1
50 out of 100 (50%)	Popularity 2
85 out of 100 (85%)	Popularity 3
As much as a conventional central heating boiler	Space 1
2 times as much as a conventional central heating boiler	Space 2
3 times as much as a conventional central heating boiler	Space 3
1 day	Construction 1
1 month	Construction 2
3 months	Construction 3

Table B.2: effects coding scheme for the categorical attribute 'substitute RHS' needed for the utility function.

Attribute level	SRHS1	SRHS2
All-electric heat pump	1	0
District heating	0	1
Hybrid heat pump using green gas	-1	-1

Table B.3: effects coding scheme for the categorical attribute 'popularity in the neighbourhood' needed for the utility function.

Attribute level	POP1	POP2
15 out of 100 (15%)	1	0
50 out of 100 (50%)	0	1
85 out of 100 (85%)	-1	-1

Table B.4: effects coding scheme for the categorical attribute 'required inside space' needed for the utility function.

Attribute level	SPA1	SPA2
As much as a conventional central heating boiler	1	0
2 times as much as a conventional central heating boiler	0	1
3 times as much as a conventional central heating boiler	-1	-1

Table B.5: effects coding scheme for the categorical attribute 'construction time' needed for the utility function.

Attribute level	CON1	CON2
1 day	1	0
1 month	0	1
3 months	-1	-1

Table B.6: dummy coding scheme for the context 'relocation' needed for the utility function.

Context level	REL
No relocation	0
Relocation	1

Table B.7: constructed choice sets by Ngene.

Choice set	alt1. heat	alt1. investment	alt1. operational	alt1. popularity	alt1. space	alt1. construction	alt2. heat	alt2. investment	alt2. operational	alt2. popularity	alt2. space	alt2. construction	alt3. heat	alt3. investment	alt3. operational	alt3. popularity	alt3. space	alt3. construction	Block
1	1	5000	1500	50	2	1	3	5000	2500	85	1	3	3	27500	2500	50	3	2	2
2	1	5000	2500	85	3	1	1	27500	2500	85	3	3	3	5000	1500	50	2	2	3
3	1	27500	500	50	3	1	3	5000	500	85	3	2	1	5000	500	15	1	3	2
4	1	5000	1500	50	1	1	1	5000	500	85	2	1	1	50000	2500	15	3	3	1
5	2	27500	2500	15	3	1	3	50000	1500	50	3	3	2	27500	1500	50	1	3	1
6	2	50000	2500	15	2	3	2	5000	2500	50	1	2	2	5000	500	85	3	3	3
7	1	5000	2500	15	2	2	1	50000	1500	50	3	3	1	50000	500	50	1	3	3
8	1	50000	1500	15	3	3	1	27500	2500	15	3	1	1	27500	1500	85	1	2	2
9	1	27500	1500	15	1	2	2	27500	1500	15	1	1	3	50000	500	50	2	2	1
10	2	50000	500	15	1	1	3	50000	500	50	2	1	2	50000	2500	85	2	3	3
11	2	27500	500	85	3	3	1	27500	500	85	3	3	3	5000	1500	85	2	3	1
12	3	50000	500	50	1	2	2	50000	1500	50	3	3	1	27500	2500	15	2	1	2

Appendix C: final stated preference survey

The distributed survey is shown below. Specifically, the third version is shown in which the third block of the constructed choice sets is nested under the non-relocation context and the first block is nested under the relocation context.

Introductie

Beste huiseigenaar,

Deze enquête is onderdeel van mijn afstudeeronderzoek aan de TU Delft. Het onderzoek gaat over de transitie naar woningen die zonder aardgas verwarmd worden en richt zich op huiseigenaren die wonen in het huis dat ze bezitten. Het doel is om het keuzegedrag van huiseigenaren omtrent aardgasvrije warmtetechnieken in kaart te brengen.

Uw deelname aan deze enquête is geheel vrijwillig. Uw antwoorden worden vertrouwelijk en geanonimiseerd opgeslagen en enkel gebruikt voor dit onderzoek. De geanonimiseerde resultaten van dit onderzoek zullen gedeeld worden met de gemeente en indien van toepassing met uw buurt- of belangenvereniging. Het gehele onderzoek komt na de zomer ook online via de TU Delft 'Repository'.

De enquête duurt ongeveer 10 minuten en bestaat uit de volgende vier onderdelen:

1. 8 keuzesituaties
2. Persoonskenmerken
3. Woningkenmerken
4. Houding ten aanzien van verschillende stellingen

Het komt het onderzoek ten goede als u de enquête zo eerlijk mogelijk invult. U kunt de enquête het beste invullen op een computer. U start de enquête door op de blauwe pijl rechtsonderin te klikken.

Neem gerust contact met mij op als u nog vragen of opmerkingen heeft.

Alvast hartelijk bedankt voor uw medewerking!

Met vriendelijke groet,

Just Voskuyl
j.q.voskuijl@student.tudelft.nl

Onderdeel 1: uitleg

Let op: lees deze uitleg goed. U kunt later namelijk niet terug naar deze pagina.

In dit onderdeel krijgt u 8 **denkbeeldige** keuzesituaties te zien waarin u kunt kiezen tussen 3 opties. Deze opties verschillen telkens een klein beetje van elkaar op de volgende kenmerken: '*warmtetechniek*', '*investeringskosten*', '*jaarlijkse kosten*', '*populariteit in de wijk*', '*benodigde binnenruimte*', '*verbouwingstijd*'. U zal gevraagd worden om bij elke keuzesituatie uw voorkeur aan te geven. **Als u al van het aardgas af bent**, stelt u zich bij het beantwoorden van de keuzesituaties dan voor dat u nog woont in een huis met een CV-ketel op aardgas.

De omstandigheden waarin u de keuze maakt verschillen per keuzesituatie. In de eerste 4 keuzesituaties moet u zich voorstellen dat u in uw huidige huis een nieuwe warmtetechniek gaat installeren. In de laatste 4 keuzesituaties moet u zich voorstellen dat u gaat verhuizen en de CV-ketel in het nieuwe huis gaat vervangen door een nieuwe warmtetechniek. **In alle keuzesituaties moet u ervan uit gaan dat alle nieuwe warmtetechnieken duurzaam zijn**.

Hieronder staat een uitleg van de verschillende kenmerken:

Kenmerk	**Uitleg**
Warmtetechniek	Dit is de duurzame warmtetechniek waarvoor de onderstaande kenmerken gelden. Er zijn drie mogelijke duurzame warmtetechnieken in de keuzesituaties: volledig elektrische warmtepomp, (hogetemperatuur) warmtenet en een hybride warmtepomp op groen gas.
Investeringskosten	Dit zijn alle kosten die u **zelf** moet maken voordat de nieuwe warmtetechniek functioneel is, bijvoorbeeld kosten voor aanschaf, isolatie en installatie. De kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken. Eventuele subsidies en fiscale maatregelen zijn niet meegenomen in deze kosten.
Jaarlijkse kosten	Deze kosten moet u jaarlijks maken en bevatten: energiekosten, belastingen en eventuele huurkosten. Ook deze kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken.
Populariteit in de wijk	Dit is het aantal mensen in uw wijk dat de warmtetechniek (het eerste kenmerk) **al heeft geïnstalleerd**. Dit kan bijvoorbeeld 15 op de 100 mensen zijn (15%).
Benodigde binnenruimte	De ruimte die binnen nodig is voor de nieuwe warmtetechniek. **Dit wordt gemeten ten opzichte van de ruimte die een CV-ketel inneemt.** De nieuwe warmtetechniek kan bijvoorbeeld evenveel ruimte innemen als een CV-ketel of drie keer zoveel.
Verbouwingstijd	De totale tijd die benodigd is voor de isolatie van uw huis en de installatie van de warmtetechniek.

Onderdeel 1: keuzesituaties zonder verhuizing

Onderaan deze pagina staat nogmaals de uitleg van de verschillende kenmerken.

Vraag 1: stelt u zich voor dat u **blijft wonen** waar u nu woont en besloten is om over te stappen naar een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Volledig elektrische warmtepomp	Volledig elektrische warmtepomp	Hybride warmtepomp op groen gas
Investeringskosten	€ 5.000	€ 27.500	€ 5.000
Jaarlijkse kosten	€ 2.500	€ 2.500	€ 1.500
Populariteit in de wijk	85 op de 100 mensen (85%)	85 op de 100 mensen (85%)	50 op de 100 mensen (50%)
Benodigde binnenruimte	3 keer zoveel als een CV	3 keer zoveel als een CV	2 keer zoveel als een CV
Verbouwingstijd	1 dag	3 maanden	1 maand

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 2: stelt u zich voor dat u **blijft wonen** waar u nu woont en besloten is om over te stappen naar een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Warmtenet	Warmtenet	Warmtenet
Investeringskosten	€ 50.000	€ 5.000	€ 5.000
Jaarlijkse kosten	€ 2.500	€ 2.500	€ 500
Populariteit in de wijk	15 op de 100 mensen (15%)	50 op de 100 mensen (50%)	85 op de 100 mensen (85%)
Benodigde binnenruimte	2 keer zoveel als een CV	Evenveel als een CV	3 keer zoveel als een CV
Verbouwingstijd	3 maanden	1 maand	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 3: stelt u zich voor dat u **blijft wonen** waar u nu woont en besloten is om over te stappen naar een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Volledig elektrische warmtepomp	Volledig elektrische warmtepomp	Volledig elektrische warmtepomp
Investeringskosten	€ 5.000	€ 50.000	€ 50.000
Jaarlijkse kosten	€ 2.500	€ 1.500	€ 500
Populariteit in de wijk	15 op de 100 mensen (15%)	50 op de 100 mensen (50%)	50 op de 100 mensen (50%)
Benodigde binnenruimte	2 keer zoveel als een CV	3 keer zoveel als een CV	Evenveel als een CV
Verbouwingstijd	1 maand	3 maanden	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 4: stelt u zich voor dat u **blijft wonen** waar u nu woont en besloten is om over te stappen naar een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Warmtenet	Hybride warmtepomp op groen gas	Warmtenet
Investeringskosten	€ 50.000	€ 50.000	€ 50.000
Jaarlijkse kosten	€ 500	€ 500	€ 2.500
Populariteit in de wijk	15 op de 100 mensen (15%)	50 op de 100 mensen (50%)	85 op de 100 mensen (85%)
Benodigde binnenruimte	Evenveel als een CV	2 keer zoveel als een CV	2 keer zoveel als een CV
Verbouwingstijd	1 dag	1 dag	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Kenmerk	**Uitleg**
Warmtetechniek	Dit is de duurzame warmtetechniek waarvoor de onderstaande kenmerken gelden. Er zijn drie mogelijke duurzame warmtetechnieken in de keuzesituaties: volledig elektrische warmtepomp, (hogetemperatuur) warmtenet en een hybride warmtepomp op groen gas.
Investeringskosten	Dit zijn alle kosten die u **zelf** moet maken voordat de nieuwe warmtetechniek functioneel is, bijvoorbeeld kosten voor aanschaf, isolatie en installatie. De kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken. Eventuele subsidies en fiscale maatregelen zijn niet meegenomen in deze kosten.
Jaarlijkse kosten	Deze kosten moet u jaarlijks maken en bevatten: energiekosten, belastingen en eventuele huurkosten. Ook deze kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken.
Populariteit in de wijk	Dit is het aantal mensen in uw wijk dat de warmtetechniek (het eerste kenmerk) **al heeft geïnstalleerd**. Dit kan bijvoorbeeld 15 op de 100 mensen zijn (15%).
Benodigde binnenruimte	De ruimte die binnen nodig is voor de nieuwe warmtetechniek. **Dit wordt gemeten ten opzichte van de ruimte die een CV-ketel inneemt.** De nieuwe warmtetechniek kan bijvoorbeeld evenveel ruimte innemen als een CV-ketel of drie keer zoveel.
Verbouwingstijd	De totale tijd die benodigd is voor de isolatie van uw huis en de installatie van de warmtetechniek.

Onderdeel 1: keuzesituaties met verhuizing

Onderaan deze pagina staat nogmaals de uitleg van de verschillende kenmerken.

Vraag 5: stelt u zich voor dat u gaat **verhuizen** en besloten is om de CV-ketel in dat huis te gaan vervangen met een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Volledig elektrische warmtepomp	Volledig elektrische warmtepomp	Volledig elektrische warmtepomp
Investeringskosten	€ 5.000	€ 5.000	€ 50.000
Jaarlijkse kosten	€ 1.500	€ 500	€ 2.500
Populariteit in de wijk	50 op de 100 mensen (50%)	85 op de 100 mensen (85%)	15 op de 100 mensen (15%)
Benodigde binnenruimte	Evenveel als een CV	2 keer zoveel als een CV	3 keer zoveel als een CV
Verbouwingstijd	1 dag	1 dag	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 6: stelt u zich voor dat u gaat **verhuizen** en besloten is om de CV-ketel in dat huis te gaan vervangen met een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Warmtenet	Hybride warmtepomp op groen gas	Warmtenet
Investeringskosten	€ 27.500	€ 50.000	€ 27.500
Jaarlijkse kosten	€ 2.500	€ 1.500	€ 1.500
Populariteit in de wijk	15 op de 100 mensen (15%)	50 op de 100 mensen (50%)	50 op de 100 mensen (50%)
Benodigde binnenruimte	3 keer zoveel als een CV	3 keer zoveel als een CV	Evenveel als een CV
Verbouwingstijd	1 dag	3 maanden	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 7: stelt u zich voor dat u gaat **verhuizen** en besloten is om de CV-ketel in dat huis te gaan vervangen met een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Volledig elektrische warmtepomp	Warmtenet	Hybride warmtepomp op groen gas
Investeringskosten	€ 27.500	€ 27.500	€ 50.000
Jaarlijkse kosten	€ 1.500	€ 1.500	€ 500
Populariteit in de wijk	15 op de 100 mensen (15%)	15 op de 100 mensen (15%)	50 op de 100 mensen (50%)
Benodigde binnenruimte	Evenveel als een CV	Evenveel als een CV	2 keer zoveel als een CV
Verbouwingstijd	1 maand	1 dag	1 maand

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Vraag 8: stelt u zich voor dat u gaat **verhuizen** en besloten is om de CV-ketel in dat huis te gaan vervangen met een van de onderstaande duurzame warmtetechnieken.

	Optie A	Optie B	Optie C
Warmtetechniek	Warmtenet	Volledig elektrische warmtepomp	Hybride warmtepomp op groen gas
Investeringskosten	€ 27.500	€ 27.500	€ 5.000
Jaarlijkse kosten	€ 500	€ 500	€ 1.500
Populariteit in de wijk	85 op de 100 mensen (85%)	85 op de 100 mensen (85%)	85 op de 100 mensen (85%)
Benodigde binnenruimte	3 keer zoveel als een CV	3 keer zoveel als een CV	2 keer zoveel als een CV
Verbouwingstijd	3 maanden	3 maanden	3 maanden

Welke optie heeft uw voorkeur?

Optie A

Optie B

Optie C

Kenmerk	Uitleg
Warmtetechniek	Dit is de duurzame warmtetechniek waarvoor de onderstaande kenmerken gelden. Er zijn drie mogelijke duurzame warmtetechnieken in de keuzesituaties: volledig elektrische warmtepomp, (hogetemperatuur) warmtenet en een hybride warmtepomp op groen gas.
Investeringskosten	Dit zijn alle kosten die u **zelf** moet maken voordat de nieuwe warmtetechniek functioneel is, bijvoorbeeld kosten voor aanschaf, isolatie en installatie. De kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken. Eventuele subsidies en fiscale maatregelen zijn niet meegenomen in deze kosten.
Jaarlijkse kosten	Deze kosten moet u jaarlijks maken en bevatten: energiekosten, belastingen en eventuele huurkosten. Ook deze kosten zijn gebaseerd op gemiddelden uit verschillende onderzoeken.
Populariteit in de wijk	Dit is het aantal mensen in uw wijk dat de warmtetechniek (het eerste kenmerk) **al heeft geïnstalleerd**. Dit kan bijvoorbeeld 15 op de 100 mensen zijn (15%).
Benodigde binnenruimte	De ruimte die binnen nodig is voor de nieuwe warmtetechniek. **Dit wordt gemeten ten opzichte van de ruimte die een CV-ketel inneemt.** De nieuwe warmtechniek kan bijvoorbeeld evenveel ruimte innemen als een CV-ketel of drie keer zoveel.
Verbouwingstijd	De totale tijd die benodigd is voor de isolatie van uw huis en de installatie van de warmtetechniek.

Onderdeel 2: persoonskenmerken

Vraag 9: wat is uw geslacht?

Vrouw

Man

Zeg ik liever niet

Vraag 10: in welk jaar bent u geboren (bijvoorbeeld 1980)? Als u dit liever niet zegt, vul dan niets in.

Vraag 11: wat is uw opleidingsniveau? Dit is de hoogst afgeronde opleiding waarvan u een diploma heeft.

- Basisonderwijs
- VMBO-b, VMBO-k, MBO-1
- VMBO-g, VMBO-t (MAVO), HAVO-, VWO-onderbouw
- MBO-2, MBO-3
- MBO-4
- HAVO, VWO
- HBO-, WO-bachelor
- WO-master, doctor
- Zeg ik liever niet

Vraag 12: tot welke categorie behoort het jaarlijks bruto inkomen van uw **huishouden**? Dit is het loon zonder aftrek van belastingen en pensioenpremies.

- Minder dan €20.000
- €20.000-€39.999
- €40.000-€59.999
- €60.000-€79.999
- €80.000-€99.999
- €100.000-€149.999
- €150.000-€199.999
- €200.000 of meer
- Zeg ik liever niet

Vraag 13: wat is de samenstelling van uw huishouden?

- Alleenstaand
- Eenoudergezin met kinderen
- Gehuwd/ samenwonend zonder kinderen
- Gehuwd/ samenwonend met kinderen

Vraag 14: uit hoeveel personen bestaat uw huishouden (inclusief uzelf)?

- 1 persoon
- 2 personen
- 3 personen
- 4 personen
- 5 personen of meer

Onderdeel 3: woningkenmerken

Vraag 15: in wat voor soort huis woont u?

- Flat/ appartement/ galerijwoning/ maisonnette/ portiekwoning/ bovenwoning
- Hoekwoning
- Tussenwoning
- Twee-onder-een-kap
- Vrijstaand

Vraag 16: wat is het bouwjaar van uw huis?

- Voor 1850
- 1850-1904
- 1905-1924
- 1925-1944
- 1945-1964
- 1965-1984
- 1985-2005
- 2005-2021
- Weet ik niet

Vraag 17: wat is de woonoppervlakte van uw huis?

- Minder dan 50 vierkante meter (m2)
- 50-74 vierkante meter (m2)
- 75-99 vierkante meter (m2)
- 100-149 vierkante meter (m2)
- 150-249 vierkante meter (m2)
- 250 vierkante meter(m2) of meer
- Weet ik niet

Vraag 18: wat zijn de cijfers van uw postcode (bijvoorbeeld 2611)? Als u dit liever niet zegt, vul dan niks in.

Vraag 19: welk energielabel heeft uw huis?

- A++++
- A+++
- A++
- A+
- A
- B
- C
- D
- E
- F
- G
- Weet ik niet

Vraag 20: op welke manier verwarmt u uw huis momenteel (meerdere antwoorden zijn mogelijk)?

- CV-ketel op aardgas
- Blok- of wijkverwarming/ stadsverwarming/ warmtenet
- Gaskachel
- Houtgestookte verwarmingsapparaten
- Warmtepomp
- Anders, namelijk

Vraag 21: is uw huis een gemeentelijk monument of een rijksmonument?

- Ja
- Nee
- Weet ik niet

Onderdeel 4: houding ten aanzien van verschillende stellingen

Vraag 22: in hoeverre bent u het eens met de onderstaande stellingen?

	Zeer mee oneens	Oneens	Neutraal	Eens	Zeer mee eens
Ik voel me sterk verbonden met de buurt waarin ik woon.	○	○	○	○	○
Ik heb veel goede vrienden in de buurt waarin ik woon.	○	○	○	○	○
Ik beschrijf de buurt waarin ik woon vaak als een fijne plek om te wonen.	○	○	○	○	○

Vraag 23: in hoeverre bent u het eens met de onderstaande stellingen?

	Zeer mee oneens	Oneens	Neutraal	Eens	Zeer mee eens
Ik vind de mening van iemand anders belangrijk als ik een keuze maak.	O	O	O	O	O
Bij het maken van een belangrijke beslissing vraag ik anderen wat ik zou moeten doen.	O	O	O	O	O
Ik vind het belangrijk om te weten wat anderen zouden doen als ze in dezelfde situatie zitten als ik zit.	O	O	O	O	O

Vraag 24: bent u lid van een energiecollectief- of coöperatie (bijvoorbeeld Deelstroom Delft)?

Ja

Nee

Vraag 25: de overheid wil dat er in de toekomst meer woningen van het aardgas worden afgekoppeld. Wist u dat?

Ja

Nee

Vraag 26: in hoeverre bent u het eens met de onderstaande stellingen?

	Zeer mee oneens	Oneens	Redelijk oneens	Neutraal	Redelijk eens	Eens	Zeer mee eens
Ik vind het belangrijk dat alle Nederlandse woningen aardgasvrij worden gemaakt.	O	O	O	O	O	O	O
Ik vind het belangrijk dat Nederland klimaatneutraal wordt.	O	O	O	O	O	O	O

Vraag 27: wilt u dat uw woning van het aardgas wordt gekoppeld?

Ja

Nee

Weet ik niet

Appendix D: factor analysis attitude statements

In this study, various categories of covariates are included to explain the taste heterogeneity among respondents (and thus latent classes). One of these categories corresponds to attitudes of respondents. Specifically, the attitudes community feeling and influence of others in one's decision. Each attitude is measured via three statements and the former attitude is also measured via the question whether people are member of an energy collective. The three statements are all slightly different from each other. In order to be sure that they capture the same underlying attitude, one has to conduct a factor analysis. It is only after such an analysis that one can treat the statements as one attitude. A factor analysis is meant for continuous variables. Energy collective membership is a nominal variable (yes/ no), which is why this variable is not included in the factor analysis. The present study assumes that the utilised five-point Likert scale is continuous and therefore suitable to analyse via a factor analysis.

Data suitability

Before the factor analysis can be conducted, the suitability of the data for such an analysis must be checked. The first measure to do this is the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO). The KMO is the ratio of the squared correlation between the statements and the squared partial correlation between the statements. A higher value for the KMO is preferable, but the bare minimum is 0.5 (Field, 2013). The KMO of this study's data is equal to 0.646, which is acceptable. The second suitability measure is Bartlett's test of sphericity, which statistically tests whether the correlation matrix is an identity matrix (H_0) or not (H_a). Since the goal is to aggregate the results of the individual statements that measure the same underlying attitude, it is undesirable to have an identity matrix. The p-value of this test for the data is <.001, which means that it is highly significant. In conclusion, the data of the six statements is suitable to use for a factor analysis.

Factor extraction technique

In order to extract the factors from the data Principal Axis Factoring (PAF) is used. This is the most commonly used technique in factor analysis and focusses on the variance that is common among variables (i.e., the statements in this case). Therefore, it is suitable to find latent factors, i.e., attitudes (Ngure et al., 2015). Another often used extraction technique is Principal Component Analysis (PCA). Although the goal of this technique is similar, namely reducing the number of dimensions (factors) with the least amount of information loss as possible, there is a fundamental difference. This difference can be best understood by looking at the causality between the factors and variables. In PCA, the variables are combined into one factor (i.e., the component). In PAF, the causality runs the other way around. The underlying factor (the attitude) causes the responses on the various statements. In this study, a factor is extracted when the eigenvalue of the factor is greater than one. This is known as Kaiser's criterion and is most often applied in factor analysis.

Factor rotation method

Factor rotation is used to maximise the loading of a statement on one factor while minimising the load on the other factors. This makes it clearer which statements relate to which factor. There are two commonly used methods: orthogonal and oblique rotation. In the former method, the extracted factors are not correlated due to the fact that the axes remain at an angle of 90 degrees. This method is suitable to use when it is expected that the underlying attitudes are uncorrelated. In oblique rotation, axes can be at a different angle than 90 degrees after rotation which causes the extracted factors to be correlated. This rotation type should be used when it is expected that attitudes are correlated with each other (Field, 2013). Since community feeling and influence of others in one's decision are expected to be uncorrelated, orthogonal rotation is used. Various orthogonal rotation method exist, but for the purpose of this study, varimax is considered to be suitable.

Factor analysis results

Table D.1 presents the rotated factor matrix, which is needed to interpret the results of the factor analysis. The factor analysis is performed in SPSS 25. The goal of the analysis is to arrive at a simple structure in the rotated factor matrix. This structure entails that each statement loads high (>0.5) on one factor and low on all other factors (<0.3). Given Kaiser's criterion, two factors are extracted.

As can been seen in table D.1, the simple structured is reached after one iteration since all community feeling statements load high on factor 1 (>0.61) and low on factor 2 (<0.09). Likewise, the influence of others in one's decision statements load high on factor 2 (>0.5) and low on factor 1 (<0.08). The cumulative percentage of the captured variance of the two factors based on their initial eigenvalue is equal to 62.3%. The rotation sums of squared loading cumulative percentage is 44.2%.

Table D.1: rotated factor matrix of the factor analysis.

Statement	Factor 1 (community feeling)	Factor 2 (influence of others in one's decision)
I feel strongly attached to the neighbourhood I live in.	0.722	0.023
There are many people in my neighbourhood whom I think of as good friends.	0.611	0.088
I often talk about my neighbourhood as being a great place to live.	0.693	-0.006
The opinion of someone else is important when I make a decision.	-0.014	0.716
During important decisions, I ask people around me what to do.	0.039	0.501
I find it important to know what other people would do if they were in the same situation.	0.074	0.704

To test whether the three statements per attitude are internally consistent, Cronbach's alpha is used. Although being debated whether a threshold value can be identified, Field (2013) argues that an alpha >.7 is desirable. Factor 1 has an alpha of 0.706 and factor 2 of 0.673. Since the influence of others in one's decision statements are formulated by the researcher and are meant for explorative purposes, it is argued that the alpha for factor 2 is acceptable.

Aggregating the statements into new variables

The factor analysis shows that the answers to the statements are correctly explained by the underlying attitudes. Therefore, the dimensions can be reduced to two variables. These two variables are called community feeling and influence of others in one's decision and are calculated per respondent by summating the five-point scores on the corresponding set of three statements. These two new variables represent two attitudes which will be used as covariates in the LC DCM.

Appendix E: sample representativeness analysis

In order to check whether the differences between the sample and proxy population are statistically significant, numerous chi-square tests have been carried out. The following characteristics have been analysed: gender (table E.1), age (table E.2), education (table E.3), household income (table E.4), household composition (table E.5), household size (table E.6), house type (table E.7), construction year (table E.8), living area (table E.9), dwelling location (table E.10), energy label (table E.11), current RHS (table E.12), energy transition knowledge (table E.13) and behaviour (table E.14), and the two attitude statements about the national goals of becoming natural gas-free and climate neutral (table E.15 and table E.16).

The chi-square test is suitable in the case of the above characteristics since they are all categorical, i.e., either nominal or ordinal. The two main aspects of the chi-square test are the observed count (O_i) and the expected count (E_i). The former is the number of times that each category of a characteristic is observed in the sample, while the latter is the expected number of times that a category would have been observed if the population distribution were to be followed in the sample. The chi-square value is calculated using equation E.1. The corresponding p-value is calculated via the chi-square distribution with the correct number of degrees of freedom, which is equal to the number of categories – 1. If the p-value of a characteristic is <0.05, the characteristic is not representative for the proxy population (H_a). Likewise, if the p-value is larger than 0.05, the sample can be considered representative for the proxy population considering the particular characteristic (H_0). Furthermore, two conditions have to be met before one can execute a chi-square test. Firstly, the expected count should be 5 or more in at least 80% of the categories of a characteristic (Franke et al., 2012). Secondly, none of the categories should have an expected count of less than one. Answer categories have been merged in the case that one of the conditions was not met.

$$\chi_c^2 = \sum_{i=1}^{j} \frac{(O_i - E_i)^2}{E_i} \qquad \text{(Equation E.1)}$$

The results show that only the characteristic behaviour, i.e., whether people want their house to be disconnected from the natural gas grid, is representative for the proxy population. Be aware that the proxy population for this characteristic is the entire Dutch population. All other characteristics are not representative for the proxy population.

Table E.1: chi-square test for gender (Municipality of Delft, 2021c).

Gender (n=160)	Sample distribution	Proxy Delft population distribution	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Male	78.8%	52.8%	126	84.48	20.4061	
Female	21.3%	47.2%	34	75.52	22.8272	
					χ_c^2	43.2333
					df	1
					p-value	<.001

Table E.2: chi-square test for age (Municipality of Delft, 2021c).

Age (n=150)	Sample distribution	Proxy Delft population distribution	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
0-17 years	0.0%	14.7%	0	22.05	22.0500	
18-26 years	0.7%	22.4%	1	33.60	36.6298	
27-39 years	5.4%	19.1%	8	28.65	14.8839	
40-54 years	25.9%	15.9%	39	23.85	9.62358	
55-64 years	24.0%	11.7%	36	17.55	19.3962	
65-74 years	34.0%	9.6%	51	14.40	93.0250	
75+ years	10.0%	6.5%	15	9.750	2.82692	
					χ_c^2	198.435
					df	6
					p-value	<.001

Table E.3: chi-square test for education (Municipality of Delft, 2018; Statistics Netherlands, 2019).

Education (n=162)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Low	2.4%	20.4%	4	33.05	25.5321	
Middle	6.8%	35.6%	11	57.67	37.7701	
High	90.8%	44.0%	147	71.28	80.4366	
					χ_c^2	143.739
					df	2
					p-value	<.001

Table E.4: chi-square test for household income (Municipality of Delft, 2017; Statistics Netherlands, 2020b).

Household income (n=138)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
0-19%	0.7%	25.7%	1	35.47	33.4942	
20-39%	8.7%	22.8%	12	31.46	12.0407	
40-59%	23.2%	18.6%	32	25.67	1.56203	
60-79%	36.2%	15.6%	50	21.53	37.6558	
80-100%	31.2%	17.2%	43	23.74	15.6346	
					χ_c^2	100.387
					df	4
					p-value	<.001

Table E.5: chi-square test for household composition (Municipality of Delft, 2020b).

Household composition (n=167)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Alone	19.8%	58.7%	33	98.03	43.1380	
Single parent with children	3.6%	6.0%	6	10.02	1.61281	
Living together	46.1%	21.0%	77	35.07	50.1319	
Living together with children	30.5%	14.4%	51	24.05	30.1997	
					χ_c^2	125.082
					df	3
					p-value	<.001

Table E.6: chi-square test for household size (Municipality of Delft, 2020c).

Household size (n=167)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
1 person	19.2%	58.7%	32	98.03	44.4749	
2 persons	48.5%	24.1%	81	40.25	41.2654	
3 persons or more persons	32.4%	17.2%	54	28.72	22.2419	
					χ_c^2	107.982
					df	2
					p-value	<.001

Table E.7: chi-square test for house type (Municipality of Delft, 2019b).

House type (n=167)	Sample distribution	Proxy Delft population distribution	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Flat/ gallery apartment house/ maisonette/ staircase-access flat	20.4%	75.1%	34	125.4	66.6343	
Terraced	73.7%	18.3%	123	30.56	279.604	
Semidetached and detached	6.0%	6.7%	10	11.19	3.42334	
					χ_c^2	349.662
					df	2
					p-value	<.001

Table E.8: chi-square test for construction year (Municipality of Delft, 2020a).

Construction year (n=167)	Sample distribution	Proxy Delft population distribution	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
<1904	19.2%	8.3%	32	13.86	23.7373	
1905-1924	4.2%	6.6%	7	11.02	1.46646	
1925-1944	17.4%	7.5%	29	12.53	21.6490	
1945-1964	1.8%	12.1%	3	20.21	14.6524	
1965-1984	32.9%	35.7%	55	59.62	0.357858	
1985-2004	18.6%	17.3%	31	28.89	0.153954	
2005-2021	6.0%	12.6%	10	21.04	5.79440	
					χ_c^2	67.8113
					df	6
					p-value	<.001

Table E.9: chi-square test for living area (Municipality of Delft, 2020d).

Living area (n=163)	Sample distribution	Proxy Delft population distribution	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
2-49 m^2	0.6%	16.8%	1	27.38	25.4205	
50-74 m^2	3.1%	25.4%	5	41.40	32.0058	
75-99 m^2	11.0%	27.8%	18	45.31	16.4641	
100-149 m^2	47.2%	22.8%	77	37.16	42.7001	
150-249 m^2	32.5%	6.1%	53	9.943	186.453	
250 m^2 or more	5.5%	1.3%	9	2.119	25.4205	
					χ_c^2	325.388
					df	5
					p-value	<.001

Table E.10: chi-square test for dwelling location (AlleCijfers.nl, 2021a; AlleCijfers.nl, 2021b; AlleCijfers.nl, 2021c).

Dwelling location (n=121)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
2611	21.5%	14.4%	26	17.42	4.22106	
2612 and 2616	12.4%	8.5%	15	10.29	2.16152	
2613	9.1%	11.4%	11	13.79	0.565930	
2614	3.3%	10.2%	4	12.34	5.63839	
2622 and 2626	10.7%	6.7%	13	8.107	2.95318	
2623	7.4%	5.4%	9	6.534	0.930694	
2624	22.3%	14.4%	27	17.42	5.26284	
2625	4.1%	13.0%	5	15.73	7.31932	
2627 and 2629	6.6%	2.6%	8	3.146	7.48929	
2628	2.5%	13.4%	3	16.21	10.7691	
					χ_c^2	47.3113
					df	9
					p-value	<.001

Table E.11: chi-square test for energy label (Municipality of Delft, 2019c).

Energy label (n=102)	**Sample distribution**	**Proxy Delft population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Label A	24.5%	13.8%	25	14.08	8.47782	
Label B	19.6%	8.8%	20	8.976	13.5393	
Label C	16.7%	23.9%	17	24.38	2.23295	
Label D	8.8%	27.8%	9	28.36	13.2125	
Label E	7.8%	14.7%	8	14.99	3.26237	
Label F	8.8%	7.2%	9	7.344	0.373412	
Label G	13.7%	3.9%	14	3.978	25.2490	
					χ_c^2	66.3474
					df	6
					p-value	<.001

Table E.12: chi-square test for current RHS (Government of the Netherlands, 2018).

Current RHS (n=165)	**Sample distribution**	**Proxy Delft and Westland population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Natural gas fired central heating boiler	82.4%	79.6%	136	131.3	0.168241	
District heating	3.0%	15.8%	5	26.07	17.0290	
Gas heater	0.6%	3.1%	1	5.115	3.31050	
Wood fired heating and heat pump	3.0%	4.6%	5	7.590	0.883808	
Different	10.9%	1.1%	18	1.815	144.327	
					χ_c^2	165.719
					df	4
					p-value	<.001

Table E.13: chi-square test for knowledge (Citisens, 2020).

Knowledge (n=167)	**Sample distribution**	**Citisens population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Yes	99.4%	96%	166	160.3	0.201238	
No	0.6%	4%	1	6.680	4.82970	
					χ_c^2	5.03094
					df	1
					p-value	0.02

Table E.14: chi-square test for behaviour (Citisens, 2020).

Behaviour (n=167)	**Sample distribution**	**Citisens population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
Yes	40.7%	37%	68	61.79	0.624116	
No	40.1%	44%	67	73.48	0.571453	
I do not know	19.2%	19%	32	31.73	0.00229751	
					χ_c^2	1.19787
					df	2
					p-value	0.55

Table E.15: chi-square test for natural gas-free statement (Citisens, 2020).

Natural gas-free statement (n=167)	**Sample distribution**	**Citisens population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
1	12.6%	14%	21	23.38	0.242275	
2	8.4%	11%	14	18.37	1.03957	
3	12.6%	13%	21	21.71	0.0232197	
4	17.4%	9%	29	15.03	12.9848	
5	21.0%	20%	35	33.40	0.0766567	
6	18.6%	18%	31	30.06	0.0293945	
7	9.6%	14%	16	23.38	2.32953	
					χ_c^2	16.7254
					df	6
					p-value	.01

Table E.16: chi-square test for climate neutral statement (Citisens, 2020).

Climate neutral statement (n=167)	**Sample distribution**	**Citisens population distribution**	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$	
1	1.8%	6%	3	10.02	4.91820	
2	3.6%	5%	6	8.350	0.661377	
3	1.8%	10%	3	16.70	11.2389	
4	7.8%	9%	13	15.03	0.274178	
5	15.6%	21%	26	35.07	2.34573	
6	29.3%	19%	49	31.73	9.39971	
7	40.1%	31%	67	51.77	4.48045	
					χ_c^2	33.3186
					df	6
					p-value	<.001

Appendix F: model estimation process

The results of the context dependent LC DCM are obtained after an iterative model estimation process consisting of four steps. First, a model with all covariates was estimated. Second, insignificant covariates were removed one by one until all remaining covariates were significant. Third, model restrictions were applied. Fourth, single covariates were removed and added again to check whether different combinations of significant covariates are possible. Each of these steps is explained below.

Step 1: 2-class model with all covariates

In this first step, a 2-class model was estimated with all six attributes, two interaction effects for the relocation context (also added as attributes), and all 21 covariates. All covariates are added as active covariates, which means that they can influence classification probabilities and parameter estimates (Vermunt & Magidson, 2006). The following covariates are treated as numeric variables since they represent some ordinal, interval, or ratio variable: age, education, household income, household size, construction year, living area, energy label, community feeling, and influence of others in one's decision. These covariates are nominal: gender, household composition, house type, dwelling location, current RHS central heating boiler, current RHS district heating, current RHS gas heater, current RHS wood fired heating, current RHS heat pump, current RHS infrared heating and/ or electric underfloor heating, monumental status, and energy collective membership.

No model restrictions are applied yet. Similar to the base MNL model, effects coding was used (see section 6.2). The default Latent Gold setting to exclude all missing values is changed into including them all. In order to maximise the chance of obtaining a global optimum instead of a local optimum, the random sets setting is set to 1,000 and the number of iterations per set is increased to 50,000. All other default settings of Latent Gold are adequate and require no further explanation.

Step 2: removing insignificant covariates

The interpretation 21 covariates is impossible which is why the model of step 1 is simplified by removing all covariates which are not statistically significantly different from 0 (i.e., Wald statistic p-value >0.05). In each step, the covariate with the highest p-value (i.e., the lowest Wald statistic) was removed from the model. The insignificant covariates are removed in the following order (the p-value is given in brackets): construction year (0.94), current RHS central heating boiler (0.80), influence of others in one's decision (1.00), current RHS infrared heating and/ or electric underfloor heating (0.89), living area (0.78), energy collective membership (0.86), community feeling (0.80), education (0.68), dwelling location (0.68), monumental status (0.92), current RHS district heating (0.75), household composition (0.59), house type (0.74), household size (0.70), current RHS wood fired heating (0.60), age (0.26), current RHS heat pump (0.22), and current RHS gas heater (0.061). This means that the following covariates are significant in this version of the model: energy label, gender, and household income.

Step 3: model restrictions

In the model version of step 2 with three significant covariates, the Wald(=) statistic of three attributes was insignificant, namely popularity in the neighbourhood, interaction effect investment costs and relocation, and the interaction effect construction time and relocation. Therefore, these effects were set to class independent. In the next iteration, the Wald(=) statistic of construction time also became insignificant. Next, it was checked whether the parameter estimates of popularity in the neighbourhood and required inside space showed a logical order. This was not the case for the latter. The parameter estimate for class 2 for the attribute level as much as a conventional central heating boiler was 0.0121, while that of the next level was 0.2640. It is unrealistic that respondents associate a higher utility for more required inside space. Therefore, the descending order restriction was set to this attribute. In section 6.3.2, several reasons are provided why the initial result for required inside space was obtained and why it is adequate to install a descending order restriction.

Step 4: significant covariate combinations

After having applied the model restrictions, it was checked whether there were different combinations of significant covariates possible. In turned out that there were three combinations possible. It is possible to have different combinations of significant covariates since the covariates can be correlated.

As a consequence, combining two covariates which are significant separately can be both insignificant when they are combined in one model. The BIC, overall R^2, and class specific R^2s of these combinations are provided in table F.1. All measures (except the R^2 of class 1) for the second combination (energy label, current RHS gas heater, and age) are the worst compared to the other two combinations. Therefore, this model is not selected to continue working with. Although the first combination performs slightly better on all measures (except the R^2 of class 2), the third combination (energy label, current RHS gas heater, and household income) is selected for two reasons. First and foremost, the interpretation of gender is in the context of this study less relevant compared to current RHS gas heater. This has to do with the fact that households often consist of both males and females and that an RHS decision is made by both parties. Also, the sample is biased towards males which might cause the covariate effect of gender to be biased. Secondly, although the R^2 of class 2 is in all combinations relatively low, it is the highest for the third combination.

Table F.1: BIC, overall R^2, and class specific R^2s of three combinations of significant covariates.

Significant covariates	**BIC**	**Overall R^2**	**R^2 class 1**	**R^2 class 2**
Energy label, gender, and household income	1949,6056	0.4117	0.4571	0.1824
Energy label, current RHS gas heater, and age	1952,7099	0.4053	0.4427	0.1785
Energy label, current RHS gas heater, and household income	1951,1539	0.4077	0.4420	0.1832