Segmenting Homeowners in the Netherlands based on Preferences and Willingness to Pay for Gas-Free Residential Heating Systems

A stated choice experiment using a latent class analysis

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Preface

Writing my master's thesis was a journey with many highs and lows. Initially, finding a topic was challenging, but thanks to the guidance of several professors from the Built Environment faculty, I discovered the subject of willingness to pay for natural gas-free renovations, a topic that sparked my enthusiasm. I have long been interested in sustainable renovations and understanding people's acceptance of them.

Once my proposal was approved, the writing began. At first, it felt daunting and isolating, and I often wondered if I was on the right track. However, the fascinating nature of this topic brought me moments of real joy, even as I started my professional career during the process. After many hours, sometimes too many in a single day, I am proud to have completed this thesis for the master's in construction management and engineering. I would like to extend my heartfelt thanks to everyone who supported and inspired me over these years. In particular, I want to express my gratitude to a few individuals.

First, I would like to thank my first supervisor, Dujuan Yang, who was always available to answer questions. Even in the first weeks of my career, when my progress slowed, she consistently provided the guidance I needed. Despite her busy schedule, she was always there for quick conversations that helped me stay on course and motivated me throughout the process. I am also very grateful to Astrid Kamperman, my second supervisor. Her expertise in methodology gave me valuable insights, especially in refining my research methods and the overall structure.

I also want to thank all the survey respondents. Each new response was encouraging, and I was especially grateful when respondents reshared my survey. Special thanks go to Dura Vermeer and other professional organizations that helped distribute my survey among their employees.

To my dear friends, thank you for listening to my endless discussions about the survey, planning, and my topic. I know I sometimes came across as frustrated, but your patience and faith in me were an immense support. I am grateful to have completed my master's at the Eindhoven University of Technology, which prepared me for my professional career and helped shape who I am today.

Finally, I would like to thank my family and girlfriend for their unwavering support, patience, endless conversations and confidence in me. Thank you for helping me in every way possible and for believing in me.

Twan Hutten
Geesteren, November 2024

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Table of Contents

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Summary

The introduction of the Paris agreement introduced a big challenge for several European countries. In this agreement, several countries have set goals for the national emitted CO2. Governments differ in approaches and goals. The Netherlands aims to achieve full carbon neutral by 2050. Approximately 15% of the country's total greenhouse gas emissions came from the built environment. This is one of the pillars the country is willing to reduce. The Netherlands plans to transform over 7 million homes and 1 million buildings into well-insulated, sustainably heated structures by 2050. Short-term goals include reducing CO2 emissions by retrofitting 1.5 million homes to reduce emissions. The current housing stock consists of 8.17 million dwellings, Most homes rely heavily on natural gas for heating, with 87.4% using gas-fired central heating systems which makes up for a large section of the CO2 production. Transitioning to a more sustainable Residential Heating System (RHS) would make a huge impact. The transition to gas-free heating systems is challenging due to the complex interactions between various stakeholders.

Currently the government is working on transforming houses by introducing the policy 'beleidsprogramma versnelling verduurzaming gebouwde omgeving'. This policy outlines five programs to accelerate sustainability in the built environment. However, the transition to gas-free heating systems has been slow, with only a 2.2% increase in natural gas-free dwellings from 2017 to 2021. The current rate of transitioning 40,000 homes per year is far below the target of 200,000 homes per year by 2030. This poses a significant challenge to the country's climate goals. Despite the Dutch government's ambitious targets to achieve carbon neutrality by 2050 and intermediate goals by 2030, the current rate of adopting sustainable heating solutions is insufficient.

Several factors contribute to this slow progress, including economic constraints, lack of awareness, and the complexities of policy implementation. The learning program (PAW) from a previous project in the Netherlands shows that particularly voluntary participation and incentives make scaling challenging. Public participation is vital because municipalities can't mandate the switch to non-gas heating systems. This can be influenced by employing energy transition strategies. Considering population heterogeneity is critical for designing these strategies. Existing research frequently relies on abstract concepts like "hurdles" or "intangible costs" to explain household responses, which are inadequate for creating effective policies. There is an urgent need for research that integrates population heterogeneity into decision-making, focusing on concrete, actionable factors like willingness to pay. This approach can provide clearer, more applicable recommendations, enhancing policy effectiveness and supporting a successful transition to renewable heating systems.

This quantitative research wants to fill this research gap by employing a stated choice experiment which data will later be analysed using a latent class model. This enables the segmentation of the research population in several classes or segments based on their preference for attributes of residential heating systems. It aims to quantify preferences using willingness to pay among homeowners. The research population includes homeowners currently using gas to heat their residences, excluding those who have already transitioned to gas-free systems and tenants of dwellings.

In the literature study the methodologies and finding of previous research are collected and examined. The random utility theory was selected as most suitable. random utility theory models decision-making by assuming individuals choose the option with the highest perceived satisfaction or utility. Each choice's utility has a predictable part and a random, unpredictable part, accounting for unknown factors. RUT is used to explain the probabilistic nature of choices in fields like consumer behaviour and market research. This is combined with a latent class analysis, which empowers the researcher to identify segments within a population that share similar characteristics or preferences.

Key factors influencing residential heating choices were found using a literature study, Which are segmented into personal variables, mental variables, and residential heating systems attributes. The key factors influencing RHS choices which are most frequently found significant in other research, provide a good basis for the generation of a survey. The questionnaire includes five heating system attributes, seven socio-demographic factors, and five dwelling characteristics along with 4 statements assessing the environmental attitude of respondents. These key factors are varied a choice experiment for which profiles are created using a fractional factorial design. After the data preparation and cleaning, 215 responses were used for further analysis.

Using Multinomial Logit (MNL) and Latent Class Analysis (LCA) models, the study identifies two distinct market segments among homeowners: Eco-Investors and Cost-Conscious Investors. Eco-Investors prioritize environmental benefits and are willing to invest in sustainable technologies. However, a high negative constant reveals that this segment is not interested in more sustainable RHS, but might prefer other sustainable investments. This makes this segment less attractive for policymakers and investors to target with subsidies because the responses would be minimal due to the general aversion of undergoing a RHS renovation. The other segment is Cost-Conscious Investors and they are highly sensitive to price and prioritize economic considerations. This segment is interesting to target for policymakers and stakeholders because here a significant difference can be made when decreasing the initial investment costs

The findings show that heating type, duration of renovation, investment costs, energy costs, and CO2 reduction levels significantly influence homeowners' RHS choices. Overall homeowners prefer heat pumps over district heating systems, shorter renovation periods, and lower investment costs. They are willing to accept some increase in annual energy costs but strongly prefer higher CO2 reduction targets.

The study acknowledges several limitations, including the representativeness of the research population. Households with a Dutch background, higher incomes, and larger detached homes were overrepresented, potentially leading to biases and limiting the generalizability of the results. The recalculation of the price parameter revealed an unexpected non-linear relationship, which was unexpected. This might be related to the respondents characteristics Further limitations include the lack of significant differences in personal variables between the identified segments and the limited explanatory power of environmental awareness. Future research could focus on expanding the sample size to improve robustness, generalizability and linearity of the cost-coefficient. Other longitudinal studies to track changes in preferences over time, and integrating more personal and mental factors into the analysis which might provide better insight in the segments.

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Samenvatting

De introductie van het Parijse akkoord heeft een grote uitdaging gesteld voor verschillende Europese landen. In dit akkoord hebben meerdere landen doelen gesteld voor de nationale CO2-uitstoot. De aanpak en doelen verschillen per overheid. Nederland streeft naar volledige koolstofneutraliteit tegen 2050. Ongeveer 15% van de totale broeikasgasemissies van het land kwam uit de gebouwde omgeving, wat een van de pijlers is die het land wil verminderen. Nederland plant om meer dan 7 miljoen woningen en 1 miljoen gebouwen om te vormen tot goed geïsoleerde, duurzaam verwarmde structuren tegen 2050. Korte termijn doelen omvatten het verminderen van CO2-uitstoot door het renoveren van 1,5 miljoen huizen om de uitstoot te verlagen. De huidige woningvoorraad bestaat uit 8,17 miljoen woningen, waarvan de meeste sterk afhankelijk zijn van aardgas voor verwarming; 87,4% gebruikt gasgestookte centrale verwarmingssystemen, wat een groot deel van de CO2-productie uitmaakt. Daarom is de overgang naar duurzamere verwarmingssystemen dringend noodzakelijk. De overgang naar gasvrije verwarmingssystemen is echter uitdagend vanwege de complexe interacties tussen verschillende belanghebbenden.

Momenteel werkt de overheid aan het transformeren van huizen door het introduceren van het beleid 'beleidsprogramma versnelling verduurzaming gebouwde omgeving'. Dit beleid omvat vijf programma's om duurzaamheid in de gebouwde omgeving te versnellen. De overgang naar gasvrije verwarmingssystemen verloopt echter traag, met slechts een toename van 2,2% van aardgasvrije woningen tussen 2017 en 2021. Het huidige tempo van 40.000 huizen per jaar is ver onder het doel van 200.000 huizen per jaar tegen 2030. Dit vormt een aanzienlijke uitdaging voor de klimaatdoelen van het land. Ondanks de ambitieuze doelen van de Nederlandse overheid om tegen 2050 koolstofneutraliteit te bereiken en tussentijdse doelen tegen 2030, is het huidige tempo van het adopteren van duurzame verwarmingsoplossingen onvoldoende.

Verschillende factoren dragen bij aan deze trage vooruitgang, waaronder economische beperkingen, gebrek aan bewustzijn en de complexiteit van beleidsimplementatie. Uit evaluaties van het PAW-programma (Programma Aardgasvrije Wijken) blijkt dat vrijwillige deelname en stimulansen het opschalen van het programma bemoeilijken. Publieke deelname is van vitaal belang, omdat gemeenten de overstap naar niet-gasverwarmingssystemen niet kunnen verplichten. Dit kan worden beïnvloed door energie overgangsstrategieën toe te passen. Rekening houden met de heterogeniteit van de bevolking is cruciaal bij het ontwerpen van deze strategieën. Bestaand onderzoek vertrouwt vaak op abstracte concepten zoals "drempels" of "immateriële kosten" om huishoudelijke reacties te verklaren, wat ontoereikend is voor het creëren van effectieve beleidsmaatregelen. Er is dringend behoefte aan onderzoek dat heterogeniteit in de bevolking integreert in de besluitvorming, met de nadruk op concrete, uitvoerbare factoren zoals betalingsbereidheid. Deze benadering kan duidelijkere, meer toepasbare aanbevelingen bieden, waardoor de beleidsdoeltreffendheid wordt verbeterd en een succesvolle overgang naar hernieuwbare verwarmingssystemen wordt ondersteund.

Dit kwantitatieve onderzoek wil deze gat opvullen door een keuzemodel te gebruiken dat later zal worden geanalyseerd met behulp van een latente klasse analyse. Dit stelt de onderzoeker

in staat om de onderzoekspopulatie in verschillende klassen te segmenteren op basis van hun voorkeuren voor attributen van verwarmingssystemen. Het doel is om voorkeuren te kwantificeren door gebruik te maken van de betalingsbereidheid (WTP) onder huiseigenaren. De onderzoekspopulatie omvat huiseigenaren die momenteel gas gebruiken om hun woningen te verwarmen, met uitsluiting van degenen die al zijn overgestapt op gasvrije systemen en huurders van woningen.

In de literatuurstudie worden de methodologieën en bevindingen van eerder onderzoek verzameld en geëvalueerd. RUT (Random Utility Theory) werd geselecteerd als het meest geschikt omdat het een robuust theoretisch kader biedt voor het begrijpen en modelleren van individueel keuzegedrag. In combinatie met een LCA (Latent Class Analysis) stelt dit de onderzoeker in staat om subgroepen binnen een populatie te identificeren die vergelijkbare kenmerken of voorkeuren delen.

Belangrijke factoren die de keuzes voor residentiële verwarming beïnvloeden, werden gevonden door middel van een literatuurstudie, die zijn gesegmenteerd in persoonlijke variabelen, mentale variabelen en verwarmingssysteemattributen. De belangrijkste factoren die de keuzes voor verwarmingssystemen beïnvloeden en die het vaakst significant worden bevonden in ander onderzoek, bieden een goede basis voor de ontwikkeling van een enquête. De vragenlijst omvat vijf attributen van verwarmingssystemen, zeven sociaal demografische factoren en vijf woningkenmerken, samen met vier stellingen die de milieuhouding van respondenten beoordelen. Deze belangrijke factoren worden vergezeld door een keuze-experiment dat is opgesteld met behulp van een fractioneel factoriaal ontwerp. Na de gegevensvoorbereiding en -reiniging werden 215 reacties gebruikt voor verdere analyse.

Met behulp van Multinomial Logit (MNL) en Latent Class Analysis (LCA) modellen identificeert het onderzoek twee verschillende marktsegmenten onder huiseigenaren: Eco-Investors en Cost-Conscious Investors. Eco-Investors geven prioriteit aan milieuvoordelen en zijn bereid te investeren in duurzame technologieën. Een hoge negatieve constante onthult echter dat deze groep niet geïnteresseerd is in duurzamere verwarmingssystemen, maar mogelijk de voorkeur geeft aan andere duurzame investeringen, waardoor deze groep minder aantrekkelijk is voor beleidsmakers en investeerders om te richten met subsidies. De andere groep, Cost-Conscious Investors, is zeer gevoelig voor prijs en geeft prioriteit aan economische overwegingen. Deze groep is interessant voor beleidsmakers en belanghebbenden omdat hier een significant verschil kan worden gemaakt door de initiële investeringskosten te verlagen.

De bevindingen tonen aan dat het type verwarming, de duur van de renovatie, investeringskosten, energiekosten en CO2-reductieniveaus significante invloeden hebben op de keuzes van huiseigenaren voor verwarmingssystemen. Huiseigenaren geven de voorkeur aan warmtepompen boven stadsverwarmingssystemen, kortere renovatieperiodes en lagere investeringskosten. Ze zijn bereid een zekere verhoging van de jaarlijkse energiekosten te accepteren, maar geven sterk de voorkeur aan hogere CO2-reductiedoelen.

Het onderzoek erkent verschillende beperkingen, waaronder de representativiteit van de onderzoekspopulatie. Huishoudens met een Nederlandse achtergrond, hogere inkomens en grotere vrijstaande huizen waren oververtegenwoordigd, wat mogelijk leidt tot biases en de generaliseerbaarheid van de resultaten beperkt. De herberekening van de prijsparameter onthulde een onverwachte niet-lineaire relatie, wat de analyse compliceert. Verdere beperkingen zijn onder meer het gebrek aan significante verschillen in persoonlijke variabelen tussen de geïdentificeerde klassen en de beperkte verklaringskracht van milieubewustzijn. Toekomstig onderzoek zou zich kunnen richten op het uitbreiden van de steekproefomvang om de robuustheid en generaliseerbaarheid te verbeteren, longitudinaal onderzoek om veranderingen in voorkeuren in de tijd bij te houden en meer persoonlijke en mentale factoren te integreren in de analyse om beter inzicht te krijgen in de klassen.

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List of abbreviations

Abbreviation	Full term
RES	Renewable Energy System
RHS	Residential Heating System
PAW	Programma Aardgasvrije Wijken (Natural Gas-Free Neighborhoods Program)
TVW	Transitie Visie Warmte (Heat Transition Vision)
RUT	Random Utility Theory
TPB	Theory of Planned Behaviour
VBN	Value-Belief-Norms Theory
DOI	Diffusion of Innovation
WTP	Willingness to Pay
MNL	Multinomial Logit
CBS	Centraal Bureau voor de Statistiek (Central Bureau of Statistics)
RVO	Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency)
PVGO	beleidsprogramma versnelling verduurzaming gebouwde omgeving (Policy Program for Accelerating Sustainability in the Built Environment)

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List of figures and tables

Figures

Tables

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1. Introduction

The introduction commences by providing a contextual backdrop regarding the decarbonization of the Netherlands, where the goals set by the government and the current situation of the residential built environment will be explained. The following section addresses the research questions, which will later be expanded upon in the research design. Following this, the significance of the thesis is explained by elaborating on its relevance. Finally, the structure of the report will be explained using a reading guide.

1.1 Background

This section will provide a comprehensive foundation for defining the research problem, detailing the context and significance of the issue at hand, and outlining the specific research objectives that will guide the study. By establishing a clear understanding of the challenges and goals.

1.1.1 Goals

The Paris agreement presented at the climate conference in 2015 has set forth a new international legal regime to strengthen the global response to climate change (Horowitz, 2016). The European Union, in particular, aims to achieve full carbon neutrality by the middle of the century (Scheepers et al., 2022). Governments differ in methodologies and pathways to meet European and global commitments. The Dutch government has determined 5 pillars where a CO2 reduction is necessary to achieve the goals. These pillars are; building environment, mobility, industry, agriculture land-use, and energy production. The energy transition of the built environment is an important step in reducing greenhouse gas emissions. In 2021, 15% of the total greenhouse gas emissions in the Netherlands was emitted by the existing built environment. This 15% produced by the built environment are a product of heating systems in residential homes and commercial buildings, such as offices (CBS, 2021).

To start reducing the greenhouse gas emissions in the built environment, the Netherlands has initiated an energy transition that aims to transform more than 7 million homes and 1 million buildings, before 2050 (Klimaat Akkoord, 2020). These buildings are generally speaking poorly insulated and heated with natural gas. The government wishes to transform them into well-insulated homes and buildings that are sustainably heated. To generate sustainable heating clean electricity is used. To stay on track and achieve the goals set for 2050, short(er)-term goals are set for 2030. The short-term goal is to reduce the CO2 emissions produced by residential homes and commercial buildings, with 3,5Mton before 2030. To achieve this target, approximately 1.5 million existing homes need to be renovated more sustainable before 2030, which is predicted to reduce 2,5Mtons of CO2. The other 1 million tons of CO2 emissions must be reduced in the existing commercial building sector by 2030. To remain on course, a steady increase in the pace of sustainability to more than 50,000 existing homes per year in 2021 is required. And before 2030, we should already be operating at a rate of 200,000 per year (Klimaat Akkoord, 2020).

1.1.2 Current housing stock

The Netherlands consisted of 8.17 million dwellings in Juli 2023 (CBS, 2023b), 60% of these dwellings are privately owned and 40% are rental dwellings. In the Netherlands' biggest cities, the percentage of rental dwellings is higher compared to smaller cities or rural places (CBS, 2020). In the Netherlands, a system is in place which describes the energy presentation of a building using labels. These labels vary from A++++ up until G. Where the houses with a label is better insulated than a houses with a G label. This energy label is determined by taking the fossil energies into account. These are expressed in Kw/h per square meter. In January 2022, 58% of the residential buildings had a label assigned to them. In Figure 1 a graph is presented which describes the division of energy labels. It is important to note that a lot of homes do not have an energy label. However, the homes that do not have an energy label are likely to be older not well insulated homes (CBS, 2023a).

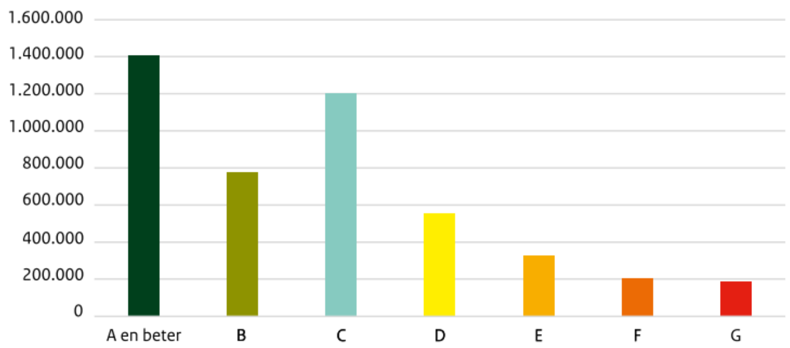

Figure 1 - Division of energy labels in the Netherlands in 2022 (CBS,2023a)

A report by the 'Rijksdienst voor Ondernemend Nederland' (RVO) determined that in 2021 87,4% of the central heating systems used natural gas as fuel. Among the homes still using natural gas, the vast majority (82%) had an individual central heating boiler as the main heating system. Only 5.7% used district heating and 1,6% used heat pumps to heat their dwelling in 2021. The homes were primarily heated electrically or through a district heating network but still had an additional central heating boiler, were categorized as 'Other non-natural gas-free' (1.8%). This division is presented in Figure 2. Due to the substantial dependence of the current built environment on gas-powered heating systems, a significant leap can be taken to address the issues related to carbon dioxide emissions and the sustainability of the current sector.

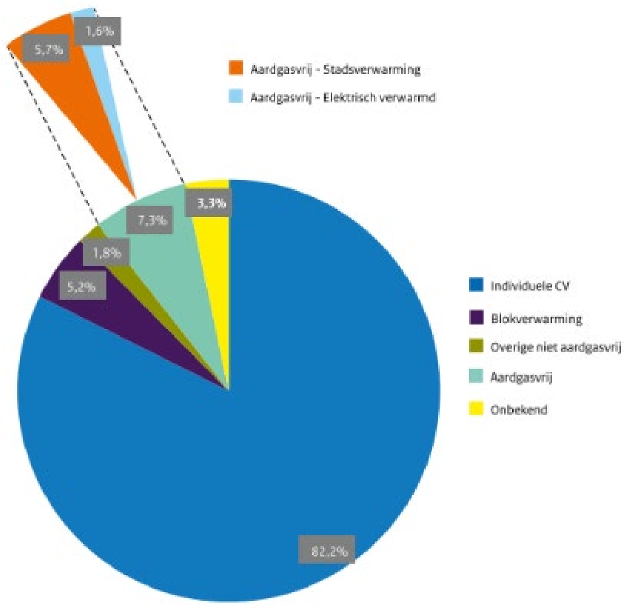

Figure 2 - RHS in the Netherlands in 2021 (Piersma,2022)

1.1.3 Current approach

The turnover to gas-free heating systems is challenging because, decision-making and policymaking in this transition are far from simple, as actors, technology, and institutions interact in a complex manner (Nava Guerrero et al., 2019). To tackle this challenge a policy called 'beleidsprogramma versnelling verduurzaming gebouwde omgeving' (PVGO) is drawn up. This policy presents 5 programs that are used to accelerate the move toward a sustainable built environment. These programs are; individual approach to homes, neighbourhood-oriented approach to homes, approach to utility buildings, energy sources and infrastructure, and innovation in the built environment. The first two pillars are directed towards residential dwellings in the Netherlands. These approaches are separated based on the initiator. The first one is an approach aimed at individual dwellings where homeowners and renting parties are the initiators. Here (Home)owners are supported with subsidies, and improved financing options are being introduced. Additionally, accessible information and a simplified application process are provided. Furthermore, arrangements are made to ensure that homeowner-occupants have access to support services.

The second approach is a neighbourhood-oriented approach where the municipality functions as the initiator. The neighbourhood-oriented approach is custom-designed for each district, encompassing villages and neighbourhoods. Because Dutch municipalities have an important role as initiators here they are obliged to draw up a Transitie visie warmte (TVW), which is a document indicating in which ways they plan on undergoing the energy transition. Over 300 municipalities in the Netherlands already adopted a TVW in mid-March 2022. In the TVW's, municipalities described the districts, neighbourhoods, and centres in which they will work on making the built environment more sustainable in the period up to 2030. They also mentioned which sustainable alternatives they are considering for each specific neighbourhood. Most of the TVW's present 3 main technologies which are district heating, all-electric, and hybrid solutions which use sustainable gas. These options are assigned to each neighbourhood based on cost and practical implication of the selected technology (Thijs, 2020).

The first neighbourhood transitions described in the TVW's are finalized or are currently in the realization phase. These first projects are described as 'proeftuinen' These are pioneering projects spread out over the Netherlands in cooperation with several different municipalities. In October 2018, the first 27 districts started the renovation. additionally 64 districts are selected as proeftuin and will be turned over to gas-free heating systems (Rijksoverheid, n.d.-a). The finalized projects were thoroughly examined and reviewed to gain insights into the neighbourhood-oriented approach and the different heating techniques and methods available (Rijksoverheid, 2021). The learning process behind these projects is ensured by a program named 'Programma Aardgas vrije Wijken' (PAW). Which ensures that the process is reviewed accurately. PAW plays a pivotal role in the transformation of 1.5 million homes by 2030. With experience gained in these pioneering projects, parties can quickly learn how to transform large numbers of homes to make them more sustainable. This allows providers to develop a more efficient and less expensive offer. Projectors gain experience in tendering for larger numbers of renovations. These are necessary conditions for actual upscaling. Broad experience is also gained on what is cost-effective and what is practical in different situations. At the individual level, building owners must also be enticed to become more sustainable. Much innovation and cost reduction are still needed to make these investments affordable through energy savings and lower energy bills. PAW provides a cost-effective scale-up and clearer cost indication. Without that perspective, a municipality cannot commission heat networks or encourage landlords and homeowners in a neighbourhood to invest in sustainability.

1.2 Problem definition

It's evident that the transition isn't progressing swiftly enough to meet the targets set in the climate agreement. Between 2017 and 2021, the percentage of dwellings without natural gas increased from 5.1% to 7.3%. This 2.2% increase represents roughly 170,000 residences over five years, averaging about 40,000 of annual transformation. This growth encompasses both newly constructed and existing homes. As of now, CBS (Central Bureau of Statistics) cannot provide precise data regarding the specific number of newly constructed homes that are natural gas-free. Nevertheless, it is safe to state that a significant proportion of these ±170,000 dwellings over 5 years will concern newly built houses (RVO, 2022). As previously explained, we should be operating at a rate of 200,000 existing homes per year before 2030 (*Klimaat Akkoord*, 2020). The current rate of 40,000 homes per year falls far short of this target, underscoring the urgent need for significant progress to meet the goal.

A sound understanding of consumer behaviour, including individual attitudes and their drivers, may help prevent opposition to specific policies and projects and thus facilitate the achievement of the energy policy goals (Martiskainen & Sovacool, 2021). When reviewing the documents describing the heating transition presented by municipalities spread out all over the Netherlands, it can be seen that the imposed technologies in several neighbourhoods are mainly based on national cost and practical incorporation. These models often overlooked the behaviour of regular households, assuming that everyone makes rational financial decisions and possesses comprehensive information about the transition plan (Berkel et al., 2021; PAW, n.d.; Thijs, 2020). However, a study by Bolwig et al. (2020) shows that socio-technical and political factors such as social acceptance may significantly affect transition pathway scenarios based on techno-economic variables alone. Therefore, the techno-economic, socio-technical and political layers of energy systems should be considered when analysing long-term energy transitions. It is important to link energy decision making with consideration of the dynamics of socio-technical factors. The inclusion of these into the decision making is important because, in reality, people's choices can be influenced by factors like their age, income, location, and the technology they already use (Chadwick et al., 2022; Motz, 2021).

This is highlighted by the evaluation report of the first round of "proeftuinen" as part of the PAW program. A key issue identified is that residents have had the option to participate in the transition voluntarily, with incentives being the primary method used to encourage involvement. This approach makes it challenging to scale the program effectively (KWINK Groep, 2022). The Climate Agreement emphasizes that active public participation is crucial for enhancing policy decision-making and increasing the adoption of renewable heating systems (Netherlands, 2016). Given that the transition occurs within the private sphere of homeowners, municipalities lack the authority to mandate the switch to non-gas heating systems (Voskuyl, 2021). Therefore, considering heterogeneity in the population is essential in designing and implementing energy transition strategies. Understanding the diverse needs, preferences, and constraints of different demographic groups can help tailor policies and incentives to achieve broader and more effective participation.

Previous research has sought to enhance techno-economic energy system models by integrating a wider array of consumer preferences. However, these attempts frequently rely on abstract notions such as "hurdles" or "intangible costs" to describe how households respond to new technologies (Li et al., 2018). In practice, these abstract terms do not provide the detailed, actionable information needed for creating effective policies. They may not capture the nuanced ways in which factors like personal values, financial constraints, or specific needs influence consumer choices.

In conclusion, it can be stated that there is an urgent need for research integrating heterogeneity in the population into energy transition decision-making. Existing models often overlook the diverse preferences and constraints of different demographic groups, leading to less effective policy measures and lower participation rates. Furthermore, current approaches frequently rely on abstract concepts, which can be challenging to translate into actionable insights for practical implementation. To address this gap, future research should focus on incorporating concrete, actionable factors such as willingness to pay. By grounding the analysis in more tangible concepts, this research can provide clearer, more applicable recommendations, ultimately enhancing policy effectiveness and supporting a more successful transition to renewable heating systems.

1.2.1 Research goal

Currently, techno-economic energy system models are frequently used to devise strategies for transitioning to new energy systems (Berkel et al., 2021; PAW, n.d.; Thijs, 2020). However, these models often focus predominantly on the supply side evaluating technology, practicality, and cost while giving less attention to the demand side. This narrow focus can result in inaccurate predictions and lower participation rates, a significant bottleneck identified by the PAW. By neglecting the demand side, these models may overlook critical factors that influence public engagement and adoption of new energy sources.

This research aims to gain insight into the willingness to pay (WTP) of Homeowners in the Netherlands for gas-free RHS. This enables decision-makers and policymakers to review their current practices and may assist in future decisions. This is done by predicting the willingness to pay of different societal segments in the Netherlands. This will be achieved by separating the research population based on preference segments and analysing these segments. The overall aim of the research is formulated as follows:

Identifying distinct market segments based on their residentials heating system preferences and computing their willingness to pay, uncovering the heterogeneity in decision-making criteria among homeowners in the Netherlands.

1.3 Research design

The transition to a more sustainable heating source can be defined as pro-environmental behaviour (Liu et al., 2023). Behaviours and choices of individuals have been a topic of numerous studies. These studies have provided insight into human behaviour and its motivators and barriers. This insight has inspired researchers to create many different decision models. Behaviours and choices are mostly researched using quantitative research methods Quantitative research methods provide an effective way of dealing with large amounts of data to predict the strength of relationships between variables. A downside to the quantitative methods is that not included variables might influence the determined relationship.

In this study a quantitative research method is employed to explore the decision-making process of homeowners in the Netherlands regarding gas-free heating systems. It is crucial to examine how specific characteristics of these heating systems, along with varying personal and mental factors, influence homeowners decisions. This research aims to quantify preferences and willingness to pay among homeowners in the Netherlands. By analysing these values, the research will investigate the heterogeneity within the population by considering several different classes in the research population. This comprehensive approach, including insights from a systematic literature review, will provide a deeper understanding of how individual differences affect decision-making in the context of energy transitions.

1.3.1 Scope of the research

It is important to limit the research to a specific research population because several studies state that choices in RHS will differ based on location due to factors such as pricing, availability, climate, and cultural norms, among others (Yazdanpanah et al., 2015). In this research, the research population will be homeowners in the Netherlands who are currently using gas to heat their residences. By excluding the homeowners who already have undergone the transformation potential biases will be limited, resulting in results that will be closer to real-world decision making. In this research, only private property owners are examined, excluding those who rent their current living arrangement.

This paper examines the energy transition away from gas in the Netherlands in a certain period, which imposes some limitations regarding available technologies. The technologies that are researched. The included technologies will only consist of technologies that are available and realistic in today's market.

1.4 Research questions

The main objective of the research is to gain insight into the decision-making process of different segments of homeowners in the Netherlands, and to use this to determine what they are willing to pay for a natural gas-free RHS. The main research question to assist in achieving this goal is formulated as follows.

What are the distinct market segments among homeowners in the Netherlands based on their heating system preferences and what is their willingness to pay for gas-free heating solutions?

The research consists of different segments, which are constructed to answer several sub-questions. First, a general overview is provided by previous literature and findings to find the factors that influence the Dutch homeowner's decision regarding RHS. After this, it is determined which attributes and levels are deemed important by a homeowner. Later on, there will be analysed if there are segments in the market. If there are distinct market segments among homeowners in the Netherlands, these segments will be analysed. Providing a deeper understanding of these segments. This process can be described by the following sub-questions which have been drawn up to answer the main research question:

1. What factors have historically influenced homeowners in the Netherlands when deciding on residential heating systems?
2. Are there distinct market segments among homeowners in the Netherlands?

3. What are the characteristics of these segments and what is the difference in willingness to pay for RHS?

1.5 Social and scientific importance

This research is scientifically important because a latent class model will be used to identify, preference heterogeneity among homeowners in the Netherlands, which will be expressed using WTP. A study conducted by Voskuyl (2021), stated that choice experiments examining heterogeneity in RHS choices have been scarcely conducted in the Netherlands. A scarce example of a heterogeneity study in the Netherlands is the study conducted by Liu et al. (2023). This study used a latent class model to examine the maximum rent increase that social housing tenants would tolerate for gas-free RHS. However, this research only considers tenants meaning; homeowners were excluded by this research. Another research conducted in the Netherlands is conducted by Voskuyl (2021) examining preferences of Homeowners in the Netherlands in Delft. This research also conducted a latent class analysis. However, this research did not examine the effect on the willingness to pay. Another study researching sustainable energy measures in the Netherlands used mixed logit, conducted by Tiellemans et al. (2022). However, they focused on finding the effect of group influence on RHS decisions in the Netherlands, rather than the market segments and the WTP.

The result of the research could be of social importance because WTP calculation resulting from this research can be used to calculate the willingness to pay of different societal groups. This has the potential to enhance the efficient allocation of funds by policymakers and organizations. For instance, it can enable the redistribution of subsidies among various demographic groups. Furthermore, it offers a valuable tool for assessing the efficacy of policies and interventions. All of this with the ultimate goal of increasing participation in the energy transition, so that the goals set by the government in 2030 and 2050 can be achieved.

This research has the potential not only to aid in subsidizing RHS but also to inform the pricing of RHS technologies and services. If this study reveals that certain individuals are willing to pay a specific amount for a particular renovation, it could serve as a pricing reference, making RHS renovations more accessible to a broader audience. This, in turn, could accelerate the growth of the current RHS market. Ultimately, resulting in more individuals being attracted to an investment in more sustainable RHS.

1.6 Reading guide

The guide can assist in navigating through the document. The reading guide is added in table 1. This guide provides an overview of each chapter to facilitate a clear understanding of the section and its findings. Each chapter is designed to build on the previous one. This guide can enhance the understanding of the study's findings and implications.

Table 1 – reading guide

Section		Description		Result
1. Introduction	→	The introduction chapter outlines the study's context, approach, and significance, while providing a roadmap for the following sections.	→	Research question: What are the distinct market segments among homeowners in the Netherlands based on their preferences and willingness to pay for gas-free heating solutions?
↓				
2. Literature review	→	The literature review selects the most suitable theory by exploring energy behaviour theories. Here the key factors influencing residential heating choices are found.	→	Random utility is selected as the most suitable theory. Several variables are found that previously have had an impact on RHS choices.
↓				
3. Methodology	→	The methodology chapter describes the types of choice experiment which will be used along with the modelling techniques.	→	The stated choice experiment is identified as the most appropriate method, and the data will be examined using MNL and LCA models.
↓				
4. Survey design	→	The survey design chapter selects relevant variables and determines their levels using empirical data and develops the experimental design and survey according to guidelines.	→	5 heating system attributes, 7 sociodemographic factors, and 5 dwelling characteristics with their levels are selected, the questionnaire is developed
↓				
5. Data preparation and analysis	→	The data preparation and analysis chapter looks at the data and excludes/recodes the data making it suitable for analysis in the results step	→	5 ID's are excluded from the research. Employment and ethnicity variables are excluded other levels are recoded, based on the number of answers. Here the research population is compared to national data. Lastly, all the attributes are dummy coded for further analysis.
↓				
6. Results	→	Here general preferences are determined based on significant results. Later the segment is segmented using LCA. These segment are further analysed and their WTP is computed.	→	The developed LCA model provides a satisfactory fit. dividing the population in 2 segments. Further analyses find no distinction between the segments based on personal and mental variables.
↓				
7. Conclusion				

2. Literature study

A literature review is preformed to create insight into the current knowledge regarding the RHS characteristics and variables that influence the RHS choice of households. The studies which are discussed in the literature study (n=30) are all articles, journals or books which are researching heating preferences of individuals or RHS choice behaviour. These studies where found and selected using keyword searching on the online data base of Scopus. By using forward and backwards searching other relevant research could be identified and included. An overview of the included studies regarding the choice/preference of RHS is presented in appendix A. In this appendix a table is presented where the included studies are mentioned along with several descriptive characteristics including; the author(s), publication year, and publication title. These articles where all examined to retrieve relevant data regarding their research method, behavioural theory, modelling approach, and country of research, which are also included.

When examining the included studies it can be seen that a large number of the included studies are published after 2000. All of the included studies focus on the choice/preference of one or numerous sustainable heating systems. The countries that are most researched are Germany, Norway, USA, Sweden, Finland and the UK. These statements align with the findings of a literature study conducted by Karytsas et al. (2019). Literature regarding the RHS choice behaviour and preferences regarding RHS in the Netherlands, can be divided by their research population. Two of the included five are only concerned with (social) tenants (Liu et al., 2023; Van der Spank, 2013). The other studies are regarding the RHS choice behaviour of Homeowners in the Netherlands (Tiellemans et al., 2022; Voskuyl, 2021)

This section commences by citing the theories that are most commonly used when researching RHS preferences and choices. The theories will be described along with their common features, differences and (dis)advantages. Secondly variables that have previously been found to significantly impact the RHS choice and preferences will be mentioned. The literature review is summarized in the conclusion which will provide an answer to the research questions (1) "*What are the factors which have previously impacted the decision-making of homeowners in the Netherlands regarding residential heating systems?*" The answer to this question are essential for the generation of the experimental design.

2.1 Energy behavioural theories

Switching RHS is examined by research along with the factors affecting it. This has been studied in several fields of social and behavioural sciences. Any scientific attempt to understand, predict, or promote any kind of preference or choice behaviour requires an adequate measurement tool based on an applicable theory. The multidisciplinary interest in preference allocation and choice behaviour has generated a large variety of such tools, ranging from domain-general and domain-specific self-report measures, field observations conducted with the help of informants, trained observers, or technical devices, to behavioural tasks for use in the laboratory (Lange & Dewitte, 2019). All of these tools try to explain the same behaviour, yet are based on different assumptions.

This section of the report will provide a theoretical background which will mention the behavioural theories used when researching RHS preferences or choice behaviour. As previously mentioned appendix A elaborates on which theory is applicable for each included record. The theories mentioned are: the random utility theory (n=15), the theory of planned behaviour (n=7), the diffusion of innovation (n=5), the goal framing theory (n=2), Energy ladder (n=2), Value believe norm theory (n=1), and Comprehensive action determination model (n=1). These theories will be explained in this section. This section is structured based on their occurrence in the included literature.

2.1.1. Random utility theory

The random utility theory by McFadden (1974) assumes that products or services can be deconstructed into bundles of attributes and that each attribute is associated with a specific level of utility. The total utility of a service or product equates to the sum of its part's utility. Random utility theory is based on the assumption that individuals seek to get the highest satisfaction (maximum utility) from their decisions, given several constraints. The maximum utility is calculated by the summing up the calculated utility and a random error component. Based upon research the structural equation can be determined. The random error component is to capture any influences on individual choices that are unobservable to the researcher. Suppose that individual *i* chooses alternative *j*, then the utility that can be derived from the total satisfaction that an individual *i* derives from choosing alternative *i.* This can be derived using the following formula:

$$U_{ij} = V_{ij} + \varepsilon_{ij}$$

Where *V* is the explanatory value and reflects the “representative” taste of the population. And ε is stochastic and reflects the distribution or pattern that may be analysed statistically but may not be explained by the explanatory value. The individual chooses the alternatives which achieve the highest *U*.

Several studies employed a random unity theory for the energy for the choice of energy appliances by households (e.g. Liu et al., 2023; Meried, 2021; Rouvinen & Matero, 2013 among others). When considering choices, these studies apply several different logit models to determine relations and interrelation between included variables. These studies rely on quantitative data. Some studies analyse data from a previously conducted (national) household study (Achtnicht & Madlener, 2014). Others create and distribute a questionnaire including a choice experiment (e.g. Côté & Pons-Seres de Brauwer, 2023; Krikser et al., 2020; Liu et al., 2023 among others). Most of the studies using the RUT are based on explanatory variables that can be classified into; demographic variables, residence characteristics, spatial variables and attributes of the RHS (Michelsen & Madlener, 2012). A study conducted by Meles et al. (2022) include an extra explanatory behavioural value computed based on several statements to further improve the model fit of their models.

2.1.2 Theory of planned behaviour

The theory of planned behaviour (TPB) by Ajzen (1991), is a popular model used to understand how attitudes influence behaviours. It has been used in predicting various behaviours (Conner & Armitage, 1998). The theory includes five dependent factors namely: Attitude towards behaviour, subjective norm, perceived behavioural control, intention, and behaviour. A schematic representation of the TPB model is presented in Figure 3. The TPB can be used to predict intentions to perform behaviours of different kinds with a high accuracy. This is determined using attitude towards the behaviour, subjective norms, and perceived behavioural control. The TPB is based upon the theory of reasoned action by Fishbein & Ajzen (1975), in both theories the individual's intention to perform a given behaviour plays a central role. The difference lies in the factor perceived behavioural control. Perceived behavioural control is not included in the theory of reasoned action but is included in the TPB.

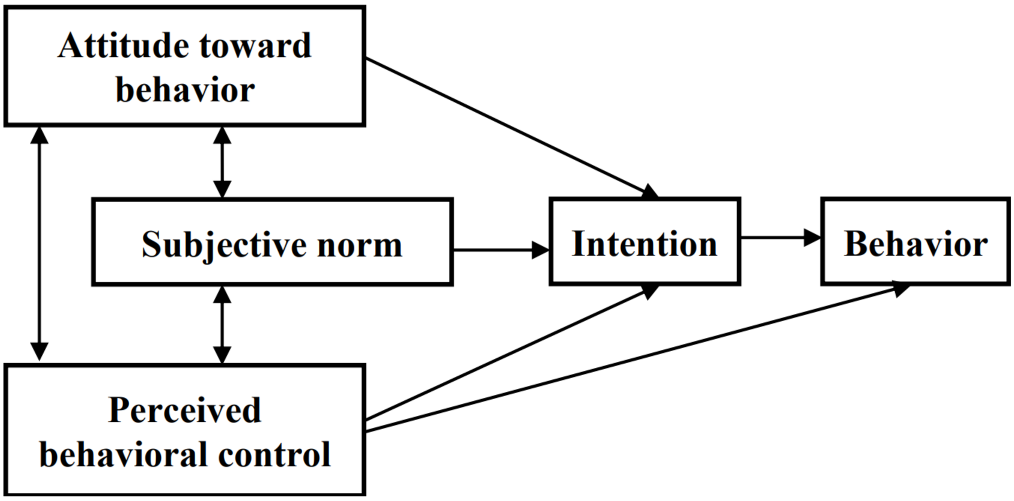

Figure 3 - Theory of planned behaviour by Azjen (1991)

The first three attributes are independent determinants of intention. Attitude towards behaviour refers to the degree to which a person has a favourable or unfavourable evaluation of the behaviour in question. The second predictor is the subjective norm which is a social factor which refers to the person's perceived social pressure to perform the behaviour. The final predictor is perceived behavioural control which refers to the perceived ease or difficulty of performing the behaviour. These three factors are used to determine an individual intention. An individual's intention refers to the degree of how much a person will try to perform the behaviour. The last factor mentioned is the behaviour factor which refers to the performed behaviour. In some cases, if a person is willing to behave in a certain way this directly translates to the preformed behaviour. However, the behaviour of an individual is commonly influenced by perceived non-motivational factors (e.g. time, money, skills, etc). these factors represent perceived control over behaviour, hence why perceived behavioural control directly influences behaviour.

Yazdanpanah et al. (2015) used the TPB to construct a framework that also included moral norms and self-identity as variables that influence intention. This framework was used to investigate public acceptance and willingness to use renewable energy sources. They found that moral norm was the most important determinant of the intention to use a specific RES, followed by attitude and perceived behaviour control. In this study, subjective norm and self-identity were found not-significant factor influencing the acceptance of RES. Another research by Fornara et al. (2016) also came to the conclusion that there was no direct association between the subjective norm and the intention. The subjective norm did influence the perceived behavioural control and the attitude which in their turn have a significant relation to intention.

2.1.3 Diffusion of Innovation

The process of adopting innovations has been studied for over 50 years, and one of the most popular innovation adoption models is described by Rogers (2003). Rogers defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system". The diffusion of innovation theory has been used in several research fields including political science, public health, communication, history, economics, technology, and education (Doyle et al., 2014; Lovejoy et al., 2009; S Cheng et al., 2004). Roger classifies diffusion in his innovation adoption framework into five onward stages: innovators (2.5%), early adopters (13.5%), the early majority (34%), the late majority (34%), and laggards (16%). A visible representation of the diffusion of innovation model described by Roger is presented in Figure 4.

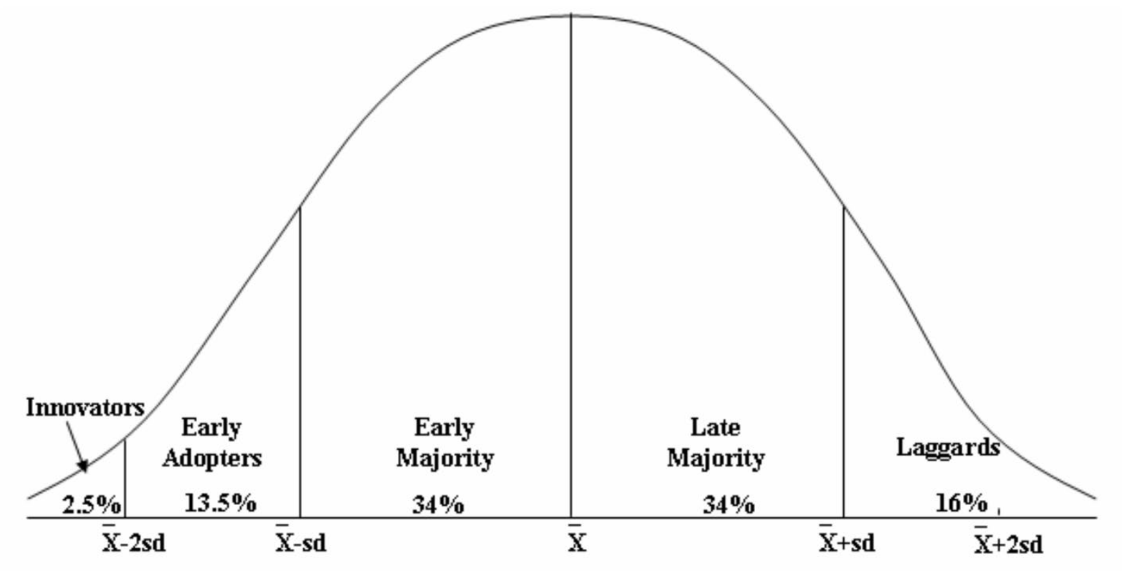

Figure 4 - Diffusion of innovation by Rogers (2003)

The four key components which influence behavioural change mentioned by Rogers (2003) are innovation, communication channels, time, and social systems. Innovation is described as the perceived newness of an idea, practice or project by an individual, the newness of an innovation mainly relies upon knowledge, persuasion and decision of the innovation-decision process of an individual. Another important factor mentioned in the innovation-decision process by Rogers is the uncertainty of the consequences when adopting or rejecting an innovation. Communication channels are the means by which a message gets from the source to the receiver, communication channels can be interpersonal channels and mass media. Time is included in the model to introduce adopter categorization and rate of adoption. Social systems are defined as a set of interrelated units engaged in joint problem-solving to accomplish a common goal. The nature of the social system affects individuals' innovativeness which is the main criterion for cantonizing adopters.

The speed of an innovation adoption is influenced by the type of innovation considered. The theory presented by Rogers suggests six attributes of innovations which have an impact on the rate of adoption over time, by influencing the uncertainty in the adoption process. Rogers reported that 49-87% of the variance in the rate of adoption of innovation is explained by these five attributes. The attributes are relative advantage, compatibility, complexity, trialability and observability. Relative advantage is defined as the degree to which an innovation is perceived as being better than the idea it supersedes. Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Trialability is the degree to which an innovation may be experimented with on a limited basis. The last characteristic is observability, which is defined as the degree to which the results of an innovation are visible to others.

Several studies researching preferences/choice behaviour regarding RHS have been conducted using the diffusion of innovation theory (Bjørnstad, 2012; Brown et al., 2023; Mahapatra & Gustavsson, 2009; Tapaninen et al., 2009). A research conducted by Tapaninen et al. (2009) used the DoI theory to explain perceived barriers to adopt wood pellet heating system. However, utilizing this theory in context of RHS proved rather difficult. The main reason are the previously mentioned attributes. The attribute - relative advantage was perceived as somewhat ambiguous, because of the varieties of ways to interpret the definition. the attributes triality and observability are difficult to incorporate because of the technically, inflexible an long-term nature of RHS. Another study conducted by Brown et al. (2023) used the DoI as theoretical basis to include knowledge and familiarity in their analysis. These variables were found to be among the most consistently significant predictors of being willing to pay for micro-environmental renovation. A research investigating the experiences from the Norwegian household RHS subsidy programme used DoI to motivate the empirical modelling of the investment satisfaction (Mahapatra & Gustavsson, 2009). Mahapatra & Gustavsson (2009) used DoI analyse the marketing campaign for RHS in Sweden. Based on the theory four key steps which were all influenced by different variables of the success full marketing were identified (1) need for a system influenced by dissatisfaction with existing system, (2) plan for a new system influenced socioeconomic characteristics, (3) collection of information influenced by mass media and interpersonal communication, (4) selection of a system influenced by relative advantage of the technology.

2.1.4 Goal framing theory

The goal framing theory by Lindenberg & Steg (2007) is a theory most prominently used in psychology. This theory states that a specific goal may be activated or become focal depending on both value properties and situational factors. The theory states that individuals have multiple goals that may or may not be compatible. Often one goal is more prominently present than other goals. (Onwezen, 2023). Three goals which are generally described in the context of sustainable choices are hedonic, gain, and normative goals. The gain motive aims to preserve or improve a person's resources. The hedonic frame leads people to focus on the things that affects their pleasures, mood, comfort and energy level. Normative goals refers to people's behaviour that is motivated by a sense of responsibility towards the environment (Liu et al., 2023). Lindenberg & Steg (2007) suggested that the normative goal frame is expected to have the greatest impact on pro-environmental behaviour. Research conducted by Un et al. (2021) contradicts this hypothesis and found that although the normative goal frame does contribute to the creation of commitment, the gain goal frame plays a larger role in the analysed cases. A research conducted in the Netherlands, Liu et al. (2023) found a significant link between obtaining gain and hedonic value and social housing tenants' willingness to participate in an environmentally friendly renovation project.

2.1.5 Energy ladder theory

The energy ladder theory is a concept used in the field of development economics and environmental studies to describe the progression of energy usage patterns among communities. This theory suggests that as societies or individuals progress economically, they tend to shift from primitive, biomass-based energy sources (like firewood, agricultural waste and animal waste) to transition fuels (like charcoal, kerosene and coal) and ultimately choose for advanced fuels (such as electricity, natural gas and biofuels). At the lower levels of the energy ladder, communities rely on basic and often inefficient forms of energy for daily needs. As families gain socioeconomic status they abandon technologies that are inefficient, cheaper and more polluting and move to a different fuel. So as individuals advance socioeconomically, there's a transition towards cleaner, more efficient, and often more expensive energy sources. This progression in socioeconomic status is driven by factors like increased income, access to technology, infrastructure development, and awareness of environmental impacts. The energy ladder also assumes that more expensive technologies are locally and internationally perceived to signify higher status (Brouwer et al., 2013).

Both Meried (2021) and Bai et al. (2023) found that the transition isn't universal or linear; different communities may move up the energy ladder at different rates due to various social, economic, and geographical factors. Meried (2021) also argued that when households experience a rise in income that household more often choose for a partial transition to cope with unstable income flows, protect themselves from fragile energy markets and to hold on to their cultural practices, while still benefiting to some extend from modern fuels. A noteworthy aspect in these studies is that most studies which use the energy ladder theory are conducted developing countries.

2.1.6 Value-belief-norms Theory

The VBN theory model has become one of the most popular and dominant paradigm models in environmental psychology (M. F. Chen, 2015). The VBN theory by Stern et al. (2000) is based on the Norm activation theory (NAT) by Schwartz (1977), but includes broader beliefs about the biosphere caused by human actions. VBN causally explains environmental realization initiation at the individual level according to an individual's values. A visual representation of the VBN can be found in Figure 5.

Personal values generate beliefs, as proposed by the VBN theory. Stern et al. (2000) proposed three values which influence an individual's ecological worldview: Biosphere values, altruistic values and egoistic values. Biospheric values are connected to feelings regarding non-human species and the environment. Altruistic values are values connected to other people than yourself and egocentric values are values connected to yourself. The ecological worldview influences the awareness of consequences. The awareness of consequences involves a level of personal awareness of the consequences of the environmental threats around an individual. Awareness generates a sense of responsibility to act. The responsibility to act refers to a person's feeling of responsibility for the negative consequences of not acting pro-social. The pro-environmental personal norm refers to a person's feeling of moral obligation to perform or refrain from specific actions

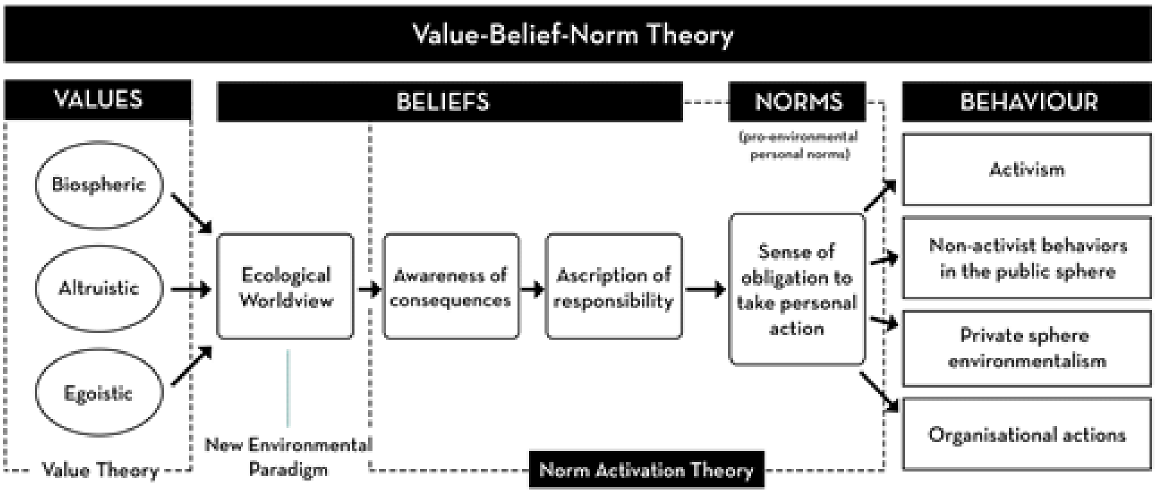

Figure 5 - Value-Belief Norm Theory by Stern (2000)

Research conducted by Fornara et al. (2016) used VBN to predict the intention to improve household energy efficiency in Italy. In this research a model was created based on VBN and TPB. Along with the factors mentioned in these theories the variables descriptive norm and trust in information sources were also included. Moral norms and informational influence emerged as the most powerful predictors of the intention to use renewable energy devises. Overall, the results substantially support the model framed on the VBN theory. The exception is the non-significant relationship between awareness of consequences and the ascription of responsibility, instead a direct link emerges between awareness of consequences and moral norms.

2.1.8 Comprehensive Action Determination Model

The Comprehensive Action Determination Model (CADM) proposed by Klöckner & Blöbaum (2010) is a theoretical framework used in psychology and behavioural sciences to understand and predict human decision-making and action. It's designed to provide a comprehensive understanding of the various factors that influence an individual's behaviour, particularly in complex or multifaceted situations. CADM integrates multiple psychological theories and concepts to create a holistic model that accounts for diverse influences on decision-making. It considers various factors across different levels of analysis, such as individual cognitive processes, social influences, environmental factors, and motivational aspects.

The model typically includes the components cognitive processes, social influence, environmental factors and motivation aspects. CADM examines the cognitive aspects involved in decision-making, including perception, information processing, reasoning, memory, and problem-solving. It looks at how individuals gather, interpret, and utilize information in making decisions. Social Influences consider the impact of social factors such as social norms, peer influences, cultural values, and societal expectations on an individual's behaviour. These influences can significantly shape choices and actions. CADM acknowledges the role of the physical environment by including environmental factors. These include, situational cues, accessibility, and environmental stimuli, in influencing behaviour. Environmental conditions and contexts can affect decision-making processes. The model also addresses motivational factors such as emotions, desires, goals, and incentives that drive behaviour. It examines how individual motivations and goals interact with other elements to determine actions.

CADM is dynamic and recognizes the interplay between these different factors, understanding that behaviour is often the result of complex interactions between cognitive, social, environmental, and motivational elements. By considering these diverse influences, CADM aims to provide a more comprehensive and nuanced understanding of human behaviour and decision-making processes in real-world contexts. This comprehensive approach allows for a more holistic analysis and prediction of behaviour compared to models that focus on single factors or aspects.

A research conducted by Sopha & Klöckner (2011) researched the adoption of wood pellet heating of Norwegian households, by using a model which combines CADM an perceived technological characteristics of wood pallets heating. The results indicate that indicated that the model received reasonable support by the empirical data and is able to explain 56% of variation in the variable underlying heating system choice. This implies that the integrated model is a promising approach to explain choice behaviour of wood pellet heating and analysing its diffusion processes.

2.2 Factors influencing residential heating choices.

This section focuses on factors that have been proved in previous researches that significantly influenced the choice behaviour of homeowners regarding RHS. Many individual decision-making models and theories differ undeniably in methodology and results. This is caused because they rely on different theories and have been conducted in different times and/or places. However, it is important to review previously conducted research and to determine all the variables which could have an influence on RHS choices, to gain a thorough understanding of the potentially influential factors.

In Appendix B a table is presented where the same records are included as in section 2.1. In this appendix all the variables which have been found significant in these studies are collected. A research conducted by Wilson & Dowlatabadi (2007) stated that the factors influencing energy decision-making can be divided in personal and mental factors. It is also important to consider the different attributes of the different technologies, which are covered by the RHS attributes. In this research the variables found in research are divided among the same groups. To give structure to the literature study these groups are further divided into subgroups. To further increase the readability of this section, Appendix B is summarized in table 3 t/m 5.

Table 2 *– Segmentation of literature study*

Personal variables	Mental variables	RHS attributes
Socio-demographic variables	*theoretical variables*	*economic attributes*
Dwelling variables	*individual variables*	*Technical attributes*
Spatial variables	behavioural variables	Convenience attributes
		Environmental attributes

Table 2 describes the structure of the literate study. This section starts with an overview of personal variables which are further segmented into sociodemographic variables, residential dwelling variables and spatial variables. Following this mental variables are explored, these variables divided in the following groups; theoretical variables, individual variables and behavioural variables. Finally, this section will focus on relevant attributes of sustainable heating systems. Which will be divided into economic variables, technical variables, convenience variables and environmental variables. Analysing the factors that affect how people choose their home heating systems helps us understand how homeowners in the Netherlands make these decisions.

2.2.1 Personal variables

In Table 3, The personal variables are identified through previous research. To enhance clarity, these variables are categorized into three distinct groups: sociodemographic variables, residential variables, and spatial variables. This organization aids in distinguishing the different types of factors and their specific influences. Additionally, the variables are ordered based on their frequency of occurrence in the literature, as indicated in the "N" column of table 3. This column provides a count of how often each variable has been found significant in existing studies, reflecting its relative importance. Below the table, further explanations is offered for each variable to provide additional context and details.

Table 3 *– Summary of the previously found significant personal variables*

Sociodemographic variables		Residential characteristics		Spatial variables	
Variable name	N	Variable name	N	Variable name	N
income	14	Size of dwelling	5	Population density	6
Education	12	Previously invested	1	Climate	3
Age	11	Current insulation	2		
Gender	9	Forrest ownership	3		
Household composition	7	Type of dwelling	5		
Employment	3	Age of dwelling	5		
Ethnicity	1	Ownership of dwelling	5		
Political preference	1				

Sociodemographic variables

A research conducted by Bai et al. (2023) identified socio-demographic characteristics as one of key driving factors for clean heating. Other research also acknowledge the importance of the inclusion of socio-demographic characteristics. This has led to numerous studies including social-demographic characteristics when researching RHS choices (ex. Bai et al., 2023; Lillemo et al., 2013; Meles et al., 2022; Ruokamo, 2016). However, when comparing records, differences can be found regarding the influence of individual sociodemographic variables is examined.

Age is a variable which has been included in numerous studies. The results of several studies show that age has a small significance impact on the RHS choices (ex. Q. Chen, 2021; Meles & Ryan, 2022; Ruokamo, 2016; Sovacool et al., 2021 among others). Michelsen & Madlener (2012) found a negative relationship between age and the perceived utility generated by the choice for a sustainable RHS. Which implies that younger people favour more innovative RHS like pallet-fuelled or a heat pump. This is backed up by Poblete-Cazenave & Rao (2023), they stated that heat pump adopters are more likely to be younger, with a peak around age 30. Contrary to these findings are the findings presented by De Bekker-Grob et al. (2010). Here the significant relation of age was positive. Which implies that older households are more willing to use a sustainable RHS, in this research there was argued that older people might want to live in a more healthy environment. Most studies found age has significant impact, while a study conducted by Lillemo et al, (2013) stated that age is insignificant and did not influence the RHS choices. A study conducted by Karytsas (2018) found that age impacts the RHS choices indirectly, through the knowledge an individual has regarding the installation requirements of RHS.

Income of the household has proven to have an positive significant effect on the choice of sustainable RHS in several different studies (e.g. Q. Chen, 2021; Karytsas, 2018; Lillemo et al., 2013 among others). In the energy ladder theory presented in previous section of the report stated that if income rises individuals are more likely to choose a heating system which uses a more sustainable fuel. This is backed by a research conducted by Michelsen & Madlener (2012), they found that a rise of income has a positive impact on the probability to choose a gas-fuelled heating systems. The positive relation is strongest for an electric heating system (e.g. heat pump). For oil-fuelled heating systems an negative relation is found in this study. The results presented in a study by Bai et al. (2023) contradict the energy ladder hypothesis by finding that the household energy structure does not improve with increasing income. In the study by Michelsen & Madlener (2012), income was one of the main variables influencing

RHS decisions. This is contradicted by a study conducted by Meried (2021) which concluded that differences between income groups do not exert a strong impact on which type of heating technology is applied. Another study found a negative weak relationship between income and sustainable RHS (Poblete-Cazenave & Rao 2023). The results of this study show that the top-earners in society experience a lower willingness to adopt a heat pump. This result was explained by arguing that households with a higher income live in a larger dwelling, which is associated with higher cost and complexity of switching heating systems. Another study that included income when researching RHS decisions did not find any significant relationship between income and a more sustainable RHS (Brown et al., 2023; Meles et al., 2022).

Karytsas (2018) found that not only the income but also the field of employment is relevant. If a person's household includes a person who has an occupation, studies or interests related to environment, technology or engineering are more likely to adopt a sustainable RHS. This is also backed by results found by Karytsas et al. (2019). They investigated the influence of people who are self-employed or are involved in energy/environment, have a significantly higher willingness to pay and willingness to accept a sustainable RHS.

Another socio-demographic factor which is often considered in the selected literature, is the education level (of the homeowner). This is a factor which has been included and found significant in several studies (ex. Meles et al., 2022; Ruokamo, 2016; Sovacool et al., 2021). The effect of education level is comparable in different researches. An increase in educational level results in a higher chance of choosing a more sustainable heating option (Q. Chen, 2021). This relation is further explained by Karytsas (2018) by stating that a higher education leads to a higher awareness and knowledge regarding RHS. A research conducted by Meried (2021) further solidifies this statement by stating that education can increase the awareness of respondents about the negative effect of using solid fuels and the importance of having sustainable energy sources. A study conducted by Meles et al. (2022) found that the income variable is interrelated with the education variable. This study showed that, a university degree leads to a higher income, and, thus, increased opportunity costs. There is however a study which contradicts these statements. This study is conducted by Lillemo et al. (2013) and found that an higher education level is associated with a lower RHS investment probability.

When researching socio-demographic variables, researchers often consider the household size and the composition of the household. A study examining preferences of rural households regarding renewable energy sources, found that household size has a significantly positive relationship with choosing an sustainable RHS (Meried, 2021). According to these findings there can be stated that larges households have a higher probability of choosing an more sustainable RHS. However, a research examining the willingness of US consumers to electrify determined that household size not to be a significant value (Brown et al., 2023). Studies often make a distinguishing between households who do include children and households who do not have children. Q. Chen (2021) states that household with a larger fractions of children are likely to have higher preference for electric heating systems. However, this effect does not correspond with the study conducted by Meried (2021). This study argues that in an all adult household, a more flexible electric heating if favourable because these dwellings will be less occupied during the day. The results presented in a study by Sovacool et al. (2021) further emphasize on the importance of household composition. This study found that. It seems that younger people, and those with more children at home, are those more willing to change RHS.

Gender is a variable which is less explored in research. The researches which do include gender often contradict each other regarding the significance on RHS choices. A study conducted by Michelsen & Madlener (2012) found an significant relationship between female and gas powered heating systems. Here this relationship was explained by arguing that females may be less familiar with (newer) technology and might have a higher risk aversion when it comes to investment decisions. This explanation is backed by a study conducted by Karytsas (2018) by stating that men are more likely to be more knowledgeable regarding RHS compared to women. However, other articles determine gender to be insignificant when it comes to RHS decisions (Brown et al., 2023; Karytsas et al., 2019; Lillemo et al., 2013; Ruokamo, 2016). A study conducted by Meried (2021) provided an inconsistent result with the other included studies regarding the influence of gender. This study found that females are more likely to use more sustainable sources of energy. Here was argued that this is caused because traditionally; collecting fire wood, cooking, baking, and domestic works at large is exclusively left for females and they are exposed to be conscious about the health and environmental impact.

A study conducted by Poblete-Cazenave & Rao, (2023) found that Ethnicity influences RHS adoption as well. In this research conducted in the USA a distinction was made based on race (White, Black, Hispanic). The results show that White households are the most and Hispanic households least likely to adopt heat pumps respectively. However, the results of this study did not further investigate on underlying differences among the groups. Another study conducted in the USA assessing the influence of ethnicity on RHS choices/preferences, found that race/ethnicity did not significantly influence the RHS decision-making process (Brown et al., 2023). This study however did include the political preferences and found that being a democrat had a positive effect on the likeliness to adopt sustainable an RHS.

<u>Residence characteristics</u>

Residence characteristics are also incorporated in several different previously conducted analysis. Here several different characteristics are reviewed. A residence characteristic which is mentioned in several different articles is size of the dwelling. A research conducted in the USA found that households that live in a larger house are less likely to invest in more sustainable heating solutions, due to higher complexity and cost of installing an new RHS system (Poblete-Cazenave & Rao, 2023). These results do not correspond to the findings of a study conducted by Lillemo et al. (2013), who investigated the effects on choice of RHS choices in Norway. Here it was found that the household size had a positive significance with sustainable RHS adoption. Here it is reasoned that this could be due to the potential decrease in heating cost. Another study conducted by Rouvinen & Matero (2013) also investigated the influence of dwelling size in Finland, however they did not find a significant correlation. An important interrelation is highlighted in the study conducted by Poblete-Cazenave & Rao (2023). They found a strong interrelation with the sociodemographic value income and the size of a dwelling. This study was conducted in the US. So there can been seen that results differ based on location of the study.

Another factor related to the dwelling is the building year (age) of the dwelling. Studies conducted by Braun (2010) and Michelsen & Madlener (2012) used a choice experiment to find variables which influence a households' space heating decisions. These researchers found that the building age is an important determinant of the RHS used to heat the dwelling. This research found a negative significant relation between more sustainable heating systems and dwelling age. This implies that households living in a younger dwelling are more likely to invest in a more sustainable heating system. In both of these studies a positive significant relation is found towards non-sustainable options. An important limitation when including this variable is that this variable neglects any renovation on energy retrofits. The results found by the previously mentioned records are contradicted by the results found by (Ruokamo, 2016). Here it was stated that households living in an older dwelling are more likely to invest in an more sustainable RHS.

The house type has proven significant in several different studies. However, the effect of this variable differ over studies. Ruokamo (2016) found that houseowners which live in an apartment are a significantly less likely to invest in a more suitable RHS. This is contradicted by Braun (2010) who has stated that a high preference for electric heating was found when assessing residents of apartment blocks. Another study which focused more on the attributes of heating systems found that respondents who live in apartments are more willing to pay for a heating system with a moderate increase in home comfort of use, compared to those who live in a terraced or detached house (Meles & Ryan, 2022). Another study found that people residing in building apartments are less probable to be willing to adopt an new RHS and are less likely to be willing to accept higher installation costs, compared to people living in attached or detached single houses (Karytsas et al., 2019).

Krikser et al. (2020) researched the likeliness that a resident wants to switch RHS in the near future. He found that homeowners are more sceptical towards a new RHS compared to tenants. This could mean that house owners are satisfied with their current RHS. However, a study conducted by Lillemo et al. (2013) showed that being the owner of the house has significant positive effects on the investment likelihood, implying that ownership of the house increases the incentive to invest.

Several studies also reference forest ownership or proximity to the nearest forest. These studies all include wood-fuelled heating systems. These researchers are mostly conducted in Scandinavia where this is a commonly used sustainable heating system (Rouvinen & Matero, 2013; Ruokamo, 2016), or in the rural residential sector in developing countries (Q. Chen, 2021). The variable proved significant in all the researches which included the variable. Ruokamo (2016) found that the household forest ownership variable was a statistically significant interaction variable that positively affected solid wood heating selection patterns.

Other less frequently residential factors identified as significant are the current insulation value and the variable describing if a suitable renovation has taken place recently. A research conducted by Poblete-Cazenave & Rao (2023) specified that households that live in a dwelling with a lower insulation value, are less likely to invest in an heat pump. This could be caused because some heating solutions will be less suitable in some cases due to a combination of lack in insulation of the dwelling and heating capacity of the RHS. A research conducted by

Karytsas (2018) found that if there has not been invested in sustainable renovations in the last five years, the current homeowner is less likely to choose to invest in a more sustainable RHS.

Spatial characteristics

The results of a study researching household preferences of hybrid home heating systems conducted by Ruokamo (2016), suggested that individuals living in lower density areas are more likely to select ground heat, solid wood fired and wood pellet alternative systems than individuals living in towns and cities. A study conducted by Poblete-Cazenave & Rao (2023) found contradicting results. This study found that urban households show a higher probability of using an heat pump. According to this study this is several factors including urban heat islands and easier to access markets. A research conducted by Meried (2021) studied the difference between rural housing and urban housing. This research concluded that the location of the dwelling does not have a significant impact on RHS choice behaviour.

The second and last spatial variable which has been proven significant in the included literature is the climate in which the residence is positioned. Lillemo et al. (2013) found that living in a cold climate significantly increases the probability of investing in sustainable RHS. This is likely because more energy is used to heat the property and a more sustainable heating system can bring down the annual heating costs. A study by Sovacool et al. (2021) argueed that climate conditions play a role in affecting energy-related behaviour. This (in)directly results in an influence on the preferences of RHS.

2.2.2 Mental factors

Psychology has provided a large body of research on why people make choices based on a number of factors. Several models have been suggested to explain mental processes preceding choices. These various different models include divers variables. To structure this wide variety of variables, the variables are divided into; theoretical variables, individual variables and behavioural variables. All the variables discussed in this section are presented in appendix B which are further summarized in table 4. These variables are further explained below.

Table 4 *– Summary of the previously found significant mental variables*

Theoretical		Individual		Behavioural	
Variable	N	Variable	N	Variable	N
attitude/concern towards environment	8	knowledge of RHS	4	sustainable lifestyle	2
perceived behaviour control	3	moral norm	3	Preferred living room temperature	1
subjective norm	1	trust in friends and neighbourhood	1	perceived compatibility	1
biospheric values	1	Procrastination	1	leaves heating on all day	1
descriptive norm	1	intention to use renew energy	1	clothing choices in the house	1
injunctive norm	1	level of satisfaction with current heating	1	Unwilling to dispose of old equipment	1
ascription of responsibility	1			buyer of environmental friendly products	1

<u>Theoretical</u>

Perceived behavioural control is a variable refers which to an individual's belief regarding their capability to adopt and effectively use a RHS. It encompasses factors such as technical knowledge, financial resources, and the perceived ease or difficulty of installation and maintenance (Yazdanpanah et al., 2015). Higher perceived control often correlates with increased willingness to adopt sustainable practices (Meles et al., 2022; Sopha & Klöckner, 2011). Another variable which has been found significant not only in relation to the theoretical but also in studies researching individual and behavioural variables is attitude towards sustainable behaviour. Attitude towards sustainable heating systems involves the evaluation of the perceived benefits and drawbacks. Positive attitudes arise from perceptions of energy efficiency, cost savings, environmental friendliness, and improved indoor comfort (Dempsey et al., 2011). Conversely, negative attitudes might stem from concerns about perceived initial investment costs or uncertainties about performance. In the included literature, attitude has a significantly positive effect related to the likeliness to adopt a RHS (e.g. Fornara et al., 2016; Karytsas, 2018; Krikser et al., 2020 among others). Another variables which has been found significant in a study conducted by Meles et al. (2022) is the subjective norm. This variable pertains to the influence of social factors on decision-making. It reflects the perceived social pressure or encouragement from significant others, such as family, friends, or community to adopt a sustainable heating system. Strong subjective norms endorsing sustainability can significantly sway individual choices. Another research including subjective norm conducted by (Sopha & Klöckner, 2011) did not find a significant relationship when examining the influence of the variable. A study conducted by Fornara et al. (2016) used to VBN to predict the intention to improve household energy efficiency. In this study the influence of the variables bio-spheric values, descriptive norm, injunctive norm and ascription of responsibly all turned out to have significant impact. These all are also interrelated, meaning that they do effect each other.

<u>Individual</u>

The level of trust an individual places in the recommendations and experiences of friends and neighbours regarding sustainable heating systems can strongly influence their decision. Positive endorsements or warnings from trusted sources within one's social network can sway preferences. Fornara et al. (2016) found that the if the trust in the advisor of the RHS system is hight the likeliness to adopt to this type of RHS is also significantly higher than when a person lacks trust in this advisor. Individual tendencies toward delaying decisions or actions can play a substantial role. Procrastination might arise due to uncertainties about the decision-making process, fear of change, or the perceived effort involved in transitioning to a new heating system. When a person has a habit of procrastinating, this effects the decisiveness in the decision-making process. A person who is more decisive of nature has a higher change of adopting a new more sustainable RHS (Lillemo et al., 2013). Moral norms do have a significant impact on the RHS decision-making process. (Fornara et al., 2016; Meles et al., 2022; Yazdanpanah et al., 2015). Moral norms describe ethical principles and values concerning environmental responsibility significantly influence decisions. Individuals guided strongly by a sense of duty to reduce their environmental impact may be more inclined to choose sustainable heating options aligned with their values. Some persons are more inclined to use sustainable products/services. Research conducted by Fornara et al. (2016) found that personal commitment or dedication to incorporating renewable energy sources into daily life directly impacts the choice of a sustainable residential heating system. Strong intentions rooted in environmental consciousness often steer individuals towards renewable energy-based heating solutions. Personal familiarity and understanding of various heating technologies, their benefits, drawbacks, and environmental impacts are pivotal personal variables (Karytsas, 2018; Sovacool et al., 2019). Higher levels of knowledge significantly increase the chance to make informed decisions favouring sustainable heating solutions (Michelsen & Madlener, 2012). The last personal/individual variable was found in a research conducted by Meles et al. (2022). They found that Personal satisfaction or dissatisfaction with the existing heating system significantly shapes the readiness to explore and adopt sustainable alternatives. Dissatisfaction with aspects like inefficiency, costliness, or environmental concerns often prompts individuals to consider and switch to new sustainable options.

<u>Behavioural</u>
Individuals inclined towards eco-conscious living may prioritize sustainable heating options that align with their broader environmental values and practices. Sustainable behaviour significantly influences the likeliness to choose for a more sustainable RHS (Brown et al., 2023; Sopha & Klöckner, 2011). The variables mentioned in literature are often habits/behaviours that individuals preforms. Personal temperature preferences impact heating choices. Individuals comfortable with lower indoor temperatures might favour heating systems that operate efficiently at lower settings, reducing energy consumption. This might be an explanation for the significance found by Lillemo et al. (2013). This same reasoning can be used to explain the significance influence found by (Sovacool et al., 2019) of leaving the heating on all day and clothing choices of individuals in the house. The last behavioural variable which has been found significant is personal behaviours in purchasing environmentally friendly products indicates a proclivity towards sustainability. Individuals habitually choosing eco-friendly products might exhibit a higher propensity to select sustainable heating systems aligned with their environmental values (Lillemo et al., 2013).

2.2.3 System attributes preferences

RHS attributes are mostly mentioned in researches that use a choice experiment. These researches include attributes to find which attribute affects choice behaviour. Often these effects are analysed using models which allow the researcher to find interrelations between other variables. In this segment, the system attributes which previously had a significant relation to the RHS choice will be discussed and elaborated on. When considering relevant system attributes that have proven significant in other studies. Differences can be found. The researched RHS attributes included in previously literature are quite diverse. In appendix B an overview of the attributes of a RHS which previously have been found significant can be found, this is further summarized in Table 5. Previous literature written by Mahapatra & Gustavsson (2009) segments the attributes into four main aspects (Economic, technical, environmental and convenience) to provide a clear and understandable structure the same division is used in this research.

***Table 5** – Summary of the previously found significant system attributes*

Economic		Technical		Convenience		Environment	
Variable	N	Variable	N	Variable	N	Variable	N
Heating costs	8	Local provider	3	Increased home comfort	4	Environmental sustainability	1
Investment costs	3	Reliability of a system	1	Control of indoor temperature	2	Neighbourhood improvement	1
Contract length	1	Dependence on grid	1	Nuisance	1	Smoke level	1
Operating costs	1	Type of heating system	1	Recommended by	1	Local air quality	1
Fuel price	1			Comfort of use	1		
Increase in home value	1			Time required to collect information	1		

<u>Economic</u>

Numerous studies have been conducted regarding the preferences of individuals when reviewing several sustainable RHS. However, some values are mentioned more often than others. Investment costs related to a new more sustainable RHS, is the attribute that has been found significant the most. The effect of the investment cost of the RHS on the willingness to adopt has been found negative in all of the studies in which it was proven significant (ex. Mahapatra & Gustavsson, 2009; Scarpa & Willis, 2010; Tapaninen et al., 2009). This means that if the investment costs of a RHS system rise, fewer people are willing to invest in this specific RHS. Even though the negative significance relation of the investment cost is undisputed in all the included literature the weight attached to this variable differed. Several studies determined investment costs to be the most influential attribute of an RHS (Côté & Pons-Seres de Brauwer, 2023; Michelsen & Madlener, 2016). Another study conducted by Scarpa & Willis (2010) found that British households deem a decrease in energy bills nearly 3 times more important than the change in the investment cost.

This same conclusion was found in a study conducted by Rouvinen & Matero (2013). They found that annual heating costs were deemed more important than investment costs. These annual heating costs or usage costs are mentioned in several articles (e.g. Lillemo et al., 2013; Tapaninen et al., 2009; Tiellemans et al., 2022 among others). Most of the studies which included heating cost found a significant negative relation. This means that an increase in heating costs results in a lower willingness to adopt a suitable RHS. A study conducted in the USA found that younger people are willing to accept an increase on energy and still choose a sustainable heating solution (Brown et al., 2023). Most studies determined the significance of annual heating costs. However, a study conducted by Chen (2021) found a non-significant relationship when examining annual heating costs.

Another economic value that has been found significant frequently in related literature is the operating costs. Operating costs refer to costs that are being made to keep the RHS running with the exception of fuel costs. This has been in included different research (e.g. Rouvinen & Matero, 2013; Ruokamo, 2016; Scarpa & Willis, 2010 among others). The relation of this factor is corresponding with the other cost variables found significant by other researchers, as the operating costs increase the perceived utility of a RHS decreases. Which means a negative relation is in place.

Another economic variable that has been found significant in several research is the fuel price (Côté & Pons-Seres de Brauwer, 2023; Michelsen & Madlener, 2016; Poblete-Cazenave & Rao, 2023; Tapaninen et al., 2009). Michelsen & Madlener (2016) Found that the current fuel price has a positive relation to willingness to switch. Meaning if the gas price rises people are more likely to switch to a more sustainable RHS. Côté & Pons-Seres de Brauwer (2023) found that price hedging was one of three drivers shaping adoption decisions for German and Swiss respondents, they argued that this could be explained by the recent increases in the price of natural gas in Europe on which German and Swiss heating systems heavily rely. This fuel price could also relate to the variable contract lengths which have been found significant in research conducted by Scarpa & Willis (2010). Krikser et al. (2020) argued that It is possible that district heating is seen as a complex system that deals with long-lasting contracts of up to 10 years This could give rise to fears that this would be expensive in the long term.

Another significant relevant variable is the increase in home value. Mahapatra & Gustavsson (2009) found that the adoption of sustainable RHS increases the market value of a house. This lead to a significantly positive relation between house value and willingness to invest in a sustainable RHS.

Technical

There are different types of heating system available on today's market. These technologies differ in fuels and attributes. The preferences for these technologies, and their attributes differ. A research conducted by Krikser et al. (2020) found results that clearly show that district heating (heated by green energy) is the preferred heating option for the analysed German households. The ranking of the other alternatives is district heating from fossil fuels, heat pump and gas (in that order). Another research conducted in Sweden that explored homeowners preferences, found that respondents perceived the relative advantages of district heating to be greater than for the other included heating systems (Mahapatra & Gustavsson, 2009). Several researchers using a choice experiment highlighted the importance of including the technology type variable, here is explained that different RHS might have underlying attributes which are not mentioned in the research (Lillemo et al., 2013; Liu et al., 2023).

An technical variable discussed by several researchers is the technical reliability of a system. A research conducted by Michelsen & Madlener (2016) found that non adopters perceive heat pumps as reliable, but perceive a high fault liability when considering pallet heating. This is presented as one of the reasons why non-adopters are more likely to choose a heat pump over a pallet heating system. A study conducted by Côté & Pons-Seres de Brauwer (2023) found that energy security is one of the key drivers of heat pump adoption. Another study researching what influences the Swedish homeowner to adopt district heating found that a reason to choose district heating over other technologies was influenced by the functional reliability of the system (Mahapatra & Gustavsson, 2009). A study conducted by Stolyarova et al. (2015) found a significant relationship when examining the influence of warranties and energy performance certificates. This attribute describes the technical reliability. This research found that homeowners of detached houses are indifferent to energy performance certification but that homeowners of apartments are very interested in certification.

The variable independent on fuels from the grid is found to be important to consider to analysis the owners decision-making process by research conducted by Michelsen & Madlener (2012). This research found that independence is highly statically significant for all the RHS. A negative influence can be found on gas and oil, but a highly positive impact can be found on heat pump and pallet heating. A research conducted by Q. Chen (2021) found that Households prefer to adopt heating system with high quality energy sources, produced in a local environment. Krikser et al. (2020) also found that district users have a preference for local providers.

Convenience

The expected increase in home comfort is one of the variables that has been found significant by several researchers (e.g. Liu et al., 2023; Tiellemans et al., 2022; Un et al., 2021 among others). Research by Meles et al., (2022) showed that the variable increase in home comfort is significant, but this research also stated that the relative importance of an increase in comfort is relatively small. All of the included studies found that the relation of home comfort and willingness to adopt a certain technology is positive. Meaning if the home comfort increases, the likeness of adopting also increases (Liu et al., 2023). However, Michelsen & Madlener (2016) found that homeowners perceive that more sustainable RHS leads to a decrease in home comfort. Because of this, it is argued that homeowners are more likely to stick to a fossil-fuelled RHS.

Another comfort factor that has been found significant in previously conducted literature is the comfort of use, this describes the required work to ensure faultless operation of a heating system, (e.g. cleaning and adjusting the device and adding fuel). Results by Ruokamo (2016) showed that the comfort of use has a positive effect on the willingness to adopt a RHS. This research explained the popularity of district heating is partly caused by the high comfort of use of this RHS. Other research also included comfort of use and found a significantly positive relation (e.g. Michelsen & Madlener, 2016; Sovacool et al., 2021; Tapaninen et al., 2009 among others). This was expected. Meaning that the if the comfort of use increases the utility also increases.

Another factor influencing the convenience of the system is the control of indoor temperature, this variable is researched by Stolyarova et al. (2015). This research found that households prefer offers that propose control temperature settings. If this is influenced by third parties some households may reject this technology due to data privacy concerns, considering that it is an invasive setting.

When considering convenience not only positive significant relations are found. Some studies also included a nuisance factor. Nuisance is caused by various reasons such as preparatory construction measures or work, which will temporarily decrease the living comfort. Research conducted by Scarpa & Willis (2010) included the inconveniences of the installation process in their research. They found the effect of perceived inconveniences of the installation process are all negative, implying that an increase in inconveniences decreased the probability of a respondent choosing a system with this attribute. Research by Meles et al. (2022) also showed that Installation hassle is a determinant of the uptake of new home heating systems but has a relatively small impact. Research by Liu et al. (2023) found a significantly negative relationship between nuisance caused by renovation projects and participation which has been found in several studies. However, not all individuals are equally affected by the presence of nuisance. Some may be more sensitive to nuisance, while others may be less so.

Another factor influencing the convenience of the system is the time required to collect information on different RHS. This was included in research conducted by Mahapatra & Gustavsson (2009). This variable was found to have a significantly negative influence on the willingness to adopt a new sustainable RHS.

Environmental

Among environmental attributes of the RHS, environmental sustainability was mentioned the most. The environmental sustainability describes the level of pollution the RHS produces when heating a home. A research examining heterogeneity in preferences for the various home heating attributes found, that individuals would prefer a heating system alternative that has a higher environmental sustainability (Meles et al., 2022). This means a positive relation can be found between environmental sustainability and the attractiveness of RHS (Ruokamo, 2016). Other studies further strengthen these statements by finding the same type of positive significant relation (e.g. Côté & Pons-Seres de Brauwer, 2023; Rouvinen & Matero, 2013; Tapaninen et al., 2009 among others). While environmental sustainability is the variable that often has been found significant by several researchers, other variables connected to the environment where also found to influence the decision-making of homeowners in previous literature. Lillemo et al. (2013) found that improving local air quality was a motive for changing to a more suitable RHS. The results showed that buyers of different technologies find the improvement of local air quality equally important. A research conducted by Mahapatra & Gustavsson (2009) also found a small significantly positive relationship. Other studies determined smoke level (Côté & Pons-Seres de Brauwer, 2023) to be significant along with general neighbourhood improvement (Liu et al., 2023) which all relate to the local environment/air quality.

2.3 Conclusion

This chapter covers the theories that are mostly used when researching the preferences of homeowners on RHS. The theories mentioned are the random utility theory, the theory of planned behaviour, the value-belief theory, and the diffusion of innovation theory. Based on the knowledge acquired, the random utility theory is selected as the most suitable for this research. Most of the research conducted in other countries which asses choice behaviour have used random utility theory and this theory has proven to excel in capturing individual preferences, allowing for an insight into choices made by homeowners based on their unique considerations.

This theory also allows for connection to price parameters which can be used to predict the WTP. Theories like the Theory of Planned Behaviour, Diffusion of Innovation, Goal Framing Theory, Energy Ladder, Value-Belief-Norm Theory, Theory of Value, and Comprehensive Action Determination Model might lack the precision, flexibility, or empirical support needed for a nuanced analysis of residential heating system preferences. However, it is important to be wary of the limitations of the Random utility theory. It is a powerful tool for modelling individual choices, but their application should be approached with a critical understanding of their assumptions and potential shortcomings.

The second section of the literature study provided insight into the factors which previously have been found significant in other studies. In Appendix B a schematic overview can be found. This table provides an overview that mentions all the factors that influence a homeowner's decision-making along with the research that found a significant relationship. To provide a readable and clear structure, the variables that influence the RHS decision-making were divided in Personal variables, mental variables and system attribute preferences. Table 6 provides a summary of Appendix B, highlighting the variables that were found to be significant the most frequently. In this table, the variables which were mentioned once are neglected to reduce the size of the research and focus on the most important factors.

***Table 6** – Summary of variables which have been found significant the most*

Personal variables		Mental variables		RHS attributes	
Variables	N	Variables	N	Variables	N
Socio-demographic		**Theoretical**		**Economic**	
Income	14	attitude/concern towards environment	8	Heating costs	12
Education	12			Investment costs	14
Age	11	perceived behaviour control	3	Contract length	2
Gender	9			Operating costs	7
Household composition	7	**Individual**		Fuel price	3
Employment	2	Moral norm	3	**Technical**	
Ethnicity	3	knowledge of RHS	4	Type of heating system	9
Residential		**Behavioural**		Reliability of a system	5
Size of dwelling	5	sustainable lifestyle	2	Local provider	2
Type of dwelling	5			**Convenience**	
Age of dwelling	5			Recommended by	3
Ownership of dwelling	5			Increased home comfort	6
Forrest ownership	3			Nuisance	8
Current insulation	3			Comfort of use	5
Spatial				**Environment**	
Population density	3			Environmental sustainability	9
Climate	6				
				Local air quality	3

3. Methodology

In this chapter the methodology is explained that is used to identify distinct market segments based on their residentials heating system preferences and computing their willingness to pay, uncovering the heterogeneity in decision-making criteria among homeowners in the Netherlands. By comparing several different previously used methodologies the most suitable one is selected. The choices made in this section functions as the foundation for the survey design. Section 3.1 describes the choice experiment. Several options are examined and reviewed. The following section (3.2) elaborates on the modelling approaches used in the study. In section 3.3 a conceptual model is presented, which is based on the previously conducted literature. The important covariables found are included along with the applicable theories. The conceptual model represents the choice behaviour of a homeowner along with the included variables.

3.1 Choice experiment

This chapter of the research elaborates on the methodology used to determine the willingness to pay for RHS. When considering different RHS, different choices are made by Dutch homeowners. To further understand the choices made by Homeowners in the Netherlands, their preferences regarding certain characteristics of an RHS can be investigated. When considering a RHS with multiple different attributes (e.g. investment cost, installation hassle), this is considered a multidimensional preferences for the attributes of the alternatives, which means that different preferences can be appointed to different attributes. When considering multidimensional choices it is not possible to ask homeowners what they think drives their choices. 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). 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. The different options of data collection are determined based on Figure 6, under the figure the terms are further explained.

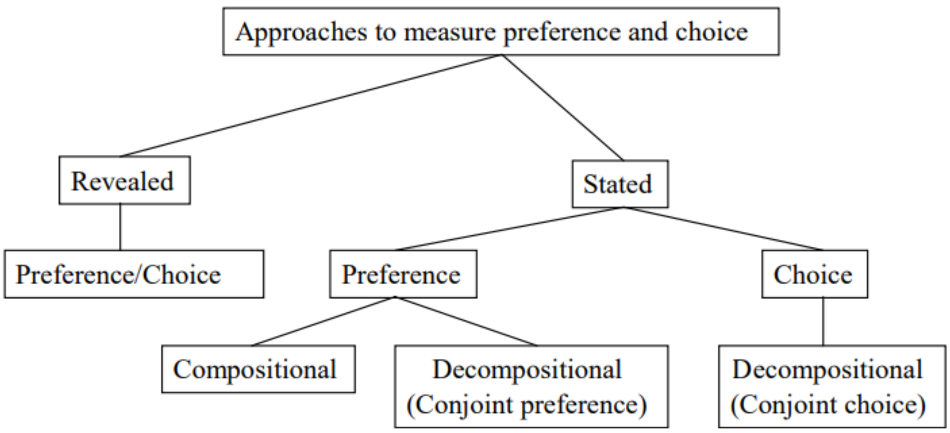

Figure 6 - Schematic overview of discrete choice method (Kemperman, 2000)

Revealed preference data is data which is based on observations made on choices which are made by people in real-life. The results of a revealed preference model are highly trustworthy. However, when using revealed preference it is difficult to access new not yet existing choices, because these are not yet real-life situations. Because the choice made by an individual, is based on real-life observations no real insight can be gained in the importance of the separate characteristics of the choice alternative influencing the choice behaviour. When presented with the options the total set of characteristic a person chooses from is unknown. Collecting revealed preference data is a resource-consuming process, because only a single observation can be gathered from each respondent (Bradley, 1991). When collecting stated preference or choice data, a respondent is presented with hypothetical choices/attributes. The choices are predetermined and can represent the real world but can also represent not yet existing choices/attributes. In this research the stated method is better suiting because a new RHS in an existing home is a question based on hypothetical choices

When considering stated experiments, a distinction can be made between stated preferences and stated choice experiments. When using the stated preference methodology , a respondent is presented with a question in which he/she needs to evaluate the attractiveness of the levels of each attribute. Then, respondents are asked to indicate the relative importance of each attribute. When using the stated preference methodology it can be determined which attributes are perceived as more important by the respondent. By multiplying the attractiveness and the importance scores of each level and attribute, the researcher can derive an alternative's overall utility and predict choices. Limitations of the this approach are: respondents may not hold all else equal when they provide ratings for the levels of an attribute; social desirability effects may occur; respondents may answer on the basis of their own range of experience over existing products; any redundancy in attributes can lead to double counting; there is little chance to detect potential nonlinearity in the part-worth function; no respondent evaluation of choice or purchase likelihood can be obtained; and finally, respondents cannot express certain trade-offs among attributes (Kemperman, 2000).

When considering the stated choice a respondent is presented with a predefined choice set up by the researcher with 2 or more alternatives. The respondent is asked to choose one of the options rather than ranking the options forcing the respondent to make an absolute decision. This decision comes closer to real live applications as is it reflects actual choice behaviour forcing the respondent in a buy not buy situation. This approach allows researchers to effectively predict discrete choices, as it captures the binary or categorical nature of decision-making, making it suitable for forecasting market behaviour or demand. Since this research is trying to predict the willingness to pay of Dutch homeowners. The stated choice methods is the most applicable method.

Based on the nature of the experiment and the presented methodologies, it can be concluded that the stated choice methodology is the best approach in this study. When comparing the stated choice methodology to the stated preference methodology, several advantages can be determined. First of all, choice tasks are closer to real world behaviour when considering RHS, because in a real world situation an RHS is not ranked but is chosen because, generally speaking there is only one RHS used to heat an individual dwelling. Secondly, choice tasks allow for predicting what homeowners will buy and how much they are willing to pay for it, preferences experiments need additional steps to be taken because only preferences can be determined (Kemperman, 2000). A disadvantage of stated choice models is that the choice data provides no information on the not chosen alternatives, this might lead to difficulties when estimating a WTP model.

3.2 Modelling approach

A discrete choice model will be used to estimate the WTP of Homeowners in the Netherlands for RHS. The discrete choice model allows to quantify the fluctuation of the WTP caused by changes in attribute levels, by considering the degree of importance of the attribute or level based on the data. As previously stated, the RUT assumes that a person (*n*) chooses an alternative (*j*) with a higher utility than all other alternatives (*i*). if the alternatives are not similar:

$$U_{jn} > U_{in} \; \forall \; i \neq j$$

To determine the total utility (U_{jn}) an individual (*n*) experiences from an alternative (*j*) a systematic utility (V_{jn}) is summed with an error term (ε_{jn}). The systematic utility is the utility that is derived from all the observed variables. The error term represents everything that has not been measured (ex. Randomness of people, unobserved attributes, measurement errors, and taste heterogeneity).

$$U_{jn} = V_{jn} + \varepsilon_{jn}$$

In the realm of discrete choice modelling, researchers explore the decisions individuals make when presented with options that have discrete and defined alternatives. This methodology section delves into various sophisticated models employed to analyse and comprehend these decision-making processes. By integrating these models, this research aims to analyse, and predict the nuanced decision-making processes underlying RHS choices, contributing to a comprehensive understanding of the decision contexts regarding RHS.

3.2.1 Multinomial logit model

The Multinomial Logit (MNL) model, is a model that is frequently applied analysis technique when conducting a Stated Choice Experiments. It serves to articulate a respondent's utility in relation to their choices, effectively predicting their preferences within a given scenario (Kemperman, 2000). MNL models are a type of statistical model used in situations where there are multiple categories or outcomes for a dependent variable. These models are an extension of the logistic regression model, which is used for binary classification problems (two categories). The MNL model can be described using the following formula:

$$P_{nj} = \frac{e^{V_{nj}}}{\sum_{k=1}^{j} e^{V_{jk}}}$$

In this formula P_{nj} is the probability that individual *n* chooses alternative *j*. V_{jk} is the observed component of individual *n* choosing alternative *k*. V_{jk} is the observed component of the number of alternatives in the choice set of individual *n.*

An important limitation of using the MNL is the Independence of irrelevant alternatives (IIA). IIA assumes that the relative preference between two alternatives remains constant even if additional alternatives are introduced. While this assumption simplifies modelling and computation, it comes with several limitations and implications. This might lead to some unrealistic choice patterns that might not accurately reflect real-world decision-making.

McFadden's ρ^2 test is valuable when employing a Multinomial Logit model because it helps to assess the goodness of fit of the model. It indicates how well the model explains the variation in the data compared to a baseline model. By using McFadden's ρ^2 test, you can evaluate the effectiveness of your Multinomial Logit model in capturing the observed choices and discern whether the model adequately represents the underlying preferences of respondents. McFaddens ρ^2 test uses the formula:

$$\rho^2 = 1 - \frac{LL_\beta}{LL_0}$$

The ρ^2 is the percentage of explained initial uncertainty and is based on the loglikelihood (*LL*) of the estimated model and the LL_0, which is the *LL* of the model in which each alterative has an equal chance of being chosen. When interpreting this model a higher ρ^2 value indicates that the model provides a better explanation of the variability in the data compared to a simple intercept-only model. A value of 0 implies that the model has no explanatory power and a value of 1 implies a perfect fit, where all the variability is explained by the model. However, the ρ^2 tends to be smaller when models in magnitude when assessing logarithmic compared to linear regression models. Even for well-fitting models an ρ^2 value around 0.2 to 0.4 is expected (Si & Kuhfeld, 2010).

3.2.2 Latent class model

A latent class model can be used in choice modelling to handle heterogeneity in individual preferences. Latent Class models handle heterogeneity by segmenting the population into distinct groups or segments with homogeneous preferences within each segment or class. Choosing between these models often depends on the nature of the data and the research objectives. The probability of choosing alternative j for an individual n in class c in a LC model can be represented as.

$$P_{nj} = p(C_j = c) \cdot P_{nj|c_j=c}$$

In this formula the P_{nj} is the probability that individual *n* chooses alternative *j*. $P(C_j=c)$ is the probability that individual *n* belongs to latent class *c*. $P_{nj|c_n=c}$ is the conditional probability of choosing alternative *j* given that individual *n* is in class *c*. The conditional choice probability within each class can be modelled using a model like the Multinomial Logit (MNL) model. For instance, the probability of choosing alternative *j* given class *c* might be formulated as;

$$P_{nj|c_n=c} = \frac{e^{V_{nj|c}}}{\sum_{k=1}^{i} e^{V_{nk|c}}}$$

Here V_{njc} represents the utility associated with alternative *j* of a an individual *n* in class *c*. *i* is the total number of alternatives. These Latent Class models aim to estimate both the probabilities of class membership and the choice probabilities within each class. These models identify distinct segments or groups within the population based on similarities in preferences and behaviours and model the choice behaviour within each segment separately.

3.2.3 Willingness to pay

The concept of marginal willingness-to-pay (WTP) in this context is explained by considering the changes in respondents' utility (satisfaction or preference) when the levels of certain attributes are varied. The marginal utility of an attribute refers to the change in utility or satisfaction that a respondent derives from a change in the level of a specific attribute, such as moving from a less efficient to a more efficient heating system. The marginal utility of price, on the other hand, refers to the change in utility due to a change in the price the respondent has to pay. To find out how much respondents are willing to pay for a change in the attribute, you take the ratio of the marginal utility of the attribute to the marginal utility of the price. Mathematically, it is expressed as in the formula below. This ratio tells us the monetary value respondents place on the change in the attribute.

$$Willingnesto\ pay = \frac{\text{Marginal utity of attribute}}{\text{Marginal utilty of price}}$$

In this study, the attributes are not continuous but discrete, meaning they are categorized into distinct levels, rather than a continuous scale of efficiency. Consequently, the calculated WTP represents the price respondents are willing to pay for a transition from the least attractive or least preferred level of an attribute to the most attractive or most preferred level. For example, if the attribute is the type of heating system, the WTP would indicate how much more respondents are willing to pay to switch from the least efficient to the most efficient heating system.

3.3 Conceptual model

This study proposes a conceptual model based on latent class model and the random utility theory (RUT). The conceptual framework presented in Figure 7, explains how a Homeowners in the Netherlands RHS choice is determined and which factors influence this choice. The layout of the figure is based on a study written by Walker & Ben-Akiva (2002). It is used to set-up a conceptual framework for generalized random utility models. In the figure the rectangular shaped figures represent the observable values included in this research and the oval shaped figures represent the non-observable values used in the research. The disturbance (indicated by dotted arrows) included in the model represents the error term which are also described by the utility theory by McFadden (1974). The remaining two arrows describe structural relationships and measurement relationships. Structural relationships refer to the connections or interactions between different elements within a system. These relationships focus on how components are organized and interconnected in a complex system. Measurement relationships, on the other hand, involve the quantitative aspects of the connections between elements. These relationships are based on numerical measurements or scales that represent the magnitude, quantity, or intensity of a particular attributes. Similar conceptual models have previously been used to examine other pro-environmental choices (Dimitropoulos, 2014).

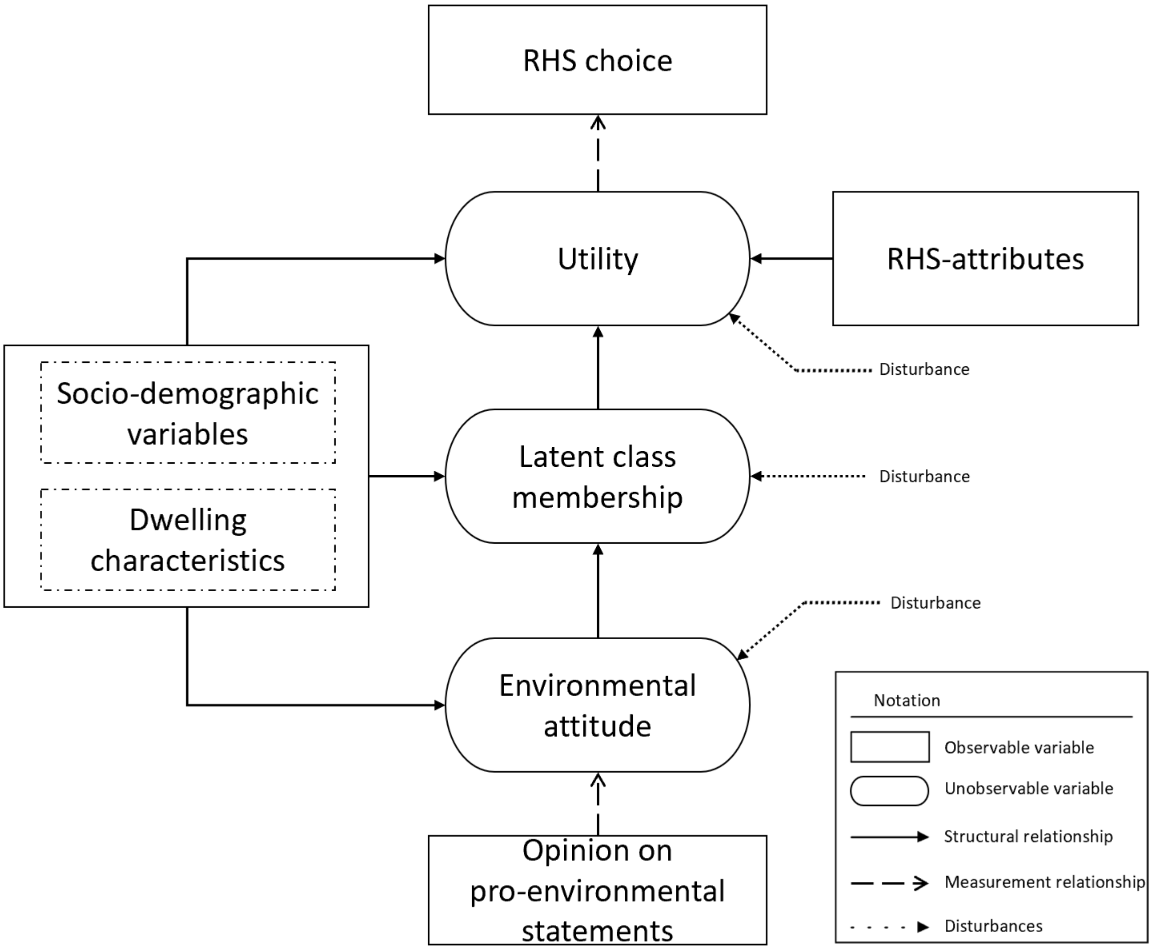

Figure 7 - conceptual framework

3.4 Conclusion

This chapter has outlined the methodology employed to identify distinct market segments based on homeowners' residential heating system (RHS) preferences and to quantify their willingness to pay (WTP) for various RHS attributes. By comparing multiple methodologies in the literature study, the most suitable approach was selected to provide a robust foundation for the survey design and choice modelling in this study. The choice experiment was developed to simulate real-world decision-making by presenting respondents with hypothetical RHS options. Stated choice is selected as the suitable methodology to use, because this simulates the future choice of RHS the best. This approach will be used to capture Dutch homeowners' preferences , which later can be used to predict WTP. The segments in the market can be made using statistical methodologies. In this experiment the Multinomial Logit (MNL) will first be used followed by the Latent Class models. These models allow for a nuanced analysis of decision-making patterns and enable segmentation within the population, accommodating variations in preferences across homeowner groups. The chapter concludes with a conceptual framework based on Random Utility Theory (RUT) and previous literature. This framework provides a quick insight in how the research is planning to determine the utility of homeowners and which factors effect it.

4. Survey design

The goal of this research is to predict WTP for RHS of Dutch homeowners. As previously mentioned a stated choice experiment will be included in a survey to gather the data which will be used for the statistical analysis,. The questionnaire was designed using LimeSurvey. LimeSurvey is an advanced online survey system to create quality online surveys. The software is used all over the world by companies, universities and individuals. The survey will be available in both English and Dutch, because homeowners in the Netherlands do not necessarily have to understand Dutch. It is expected that the Dutch survey will be used considerably more but to not exclude anyone from the survey, an English version is also available. Respondents can change the language at the start of the questionnaire to their preferred version. After selecting the preferred language, the respondents are forwarded to an introduction page of the survey where they were asked to agree with the terms and conditions. The terms and condition are mostly related to privacy. Once the terms and conditions were accepted, 2 inclusion questions needed to be answered. These questions where *"Are you currently (co)owner of a dwelling in the Netherlands?"* and *"Do you currently use gas to heat your home?"* These questions where included to ensure that the respondents where part of the research population. If the answer to either of these questions was "*no*" the respondents were not able to take part in the survey. After the inclusion variables the survey commenced.

The last section presented in the survey was the choice experiment. This experiment presented the responded with several alternative RHS to choose from. To generate this experiments several steps needed to be taken. These steps are mentioned in the first part of this section. In this segment there will be determined which variables will be in and excluded. This is mentioned in the second part of the study, there will be mentioned which variables found in the literature study will be incorporated into the study. Finaly some additional information needed for a survey design will be explained.

4.1 Experimental design

This study employs a stated choice experiment. Selecting the right experimental design is important step in the methodology. Among the available experimental design options, two primary approaches stand out: the full factorial design and the fractional factorial design. The full factorial design examines every conceivable combination of attribute levels, providing an exhaustive but thorough exploration of their collective impact on the outcome variable. Contrary to this, the fractional factorial design can be used. This design strategically reduces the number of experimental runs while trying to capture the influence of attributes on the outcome. A fractional factorial design offers efficiency in reducing the number of runs required, but it's imperative to acknowledge its trade-offs. The deliberate reduction in experimental runs may inadvertently overlook complex relationships among attributes. In this research a fractional factorial approach is more suitable, given the resource-intensive nature of the full factorial design. The full fractional design, presents practical challenges that surpass the scope and feasibility of this particular research.

The implementation of a fractional factorial design demands a strategic and efficient approach. The design selected impacts the experiment, including its efficiency, efficacy in revealing essential effects, and the overall interpretability of the results obtained. A well designed fractional factorial experiment seeks to estimate significant effects utilizing the limited available resources. It aims to gain insights into the relationships between attributes and choices, all while navigating the constraints imposed by factors like time, budget, and the available sample size.

4.1.1. Selection of attributes

The first step in generating a fractional factorial design is selecting relevant attributes of RHS. Attributes are the characteristics or features of a product, service, or policy. The attributes for RHS where selected for this experiment through a literature study, this is presented in section 2.2.3 of this report. The attributes which where most frequently significant in the previously conducted studies were included in this research. The inclusion of RHS attributes in the choice experiment is limited to five to ensure respondent clarity and understanding while aligning the required sample size with the research's time constraints. In table 7 a short overview containing the definitions of the attributes is provided, along with their corresponding levels. Underneath the figure the attributes and levels will be further explained.

Table 7 *– Overview of the selected attributes and corresponding levels*

Attributes / level	description
Technology	
Heat pump	Technology refers to type of residential heating system which will be used to head a dwelling.
District heating	
Duration of renovation	
1 day	Duration of renovation refers to the scale and extent of changes being made to a building or space.
1 week	
1 month	
3 months	
Investment cost	
€8.000	Investment cost refers to the initial cost or amount of money required to purchase or install a product or service.
€20.000	
€30.000	
€50.000	
Energy costs	
€0/year	Energy cost refer to the annual cost for the electricity of residential property. Which is made up to a large extent out of energy costs used for heating.
€500/year	
€1.500/year	
€3.000/year	
Reduction in CO_2 production	
5%	Reduction in CO2 emissions refers to the decrease in the release of carbon dioxide into the atmosphere, as a result of using a more efficient or sustainable heating system.
15%	
30%	
55%	

<u>Technology</u>

The technological alternatives which are included in the experiment are based on the 'TransitieVisie Warmte' (TVW) of multiple municipalities all over the Netherlands (e.g. Eindhoven, Zwolle, Enschede among others). In a TVW, a municipality explains their goals, timeline and main challenges. The TVW's also contains a visual representation of the city, where it is indicated which type of technology is planned in which neighbourhood. The TVW municipalities use 3 different solutions for going off gas: all-electric, heat network and sustainable gas. When considering the all-electric heat solution, there is mainly revered to a heat pump solution. The heat network option refers to district heating which supplies whole neighbourhoods with a heating solution instead of individuals dwellings. The sustainable gas option involves retaining the existing natural gas pipelines and replacing natural gas with biogas, green gas, or other forms of renewable gas like hydrogen. This option requires minimal adjustments to the infrastructure.

In the choice experiment only heat-pumps and district heating are included. The natural gas option is excluded from this experiment, because this research focuses on the turnover of privately owned dwellings in the Netherlands. In the TVW's there is assumed that hydrogen will not be available for residential use before 2030, and its adoption will be limited. In the built environment, sustainable gas will mainly be employed in locations where other alternatives are impractical, such as historic city centres with complex underground structures and monuments that cannot be adequately insulated (Thijs, 2020). The TVW's also state that the current availability of renewable gas in the Netherlands is limited, making it unsuitable as a large-scale solution for heating the built environment.

<u>Duration of renovation</u>
The attribute levels of duration of renovation refer to different renovation which take place. The levels of duration of the renovation are based on research conducted by Voskuyl (2021), here the duration of renovation times is determined in cooperation with professionals. There is stated that The one-day level signifies a scenario where only the RHS installation is necessary, and there is a minimal requirement additional work. However, if additional work is needed, especially in cases where the existing insulation is inadequate, the construction time can increase significantly. The upper threshold of three months is relevant when poorly insulated homes (rated E or lower) need to be upgraded to, for instance, level B insulation. This upgrade is essential to lower the heat demand and make an installation of low temperature heating system (ex. Heat pump or low temp. district heating) possible.

<u>Investment cost</u>
In this research investment cost refers to the initial cost or amount of money required to purchase and install a RHS, including the additional steps necessary to make this technological feasible. To make a dwelling liveable without using gas can be a costly operation. Some of the dwellings do not have sufficient insulation or proper heat distribution, which could lead to substantial investment costs (RVO, 2018). The investment costs depend on several factors including the current insulation in the dwelling, dwelling type, dwelling size, type of heating system and current heat distribution system (Voskuyl, 2021). The attribute levels have been selected in a way that several combinations of the factors above might be selected. Because the study focuses on all Dutch homeowners, a wide variety in levels should be included, to consider diverse situations. The prices are based on several sources. However, while there is a substantial difference between the references, this is mostly caused by underlying assumptions, predicted price developments, heat source costs and current market pricing.

<u>Attribute level €8.000</u>
This is the lowest attribute level regarding investment cost, included in the research. According to (RVO, 2018) this could cover the costs the installation of a small all-electric heat pump suitable for already well insulted or small dwellings. According to Berenschot (2019), 8000

euros will make it possible to connect a (convenient located) dwelling to a high temperature district heating network, enabling dwellings with a lower energy label and radiators to heat the dwelling without using gas. previous studies conducted towards heating district indicate that the connection fees for the owner of the dwelling differ between 4.000 and 17.000 euros, depending on different neighbourhood characteristics (EIB, 2021).

Attribute level €20.000
According to Berenschot (2019), this level applies to bigger dwellings which are poorly insulted and want to connect to a high temperature heating system. However, this scenario is less occurring because city heating is mostly used in densely populated neighbourhoods consisting of smaller dwellings (Klaassen & Patel, 2013). This level is also applicable to smaller houses (ex. terraced houses) which are already decently insulated and want to instal a low temperature heating system, along with some small adjustments to make it technology feasible. Some examples are mentioned in the report of RVO (2018), where renovations regarding this budget mention changes like floor heating, or changes in the electrical circuit.

Attribute level €30.000
This level belongs to smaller less insulated dwellings which are installing a low temperature heating system, and need to improve the insulation of the building (Berenschot, 2019; EIB, 2021; RVO, 2017). This also consists out of a large renovation of the several parts of the dwelling. This level also describes bigger dwellings with good isolation which have a higher heat demand compared to smaller dwellings with good isolation, hence why the RHS needs to have a bigger capacity (Nagano et al., 2006), this leads to a more expansive RHS. These bigger dwellings need to be well insulated, because there is no budget for big renovations. (EIB, 2021; Tigchelaar et al., 2019)

Attribute level €50.000
This is the highest attribute level. This level applies to bigger detached houses with a low energy label. This level revers to an almost a full renovation of the dwelling. According to (EIB, 2021; RVO, 2018; Tigchelaar et al., 2019) this budget could cover a renovation consisting out of extra insulation in the wall/floor or roof of the dwelling. It also includes the replacements of the glazing and the radiators. Along with an installation of a low temperature RHS.

Energy cost
The energy levels that are included in the research need to be realistic but need to be chosen in a way that emphasizes relevant differences and leads to reliable results that align with the actual preferences of the respondent. This contributes to the usefulness and effectiveness of the experiment. The costs mentioned in the levels are annual energy costs. Annual energy costs of a residential dwelling are largely attributed to the energy used for residential heating systems. (Piersma, 2022).

Attribute level €0/year
This level is related to dwellings which have a high insulation value and can compensate the energy usage with their own energy generation (Berkel et al., 2021). This level is mostly applicable to all-electric homes, here heat pumps are used in well-insulated houses (EIB,

2021). This cost indication will only be achievable if homeowners are exceptionally cost conscious throughout the whole year (Voskuyl, 2021).

Attribute level €500/year

When evaluating all-electric heat pumps, the €500 level is applicable across a diverse range of dwellings, regardless of their type (including size) and current insulation level (Berenschot, 2019; van Polen, 2021). District heating is generally speaking more expensive than 500 euros (Garcia & Kamsu-Foguem, 2019; Voskuyl, 2021).

Attribute level €1.500/year

According to Berenschot (2019), this level is applicable to smaller less insulated, and bigger good insulated all electric houses. This level could also be used to describe the yearly costs of smaller houses with a good insulation value which are heated using an district heating with an more expensive supplier. Voskuyl (2021) argues that this level is applicable for high-temperature district heating in apartments and row houses that already have either good or mediocre energy efficiency ratings (Voskuyl, 2021).

Attribute level €3.000/year

In the case of high-temperature district heating, the energy bill for dwellings is anticipated to be similar to that of a gas-heated dwelling (van Polen, 2021). For high-temperature district heating, the annual heating cost for a poorly insulated terraced or corner dwelling is approximately €2.600. Similarly, a semi-detached house with an energy label of D or a detached house also incurs an annual cost of around €3.000 (Berenschot, 2019). Given the current energy costs and the insight in the development it is unlikely that an all-electric dwelling will raise the energy bill to this level however if larger dwellings, with less energy conscious inhabitants and/or a unfavourable energy contract where to use a heat pump this level still is realistic (Voskuyl, 2021).

Reduction in CO2 production

To make sure the CO2 emission values are understandable for the respondent the reduction in CO2 will be presented as a % compared with the general households in the Netherlands. When adopting a more efficient or sustainable heating system the CO2 emissions decrease compared to the previous situation. According to the Rijksoverheid (n.d.) the reduction maximum a CO2 reduction of 55% could be achieved when implementing a heat pump in a smaller well insulted home. Other sources mention that the implementation of a district heating system could reduce the CO2 production with 15% (van Polen, 2021) in a small home. However this is all dependent on the insulation value of the houses and the area which needs to be headed. A study conducted by Voskuyl (2021) mentioned that the reduction of C02 is 30% with a heat pump in a large dwelling and only 5% in a smaller dwelling

4.1.2 Choice sets and randomization

After the selection of the attributes the choice sets can be generated which will be used in the experiment. This is an important step when utilizing a fractional factorial design. The utilization of SAS Studio software emerges as an valuable tool when generating a efficient fractional factorial design. This software assist in the generation of choice sets that align most fittingly with the included attributes and their respective levels. The input data utilized for the

SAS software's computations are presented in appendix C, providing transparency and clarity regarding the data that underpins the experimental design. The resulting output generated by inputting this data into the SAS system is also included in appendix C, presenting critical insights derived from the software's analysis. The SAS output presents a crucial table useful when making alternatives essential for constructing the most efficient fractional factorial design. Through analysis, the SAS software determined that the creation of the most efficient design could be achieved with 16 alternatives. The next step was randomly linking of the 16 alternatives, aiming to curate choice sets without a decisive winner. The avoidance of a clear victor in these sets is instrumental, as it prevents skewing the results and maintains the robustness of the analysis by facilitating the identification of significant attributes.

A example of an choice set included in the survey is presented in figure 8. Each choice set, Has three answer possibilities; alternative 1, alternative 2, and the preservation of the currently installed gas-fuelled RHS.

	Alternative 1	Alternative 2
Technology	District heating	Heat pump
Duration of renovation	1 day	1 day
Investment cost	€20.000	€50.000
Energy cost	€500/year	€3.000/year
Reduction in CO_2 production	55%	30%

Figure 8- example of a choice set

Initially, 8 choice sets were constructed from the 16 alternatives, organized into the first block. However, to further mitigate the effects of unfair matchups between alternatives, a second block of choice sets was developed. This involved a randomized reassignment of the same 16 alternatives, creating new choice sets within block 2, ensuring diverse combinations while maintaining the exclusivity of each alternative within each block. The result is a total number of 16 choice sets, 8 belonging to block 1 and 8 to block 2. Each alternative featured in these sets was intentionally allocated only once within each block, ensuring a diverse yet balanced representation of alternatives across the experimental design. An overview of the choice sets included in study are added in appendix D. This deliberate construction of choice sets within the fractional factorial design aims to yield robust, unbiased insights into attribute influences while minimizing the risk of skewed or unfair matchups that could compromise the statistical validity of the subsequent analysis.

4.2 Questionnaire design

The experimental design will be accompanied with questions regarding personal variables and mental variables. The literature study previously conducted shows that having a well-designed survey with sound variables can increase the reliability of the results and increase the ability to make assumptions based on the generated results. To determine the levels, the databases of well-established national data corporations are used. This also allows for comparing the sample to national averages.

4.2.1 Personal variables

The personal variables considered in this section align with those identified in the literature review. First, the sociodemographic variables will be discussed, followed by the dwelling characteristics. The spatial characteristics have been excluded from the research because the Netherlands is a small country where the climate / spatial characteristics are comparable meaning that this variable is expected to have little to no explanatory power.

<u>Socio-demographic variables</u>

The first part of the survey consisted out of socio-demographic variables. Socio-demographic variables encompass a range of characteristics that define individuals or groups within a society. The previously conducted literature study found that these variables are fundamental in understanding RHS preferences, and decision-making processes.

An important aspect to take into account when including the socio-demographic variables in the survey is compatibility with the empirical data. By curating that the survey's responses. The applicability and utility of the data can be strengthened. The levels which are used as answer option in the socio-demographic questions, are based on data found by the Central Bureau of Statistics (CBS). The CBS is the official statistical agency in the Netherlands responsible for collecting and publishing statistical information about the country's demographics, economy, society, and environment.

All the answer options are directly adopted from the data files of CBS. Only the variable education was segmented into more answer options than provided to increase readability of the question. The answer options will later be recoded so that it corresponds with the data. The included socio-demographic variables are mentioned in table 8.

Table 8 *– included sociodemographic variables*

Variable / level	*Scale*	*Data source*	*Level*
Gender	Nominal	CBS (1)	Postal code (6)
Male			
Female			
Other			
Education	Ordinal	CBS (1)	Postal code (6)
Primary school			
VMBO or MBO level 1			
First 3 years of HAVO or VWO			
HAVO			
VWO			
MBO (level 2,3, or 4)			
HABO			
WO			
I prefer not to answer			
Age	Ordinal	CBS (1)	Postal code (6)
15 – 24			
25 – 44			
45 – 65			
65+			
Ethnic background	Nominal	CBS (1)	Postal code (6)
Born in the Netherlands with a Dutch origin			
Born in the Netherlands with a European origin			
Born in the Netherlands with a non-European origin			
Born outside the Netherlands with a European origin			
Born outside the Netherlands with non- European origin			
Other			

Household composition	Nominal	CBS (1)	Postal code (6)
1 person household			
More persons without children			
Single parent With children			
Multiple parents with children			
Other			
Household size	Ratio	CBS (1)	Postal code (6)
Open question			
Household income	Ordinal	CBS (2)	Neighbourhood
< €25.000			
€25.000 - €45.000			
€45.000 - €65.000			
€65.000 - €80.000			
€80.000 - €100.000			
> €100.000			

**(1) Kerncijfers per postcode (CBS,2021); (2) Income distribution (CBS, 2022).*

Dwelling characteristics

Residential variables include a spectrum of aspects describing the residential environment that significantly influence RHS preferences and decision-making. As concluded in the literature study conducted previously, the inclusion of these variables could lead to explanatory power. While socio-demographic variables provide insight into the individuals themselves, residential variables shed light on the contextual factors within their living environment. These factors can significantly impact heating preferences, energy consumption patterns, and the suitability of specific heating solutions.

Similar to socio-demographic variables, ensuring coherence between the survey's results and the empirical data is important. The variables included in this segment are detailed in table 9. Each variable is accompanied with the answer options presented in the survey.

***Table 9** – included sociodemographic variables*

Variable / level	Scale	Data source	Level
Dwelling type	Nominal	CBS (1)	Postal code (6)
Flat, Apartment, Maisonette, Gallery apartments			
Corner house			
Terraced house			
Semi-detached house			
Detached house			
Other			
Dwelling age	Ordinal	CBS (2)	Postal code (6)
Before 1945			
1945 – 1965			
1965 – 1975			
1975 – 1985			
1985 – 1995			
1995 – 2005			
2005 – 2015			
After 2015			
I don’t know			
Dwelling size	Ordinal	CBS (3)	Postal code (6)
Less than 50m2			
50m2 – 74m2			
75m2 – 99m2			
100m2 – 149m2			
150m2 – 250m2			
More than 250m2			

Current energy label A or better B C D E F G I don't know	Ordinal	CBS (4)	Postal code (6)
Current annual gas consumption Less than 500m3 500m3 – 1000m3 1000m3 – 1500m3 1500m3 – 2500m3 2500m3 – 3000m3 More than 1000m3 I don't know	Ordinal	Enexis netbeheer (4)	Postal code (6)

source; (1) Woningvoorraad; woningtype op 1 januari (Cbs, 2023)*; (2) Voorraad woningen; gemiddeld oppervlak; woningtype, bouwjaarklasse, regio* (CBS, 2023c)*; (3) Voorraad woningen; woningtype, oppervlakteklasse, regio* (CBS, 2023d)*; (4) Energielabels van woningen* (CLO, 2023)*; (5) Verbruiksdata kleinverbruikaansluitingen* (Enexis, 2023).

4.2.3 Mental variables

Previously conducted literature studies indicate that several mental variables have a significant influence on an individuals' RHS decision-making processes. For instance, an individual's inclination toward using sustainable products and services can significantly impact their decision to adopt a RHS, by influencing preferences for specific heating technologies or energy sources. In various studies the inclusion of mental variables lead to an increase in predictive capacity of the model (Krikser et al., 2020; Meles et al., 2022; Scherer, 2022). The most frequently mentioned mental variable is environmental attitude. This variable will also be included in this research.

A mental variable is often gauged through a set of indicators, reflecting preferences or opinions regarding various statements or scenarios related to environmental concerns. These indicators are measured using a Likert scale, allowing respondents to express the strength of their agreement or disagreement on a scale (e.g., strongly agree, agree, neutral, disagree, strongly disagree). To ensure the reliability and validity of the measurements, a factor analysis methodology is employed. This statistical technique fuses multiple indicators into a single factor, effectively creating a more robust and dependable variable.

The statements used to measure the environmental attitude are (1) Using environmentally friendly products is important. (2) I am willing to pay extra for products that are sustainably produced, (3) The government should introduce stricter environmental laws, (4) I feel personally responsible for preserving the environment. A similar type and number statements where utilized in a study conducted by Scherer (2022) to measure environmental attitude. However, in that study, the focus was placed primarily on identifying hassle factors. Hence some minor modifications were made to these statements to make them applicable for the current research.

The alignment of these indicators with the Likert scale responses ensures a coherent and meaningful assessment of respondents' environmental attitudes, providing a possibly important variable in the predictive model. By including the environmental attitude variable, this study seeks to enhance both the predictive accuracy and the alignment of the model with actual consumer behaviour.

4.3.4 Questionnaire testing

Questionnaire testing is essential in survey research as it ensures the reliability and effectiveness of the survey. Testing helps validate the questions, ensuring they accurately measure the intended aspects while maintaining clarity and understandability for respondents. It allows for the identification and rectification of errors, ensuring a smooth flow and logical structure in the survey. The testing of this survey was done on 6 people in different occasions with no academic background and without prior experience regarding RHS. Here was found that the attributes and the levels in the choice sets needed to be concise and clear. Another valuable take away was the desire for explanation of the attributes. When no explanation was provided some questions regarding the definitions arose. However, when the definition was given visible for each question the amount of text accompanying the question was perceived as overwhelming. To counter this effect a button was created where definitions of the attributes were presented which appeared when the respondent had a desire for more explanation. Other small errors regarding language and logical structure where also found and adjusted. Ultimately, minor adjustments were made and the survey was finalized.

4.3.5 Privacy

Privacy serves as a foundational principle in survey research, ensuring ethical practices and respecting the rights of individuals. It is important to create a space where participants feel comfortable being open and honest. By keeping information private, it encourages honest responses and strengthens the trust and reliability of the collected data.

In this survey, the commitment to privacy and ethical standards are reviewed and approved by the Privacy and Ethical Reviews Board of the TU/e (Eindhoven University of Technology). This process is mandatory for studies which involve human participants or personally identifiable data. This process highlights the commitment to ethical data handling. The board's documentation shows careful data processing and storage, highlighting transparency in handling sensitive information.

To reinforce these principles, respondents encountered a privacy and ethics statement at the beginning of the survey. Here a direct link to the informed consent form was included. Additionally, a concise summary of these terms and conditions was presented for clarity and understanding. This initial page referred to an information sheet which explained the procedures ensuring privacy and data handling methods in greater detail. if participances wanted to proceed with the survey, they were required to consent to the terms and conditions outlined in this form. Appendix E supplements these measures, providing the Informed Consent Form in both English and Dutch. This form offers a comprehensive overview of participant rights, data processing procedures, and the voluntary nature of participation. Its inclusion ensures that participants are well-informed and have consented to the terms before engaging in the survey. Furthermore the survey is approved by the ethical review board of the TU/E.

4.3 Conclusion

The first steps in designing a survey which includes a discrete choice experiment is the careful selection of relevant attributes and levels. A literature study was used to find the relevant attributes and levels. In this research; technology, renovation duration, investment cost, energy cost, and CO2 reduction will be used as attributes. Following this a fractional factorial design is used to further design the choice sets of the experiment. The fractional factorial design balances efficiency and thoroughness, optimizing resource use while capturing significant effects.

To enhance this research explanatory power, the questionnaire also integrates both personal and mental variables. The inclusion of these variables are carefully considered, and for each variable different answer options (levels) are drawn, which are based upon empirical available data. Personal variables are segmented in socio-demographic data, dwelling characteristics which is comparable with the literature review. The spatial characteristics are excluded from the survey due to the fact that these are comparable in each situation in the Netherland. The mental variables are calculated using 4 statements which can be answered through a Likert scale and analysed using factor analysis. Ultimatly 1 variable is created named 'environmental attitude'. The aim of including this variable is to enhance the model's predictive capacity despite the absence of direct empirical data which can be inputted for environmental attitude. The questions included in the survey are presented in Appendix D.

5. Data preparation and analysis

The research questions presented in the first section of the study can be answered by statistically analysing the data. This data is gathered by using a questionnaire with an incorporated stated choice experiment. The design of this experiment is explained in section 4.3. This section focuses on how the data was cleaned and describes the gathered data by providing insight in demographics data, residential data and environmental attitude data. These are explained in the descriptive analysis.

5.1 Data collection and cleaning

This section focuses on the critical process of data cleaning, a phase in which the responses are evaluated. The data cleaning aims to remove inaccuracies, inconsistencies and invalid entries within the dataset. This phase ensures the quality and reliability of the data resulting in an analysis that is more trustworthy and representative of real world decisions.

The survey distribution primarily used personal relationships and partnerships with companies with large employee counts. This approach aimed to use existing connections and networks to reach a broad and diverse participant base. Personal relationships helped spread the survey among various social circles, while partnerships with organizations allowed access to a large pool of potential respondents. This strategy maximized the survey's visibility and accessibility, fostering participation from a wide range of demographics and professional sectors.

The questionnaire which was used to obtain the data was filled in a total of 411 times. The Dutch version has been used 408 times and the English version has been used 3 times. This was expected because most of the homeowners in the Netherlands speak Dutch. Out of these 411 responses, 191 responses were found to be invalid because the questionnaire was not completed. The remaining responses (n=220) had no missing values because all questions were mandatory. This was confirmed by a check for missing values. The remainder of the responses were checked on the time they took to fill in the questionnaire. Using the questionnaire testing the least minimal amount of time needed to read and fill in the survey could be determined, this is approximately 3 minutes. A total number of 4 respondents filled in the survey using less than 3 minutes these were excluded. In addition, one respondent indicated that they currently have a household size of 150 individuals, which is an extreme value compared to the rest of the response indicating that this or multiple questions could be misunderstood or not carefully answered. This respondent was also excluded from the analyses. This led to the exclusion of survey id's 241,263,371,422,424. resulting in a total of 215 valid respondents.

5.2 Descriptive analysis

To determine the quality and representativeness of the data sample, descriptive analyses were conducted. The analysis was conducted using the statistical software of SPSS. The first section focuses on the socio-demographic data followed by an overview of the dwelling characteristics, this is followed by reviewing the response to the statements included in the questionnaire and lastly a correlation matrix is computed and examined.

The direct output from the survey regarding the personal and mental variables is added in appendix G. The data is compared with the national average to determine the representative of the data sample using a Chi^2 test. All the tests are added in appendix H. The comparison between the sample and the national Dutch population is presented in table 10 and 11. The research used questions with several answer options for each question. In some cases, this lead to several levels with a low response count, which might negatively alter the further analyses. To counter this effect some of these levels are combined with others, to ensure sufficient response. The data presented in table 10 and 11 is after the combination of the levels.

5.3.1 Analysis of personal variables

In this section of the report, the personal variables of the research population are reviewed and compared with national averages. This comparison aims to identify significant differences or similarities between the sample and the broader Dutch population. The national averages where computed by the CBS. This is a well-known bureau which computes statistical data in the Netherlands. The sources of the national averages are added in the table presented below.

<u>Sociodemographic variables</u>

The first demographic variable considered is the gender of the respondents. In table 10 it can be seen that there are more male respondents than female respondents and that one single respondent identifies as another gender. This last group is not sufficient to generate trustworthy results, this leads to exclusion of this respondent in the Chi^2 analysis. At first glance it can be noticed that the general population is more evenly divided then the sample. When reviewing the data using a Chi^2 analysis, a significant Chi^2 value of 19.917 is found. This suggests that the gender distribution in the sample differs significantly from the national averages.

The first three levels of education are combined into one level. So education is now measured by the following levels: highly educated (HBO and WO) and middle/low educated (Primary school, VMBO or MBO, HAVO, VWO). The education data showed that a relatively large group of high educated people participated in the survey, compared to the national averages. When analysing the education levels using the Chi^2 test, the value turned out significant, meaning that there are significant differences between the sample and the Dutch population.

When considering the age category it can be seen that the age category 65+ is relatively small compared to national averages. The gap in 65+ can be explained because this population is hard to reach when using conventional sources (Liu et al., 2023). To still be able to include these results the 65+ age level is combined with the 45 – 65 age level, resulting in a new level: ≥45. It can also be seen that there are a small number of participants between the ages 15 and 24. This can be explained because the target population of the research is homeowners in the Netherlands. Generally speaking, there are fewer people in this age category who own a dwelling. This level is combined with the level 25 - 44 into a new variable <45. When analysing these levels using Chi^2 a small significant relation can be found meaning that that are differences between the sample population and the national data.

The ethnic background of the respondents is quite one-sided. It can be noticed that respondents born in the Netherlands with a Dutch origin are far more present in the sample. The number of people born with a non-Dutch ethnicity is too low to include this variable in the analyses and might result in skewed results. To prevent this, this variable is excluded from further analysis. A question regarding receiving benefits was also included in the survey but the answers and feedback provided afterwards showed that this question was not clearly formulated. In order to ensure trustworthy results this data was excluded from the research.

When reviewing the household composition it can be seen that the expected value of the 1 person household is considerably larger than the sample count. Households that include multiple parents with children is over represented in the sample. To minimize the differences and make this variable suitable for analyses a distinction is made between households with children and households without children. Three respondents chose the other option. One of them (ID 156) added a description of their status, which made clear that children were present in the household. This made it possible to recode them. The other two respondents who chose the other option were excluded from the Chi^2 analyses, but their other answers were used to avoid losing valuable information for the rest of the research.

When recoding the income variable the last options >€100.000, €80.000 - €100.000 and €65.000 - €80.000 are combined because otherwise the expected count would become lower than 5, which is an assumption of the Chi^2 test. In further research these variables are separated again to not lose possibly valuable data. This question also included a choice where the respondent could choose not to answer this question. This option is used quite frequently (n=28). These are excluded from the chi^2 analyses leaving n=187 respondents. Overall the response is quite dispersed over the levels. It can be seen that the sample has relatively big difference compared to the national averages. In the sample, the mode income is €65.000 - €80.000 while in the population data, the mode income is €25.000 - €45.000. This might be related to the educational characteristic, as a significant portion of highly educated respondents are involved. Previous literature has indicated that these two characteristics may be correlated. This significant difference in income distribution is further confirmed by the Chi^2 analysis, which shows a Chi^2 value for income that is considerably larger than those for the other characteristics.

***Table 10** – Personal data compared with national data*

Factor	Sample		Population of Netherlands			
	count (n=215)	%	Expected count	%	Residual (SC-EC)	Test statistics
Gender						n=214
Male	139	65.3%	106	49.70%(1)	33	Chi^2 = 20.357
Female	75	32.2%	108	50.30%(1)	-33	p = < .001
Other (excluded)	1	-	-	-	-	
Education						n=215
Low/middle educated	68	31.6%	136	25.44%(2)	-68	Chi^2 = 92.532
High educated	147	68.4%	79	74.56%(2)	68	p = .000
Age						n=215
<45	106	49.3%	91	42.34%(1)	15	Chi^2 = 4.287

≥45	109	50.7%	124	57.66%(1)	-15	p = .038
Household composition						n=213
Household without children	76	35.7%	156	73.0%(1)	-79	Chi^2 = 149.322
Household with children	137	63.3%	58	27.0%(1)	-79	p = < .001
Other (excluded)	2	-	-	-	-	
Income						n=187
< €25.000	5	2.7%	55	29.2%(3)	-50	Chi^2 = 1616.915
€25.000 - €45.000	18	9.6%	91	48.6%(3)	-75	p = < .000
€45.000 - €65.000	31	16.6%	31	16.8%(3)	0	
>€65.000	133	71.1%	10	5.4%(3)	123	
I prefer not to answer (excluded)	28	-	-	-		

source; (1) Kerncijfers per postcode (CBS, 2022); (2) hoogstbehaald onderwijsniveau en onderwijsrichting (CBS, 2022); (3) Income distribution (CBS, 2022).

Dwelling characteristics

In table 11 presented below the dwelling characteristics are described in the same way as the sociodemographic data above. When reviewing the dwelling type there can be seen that three respondents chose the option other. However, these respondents did describe their dwelling in the next questions. Based on this description all three of the respondents could be considered as semi-detached houses. When assessing the sample data there can been seen that a considerably large number of the respondents is owner of detached house. Another noteworthy difference can be found when comparing the national amount of apartment owners with the sample. This difference may be linked to the large number of respondents with high incomes, which might enable them to afford detached houses, generally valued higher. Analysis using the Chi^2 test reveals a high Chi^2 value that is statistically significant, indicating differences between the data sample and the general population of the Netherlands.

In the survey, the dwelling age is separated in 9 different levels. The responses are all quite evenly dispersed over the levels. To improve the analysis of the dwelling age several levels are combined. In the sample the houses appear to be built later compared to the national averages. The Chi^2 did come back significant, indicating that there is a significant difference between the population and the sample.

In the dwelling size a slight trend to bigger dwellings can be detected, which corresponds with the previously found characteristic of the sample, which describes that the detached houses are overrepresented in the sample. The mode in the national data is less then $99m^2$ while the mode for the sample data is $150m^2$ – $250m^2$. The difference is confirmed by the Chi^2 analysis which yielded a significant difference, indicating that there is a difference.

The data in describing the energy label first was included in the survey using 7 different levels and an I do not know option. In the analysis the levels are reduced to 4 and an I do not know option. By doing this all answer option have sufficient response for the analysis. The I do not know option was selected by 65 respondents. These were excluded from the Chi^2 analysis but are incorporate in the rest of the analysis. The exclusion of this option leaves 150 responses for the Chi^2 analysis. The current energy label has the lowest Chi^2 value of all the characteristics, indicating that this is the best fitting variable. However, the Chi^2 test still shows significance meaning that there is a difference between the sample population and the national population.

The last variable to analyse is the current annual gas consumption. In this variable some options where combined, which resulted in the levels presented in the table below. All the responses seem to be divided in a comparable way to sample. There however is one group (>2500m^2) in the sample which is considerably smaller than the national averages. These responses result in a Chi^2 value of 79.564 which is significant.

***Table 11** – dwelling characteristics data compared with national data*

Factor	Sample		Population of Netherlands		Residual (SC-EC)	Test statistics
	count (n=215)	%	Expected count	%		
Dwelling type						n=215
Flat, Apartment, Maisonette, Gallery apartments	9	4.2%	73	34.1%(1)	-64	Chi^2 = 308.554
Semi-detached house	59	10.2%	20	13.6%(1)	39	p = < .001
Terraced house	27	12.6%	63	29.3%(1)	-36	
Corner house	22	26.0%	29	9.2%(1)	-7	
Detached house	98	45.6%	30	13.8%(1)	68	
Dwelling age						n=213
Before 1965	40	18.8%	69	32.3%(2)	-29	Chi^2 = 75.876
1965 – 1985	43	20.2%	64	30.1%(2)	-21	p = < .001
1985 – 1995	35	16.4%	27	12.7%(2)	8	
1995 – 2005	56	26.3%	22	10.3%(2)	34	
After 2005	39	18.3%	31	14.6%(2)	8	
I do not know	2	-	-	-	-	
Dwelling size						n=215
Less than 100m2	33	15.3%	94	43.7%(3)	-61	Chi^2 = 128.167
100m2 – 149m2	78	36.3%	78	36.2%(3)	0	p = < .001
150m2 – 250m2	81	37.7%	35	16.4%(3)	46	
More than 250m2	23	10.7%	8	3.8%(3)	15	
Current energy label						n=150
A or better	52	34.7%	48	32.1%(4)	4	Chi^2 = 9.954
B	37	24.7%	25	16.7%(4)	12	p = .020
C	33	22.0%	38	25.3%(4)	-5	
D or worse	28	18.7%	39	26.0%(4)	-11	
I do not know	65	-	-	-	-	
Current annual gas consumption						n=187
Less than 500m3	16	8.6%	4	2.3%(5)	12	Chi^2 = 79.564
500m3 – 1000m3	53	28.3%	28	15.2%(5)	25	p = < .001
1000m3 – 1500m3	51	27.3%	70	37.5%(5)	-19	
1500m3 – 2500m3	51	27.3%	44	23.6%(5)	47	
More than 2500m3	16	8.6%	40	21.4%(5)	-24	
I do not know	28	-	-	-	-	

source; (1) Woningvoorraad; woningtype op 1 januari (Cbs, 2023)*; (2) Voorraad woningen; gemiddeld oppervlak; woningtype, bouwjaarklasse, regio* (CBS, 2023c)*; (3) Voorraad woningen; woningtype, oppervlakteklasse, regio* (CBS, 2023d)*; (4) Energielabels van woningen* (CLO, 2023)*; (5) Verbruiksdata kleinverbruikaansluitingen* (Enexis, 2023).

5.3.2 Analysis of mental variables

In the questionnaire statements were used to gauge environmental attitude. These statements were answered with the aid of a 5-point Likert scale. In the results these Likert scale responses are represented using numerical values, where 1= strongly agree, 2=agree, 3=neutral, 4=disagree and 5= strongly disagree. Here the statements will be analysed. This will be done using a factor analysis and a Cronbach's alpha analysis. In the figure 9 presented below, frequency results are presented using a histogram chart, which provides a general overview of the collected data regarding responses. These descriptive statistics show plausible distributions. there can be seen that overall response relatively agree with the provided statements. The highest mean (lowest agreement) was found by the statement regarding stricter environmental laws. And the lowest means (highest agreement) was found by the statement regarding the importance of environmental friendly products. When analysing the descriptive statistics 215 cases where analysed meaning that there were no missing variables.

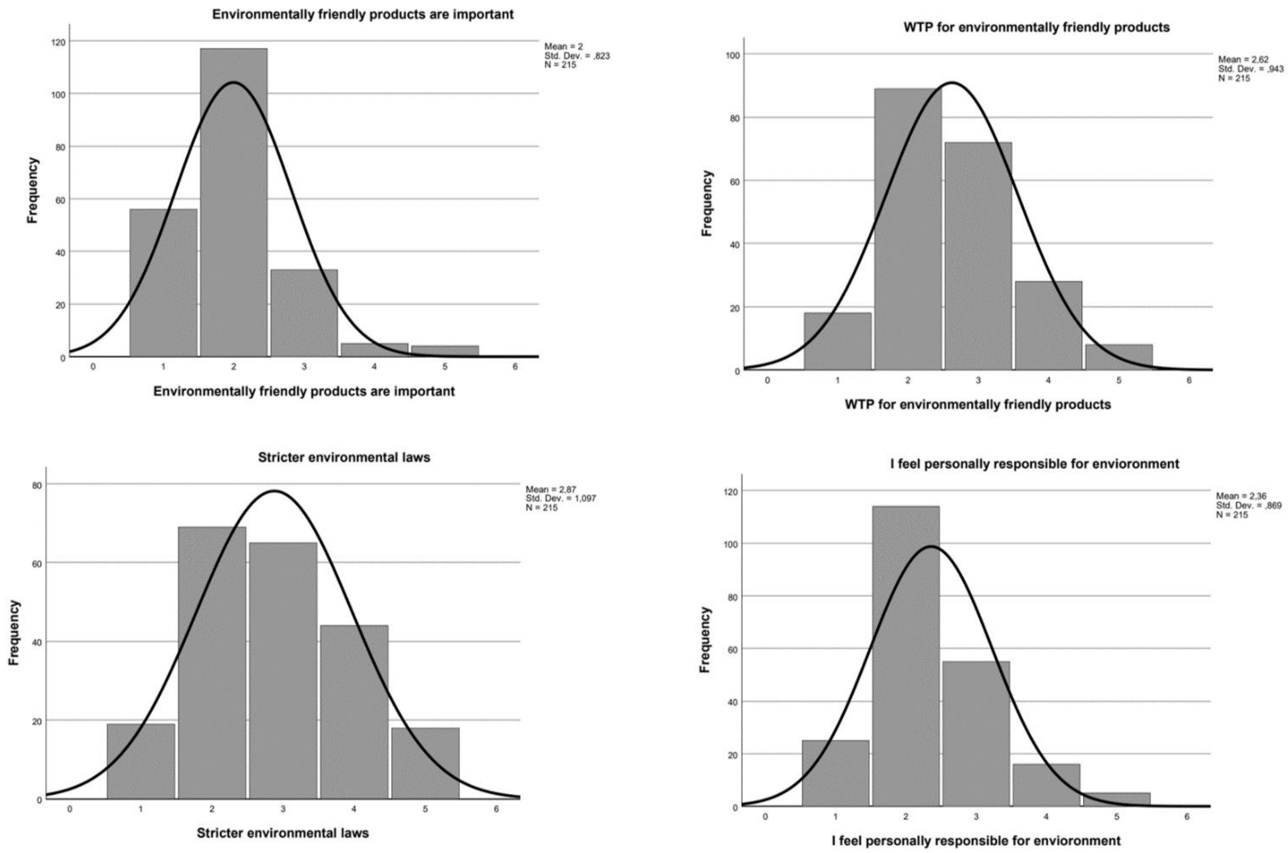

Figure 9 - mental statements analysis

Factor analysis

In addition to the frequency results, a factor analysis and Cronbach's alpha analysis have been conducted. The tables related to the factor analysis can be found in appendix I. When considering the correlation matrix there can be seen that the statement do correlate to each other. Here the highest correlation factor (.684) can be found between finding environmentally products important and the WTP for them. The lowest correlation factor (.523) is between stricter environmental laws and feeling personally responsible for the environment. The determinant factor mentioned under the table is .169 is higher than .001 meaning that the statements are related and that the correlation is sufficiently high. The correlation matrix based on these statements no value is above the threshold of 0.8, indicating that no multi-colinearly is detected between the statements.

Looking at the Kaiser-Meyer-Olkin (KMO) an Bartlett's test. Both KMO and Bartlett's test help researchers decide whether the dataset is appropriate for factor analysis. KMO assesses the adequacy of the sample, while Bartlett's test examines if the correlations between variables are significant enough to warrant the use of factor analysis. For the KMO a value of .814 can be observed. This value preferably needs to be above 0.5, however how greater the value the better. When examining Bartlett's test a significant value is found indicating that the variables are related to each other. Both test yield favourable results, suggesting that the data is suitable for factor analysis.

When reviewing the explained total variances and the scree plot, it can be concluded that 1 component is above the Eigenvalue of one. The first component had an eigenvalue of 2.800. This component could be used to explain 70% of the variance, Which is substantial and suggests that it captures a considerable amount of information in the dataset. So based on these results, it appears that retaining only one component is sufficient to explain a substantial portion of the variance in the data. This is also backed by the component matrix which only extracted a single component. So one single factor was included in further analysis representing environmental attitude. The single factor was computed by using the values presented in the communalities table (appendix I) which represents the relative importance of each of the statements. This table shows that the statement regarding environmentally friendly products yields the highest extraction of .738. The lowest value is .619 which is found when reviewing the statement regarding the personal responsibility perception of respondents. The values 1-5 gathered using the Likert scale are multiplied by the corresponding extraction value and summated. This value is divided by a summation of the extraction values so that the average environmental attitude will be represented using a value between 1 and 5. The average environmental attitude of the respondents is 2.46.

<u>Cronbach alpha analysis</u>

To determine if the statements represent environmental attitude a Cronbach's Alpha analysis had been conducted. Cronbach's alpha is a statistic used in research to measure the internal consistency of a set of items in a questionnaire or survey that are supposed to measure the same underlying construct. Cronbach's alpha can be used when evaluating if statements in an experiment are all measuring the same thing. In this case, the survey includes multiple statements intended to measure someone's environmental attitude, Cronbach's alpha helps assess if those statements are all reliable indicators of environmental attitude. It helps in ensuring that the items are consistent and reliable in measuring the construct they are supposed to measure. So the analysis is a useful tool. A higher alpha value indicates greater internal consistency among the items. The complete results of the Cronbach alpha test are presented in Appendix I. When reviewing these results a value of 0.856 can be found. This value had to be above the satisfactory 0.700 to prove the representativeness of the statements. So it can be concluded that the statements which were included are reliable predictors of environmental attitude

<u>Correlation matrix</u>

A correlation matrix was used to gain insight into the relationship between the included variables. In this correlation matrix a high correlation value means that the variables are highly interrelated. This can lead to multicollinearity. Multicollinearity occurs when two or more variables in a regression model are highly correlated. This is a phenomenon that occurs when the correlation coefficients are too high (above 0.8). checking and excluding this phenomenon is crucial for ensuring the accuracy, stability, and interpretability of regression models, allowing for better-informed decision-making based on the analysis. The correlation matrix is added in Appendix J. In the appendixes the number closest to 1 and -1 are presented with a brighter red colour compared to values that are closer to 0. This is done to be able to interpret the results more efficiently. When reviewing the correlation matrix.

In the correlation matrix it can be seen that that is a high correlation between the levels of household composition, dwelling age, dwelling energy label and gas consumption of the dwelling. A way to resolve this issue is to recode these variables using fewer levels. Once these variables where recoded another correlation matrix was run to see if the issues were resolved. When comparing these two correlation matrixes a significant improvement can be recognized. The variables of household composition and dwelling age show the most improvement. The levels describing dwelling energy label and gas still show a high inter correlation however a small improvement can be found. These findings indicate that recoding the variables into fewer variables is an important step in recoding the data.

5.2 Data coding

Prior to any analysis, the data required recoding. Some aspects, such as reworking the education data, were relatively straightforward. The data initially presented four levels, whereas respondents in the questionnaire were offered eight response options, to increase the readability of the questions. These options were segregated yet utilized identical terminology. These 8 response options were coded back to 4 options which correspond with the available data. Additional basic steps involved converting variables from string to numeric formats, enabling seamless analysis. For instance, transforming the names of variables into id's. The names of the variables were transformed because statistical software often struggles with long(er) variable names. This can cause problems if the first characters of two or more parameters are exactly the same.

Once all the basic steps were implemented, the raw data provided when exporting the survey were recoded using the effect coding technology. Dummy coding was used as the method of choice by this study. This is a way of encoding categorical variables into numerical values to use them in statistical analyses. In dummy coding, each category or level within a categorical variable is coded as a set of contrasts against a reference category. Dummy coding allows capturing the effect of each category relative to the reference category. This method helps in examining how each category differs from the reference category. One important note is that the choice of reference category doesn't affect the overall model's predictions or significance. It only influences the interpretation of the coefficients associated with each category in relation to the reference category. The categories are coded according to a coding scheme which implies which levels have been selected as base levels. The coding scheme is presented in Table 12.

Table 12 *– dummy coding scheme*

ID	Levels	x1	x2	x3

CONS	No heating (prefer to stay with current RHS)	0	0	0
	Heating type			
	District heating	0		
A1	Heat pump	1		
	Duration of renovation			
	1 day	0	0	0
A2	1 week	1	0	0
A3	1 month	0	1	0
A4	3 months	0	0	1
	Investment costs			
	€8.000	0	0	0
A5	€20.000	1	0	0
A6	€30.000	0	1	0
A7	€50.000	0	0	1
	Energy costs			
	€0/year	0	0	0
A8	€500/year	1	0	0
A9	€1.500/year	0	1	0
A10	€3.000/year	0	0	1
	Reduction of CO2 production			
	5%	0	0	0
A11	15%	1	0	0
A12	30%	0	1	0
A13	55%	0	0	1

5.3 Conclusion

In conclusion, the descriptive analysis conducted in this research was used to determine the quality and the representatives of the data sample used in this research. This section utilizes various statistical methods. Based on the data analysis, it was determined that the number of individuals with a non-Dutch ethnicity was insufficient for meaningful inclusion in this research. Consequently, this variable has been excluded from further analyses.

The results revealed that there was a significant difference between the Dutch population and the data sample across several personal variables. Part of this can be explained. Nevertheless, these findings indicate limited generalizability to the entire population of the Netherlands. It can be seen that there is an overrepresentation in the sample of homeowners who have a higher income, large detached houses and have children are overrepresented based on the national averages.

The attitude statements related to environmental attitude were measured using a Likert scale. To provide a comprehensive understanding of these statements a factor analysis, Cronbach's alpha analysis and cross-tabs with socio-demographic variables were used. The results indicate that the statements do in fact demonstrate reliability and internal consistency regarding environmental attitude, as confirmed by a satisfactory Cronbach's alpha value of 0.856.

The correlation matrix assessing interaction between the levels of demographic and dwelling data found a high correlation between levels indicating a higher chance of multicollinearity issues. This issue is addressed by recoding the data into fewer levels making the interrelation value smaller.

In summary, the descriptive analysis provides a general overview of the studied data sample in this research. The analysis lead to the exclusion of the ethnic background variable, due to an insufficient number of non-Dutch respondents. The analysis also emphasized on the importance of careful consideration and potential adjustments in interpreting and generalizing the study findings. The analysis also lead to recoding the variables into variables with lesser variables household composition, dwelling age, dwelling energy label and gas consumption of the dwelling.

6 Results

From the choices made by respondents in the experimental choice situations an estimation can be drawn up which estimate which attributes influence RHS choices. NLogit 6 was used for the multinomial logit model and the latent class mode. Further analyses are conducted using SPSS. First a MNL was computed which gives insight in the influence in the attributes. Next, a LCA model is generated which separates the responses into segments. These segments are later compared using the personal and mental variables gathered in the survey.

6.1 MNL model

In table 13 the results of the MNL model are presented. This is a direct product of the output from NLogit. The in- and output can be found in Appendix K. As previously stated the MNL model is used to provide insights into the attributes which influence RHS decision-making. The included variables are heating type, duration of renovation, investment costs, energy costs, and CO2 reduction. These attributes all have varying levels of impact on the choices made by individuals which are further explained below per attribute. First the general model results and performance are explained later the effect of each level is described.

Table 13 – Results MNL model

ID	Level	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence	
CONS	Constant	-0.455***	0.148	-3.070	0.002	-0.745	-0.165
	Heating type						
	District heating	.000	(base)				
A1	Heat pump	0.413***	0.078	5.290	0.000	0.260	0.566
	Duration of renovation						
	1 day	.000	(base)				
A2	1 week	0.221	0.166	1.330	0.184	-0.105	0.547
A3	1 month	0.085	0.121	0.700	0.484	-0.153	0.322
A4	3 months	-0.647***	0.144	-4.510	0.000	-0.928	-0.366
	Investment costs						
	€8.000	.000	(base)				
A5	€20.000	-1.001***	0.154	-6.500	0.000	-1.303	-0.699
A6	€30.000	-0.378***	0.128	-2.950	0.003	-0.629	-0.127
A7	€50.000	-1.092***	0.144	-7.610	0.000	-1.373	-0.811
	Energy costs						
	€0/year	.000	(base)				
A8	€500/year	0.557**	0.164	3.400	0.001	0.236	0.879
A9	€1.500/year	0.507***	0.161	3.160	0.002	0.192	0.822
A10	€3.000/year	-0.397***	0.147	-2.700	0.007	-0.685	-0.109
	Reduction of CO2 production						
	5%	.000	(base)				
A11	15%	0.529**	0.209	2.540	0.011	0.120	0.938
A12	30%	0.744***	0.123	6.020	0.000	0.502	0.986
A13	55%	1.227***	0.120	10.210	0.000	0.991	1.462
Model fit statistics							
Number of observations		1720					
LL(0)		-1889.056					
LL(β)		-1658.123					
McFadden's ρ^2		.122					
ρ^2 adjusted		.115					

***, **, * ==> Significance at 1%, 5%, 10% level.

6.1.1 General model performance

The MNL model shows moderate but significant explanatory power in predicting the choice probabilities,. The McFadden's ρ^2 and the adjusted ρ^2 indicate the model's goodness-of-fit. A ρ^2 value of 0.1222 is reasonable for a discrete choice model. The significance at the 1% of most coefficients suggests that the model is well-specified and the included variables are relevant to the decision-making process being studied. The constant considered in the MNL model describes the overall preferences of homeowners for gas-free heating solutions.

To analyse the importance of the attributes the relative importance is calculated. The relative importance is calculated by first taking the range of the parameters per attribute, then summing up the ranges of all attributes to get the total variation, and subsequently dividing the range of each attribute by the total variation to get the percent contribution of each attribute. Figure 10 depicts the relative importance of each one of the attributes under study.

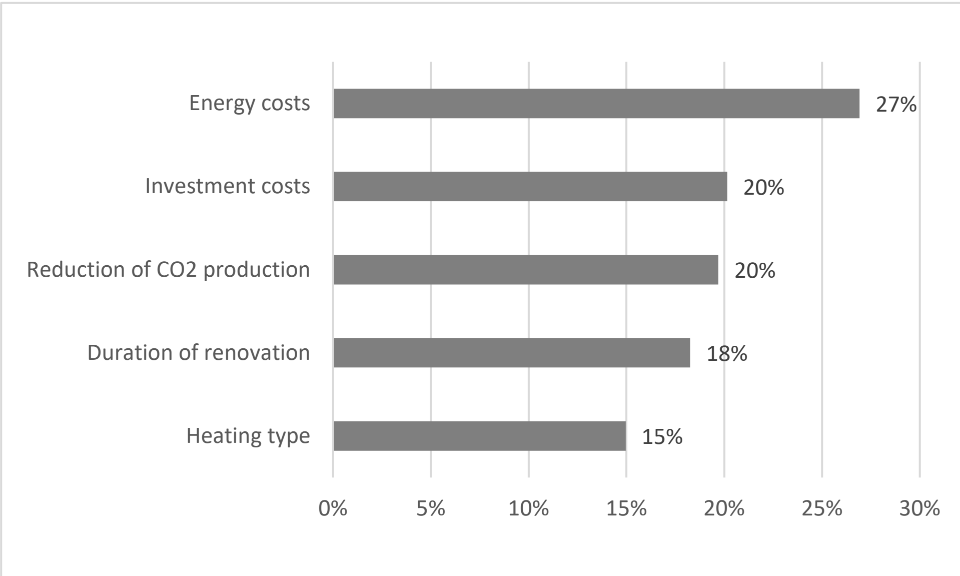

Figure 3 - Relative importance of attributes

Energy Costs are the most influential at 27%, indicating that ongoing expenses related to energy consumption are a primary concern. Reduction of CO2 Production and Investment Costs both follow at 20%, underscoring the significant role of environmental sustainability and financial implications in choices. Duration of Renovation holds an 18% importance, reflecting concerns over the inconvenience of lengthy renovations. Lastly, Heating Type at 15% suggests that while the choice of heating systems like district heating and heat pumps is moderately impactful, it is less critical compared to other factors.

6.1.2 Attribute Impact Analysis

<u>Constant</u>

The constant resulted in a significant variable, indicating that there is a general preference for gas-free heating solutions. The coefficient is negative which indicates that homeowners prefer not to undergo a renovation, and remain using their current gas-using heating system. The constant has a moderate impact (-0.455) compared to other significant variables, suggesting a slight preference against choosing a gas-free heating solution. This contradicts previous studies that found a positive reaction to gas-free heating renovations. This discrepancy may be due to people being satisfied with their current heating systems and resistant to change and the inconvenience of renovation.

Heating type

The coefficient for heat pumps is 0.413 (significant at the 1% level), indicating a preference to heat pumps over district heating systems. This could be due to perceived inefficiency, lack of control or other general perceived aspects of district heating. This results is in line with other literature which also found heat pumps to be preferred over other heating systems (Michelsen & Madlener, 2012; Scarpa & Willis, 2010).

Duration of renovation

The model indicates that a shorter renovation duration of one day is generally preferred, aligning with the expectation that minimal disruption is desirable. Although the exact coefficient for this duration is manually calculated and not specified in the provided table, the preference for a brief renovation period is clear. For a one-week renovation period, the coefficient is 0.221, which is positive but not statistically significant. This suggests the effect of this level is not strong enough to be conclusive. The coefficient for a one-month renovation period is 0.085, indicating a minor positive preference, but it is also not significant. This lack of significance implies that respondents may be indifferent to a 1 week and an one-month renovation period compared to the reference category. In contrast, the option of a three-month renovation period has a significantly negative coefficient of -0.647, significant at the 1% level. This strong preference against a three-month duration likely reflects the prolonged inconvenience and disruption associated with extended renovations, likely due to the prolonged inconvenience and disruption associated with extended renovations.

Investment costs

The coefficient for an investment cost of €8,000 needs to be manually calculated but is expected to be positive, reflecting a preference for lower investment costs. Generally, lower costs are more appealing, indicating that respondents are likely influenced by budget constraints or the desire for cost-effectiveness. For an investment cost of €20,000, the coefficient is -1.001, significant at the 1% level, showing a strong preference against this higher cost. The coefficient for an investment cost of €30,000 is -0.378, also significant at the 1% level, indicating that this level of cost is undesirable, though less so than €20,000. This was unexpected, the hypothesis was a negative linear relation divided over the different investment costs levels. For the highest investment cost of €50,000, the coefficient is -1.092, significant at the 1% level, indicating the strongest aversion to this cost level. The significance and magnitude of this coefficient highlight the critical impact of investment costs on preferences, with higher costs significantly deterring choices. Although the impact of investment costs isn't straightforward, future analysis will simplify this by using just one parameter for price. This approach makes it possible to understand how much people are willing to pay. By doing this, there can be analysed how different costs influence people's decisions.

Energy costs

In the model, an energy cost of €0 per year serves as the reference category with a manually calculated negative base coefficient, setting the standard against which other energy cost options are compared. Moving to an energy cost of €500 per year, the model reveals a coefficient of 0.557, which is significant at the 5% level. This suggests a preference for this relatively low annual energy cost, likely due to perceived efficiency or sustainability benefits, indicating that even a small annual cost is seen as more favourable than having no energy costs at all. As energy costs increase to €1,500 per year, the model still shows a preference for this option over the reference, with a positive and significant coefficient of 0.507. This indicates that respondents are willing to pay higher energy costs if they perceive benefits from doing so. However, when energy costs rise to €3,000 per year, the model indicates a shift with a coefficient of -0.397, significant at the 1% level. This shift signifies a strong aversion to this higher cost, highlighting a sensitivity to increasing energy expenses that can deter individuals from opting for such options in their decision-making.

Reduction of C02 production

reduction serves as the baseline with a manually calculated negative coefficient, setting the reference level for comparing more substantial reductions. As CO2 reduction targets increase to 15%, the model reveals a positive coefficient of 0.529, significant at the 5% level, indicating a preference for moderate reductions. This shows an inclination towards environmentally friendly choices. But the preferences is even greater for higher reductions. At a 30% reduction, the coefficient increases to 0.744, significant at the 1% level, signalling a strong preference for substantial CO2 cuts. This highlights the importance of significant environmental impact in decision-making. For the highest target of 55% reduction, the coefficient soars to 1.227, also significant at the 1% level, showing the strongest preference. This underscores the high value placed on aggressive CO2 reduction, reflecting a deep commitment to environmental considerations.

6.2 Latent class model

While the MNL model presented and explained above, gives some interesting insights into the RHS choice behaviour, it does not fit the data very well (McFadden's ρ^2 = .1222). This can be caused because an MNL assumes that all respondents share the same preferences and willingness to pay in relation to RHS. It can occur that market segments with distinctly different preferences may be present in the data set. Therefore a LCA model is estimated. Which accounts for heterogeneity among passengers by extracting segments that share similar impactful attributes of RHS choices. To find the best fitting models several models with a different number of segments have been estimated. To determine the optimal number of segments, model statistics and interpretation of segment distribution. The in- and output of the estimated models with 2 and 3 segments are added in appendix K. When comparing the results of the model containing 2 segments to the model containing 3 segments. It can be seen that the three-class model, provides a superior fit to the data. This superiority is evident from the improved log-likelihood, AIC and R-squared values. However when examining the effects on the attributes it can be seen that, the three-segment model exhibited several highly deviant parameters, indicating that this separation is not suitable. Based on these indicators and interpretation a latent class model with two segments emerged as best. This finding confirms the existence of heterogeneity. In table 14 the results from the two-segments LCA are summarized and presented.

Table 14 – Results Latent Class Analysis

ID	Level	Segment 1			Segment 2		
		Coeff.	Prob. |z|>Z*	WTP[a)]	Coeff.	Prob. |z|>Z*	WTP[a)]
CONS	Constant	-2.976***	0.000	-€ 197.911,82	2.251***	0.000	€43.869,74
Heating type							
	District heating	0.000	(base)		0.000	(base)	
A1	Heat pump	0.662***	0.000	€ 44.024,24	0.622***	0.000	€12.122,16
Duration of renovation							
	1 day	0.000	(base)		0.000	(base)	
A2	1 week	1.139***	0.000	€ 75.746,46	0.474**	0.039	€ 9.237,79
A3	1 month	0.278	0.188		-0.160	0.428	
A4	3 months	-2.131***	0.000	-€ 141.717,10	0.670***	0.006	€13.057,69
Energy costs							
	€0/year	0.000	(base)		0.000	(base)	
A8	€500/year	1.805***	0.000	€120.037,24	-1.945***	0.000	- €37.906,10
A9	€1.500/year	1.499***	0.000	€ 99.687,44	-1.142***	0.000	-€22.256,44
A10	€3.000/year	0.280	0.368		-1.713***	0.000	-€33.384,65
Reduction of CO2 production							
	5%	0.000	(base)		0.000	(base)	
A11	15%	-0.181	0.631		1.393***	0.000	€27.148,17
A12	30%	0.385	0.116		0.432**	0.031	€ 8.419,25
A13	55%	2.222***	0.000	€ 147.768,84	0.248	0.210	
Segment probability		0.519***	0.000		0.481***	0.000	
Price parameter		1.50E-05*	0.059		-5.13E-05***	0.000	
Model fit statistics							
Number of observations		1720					
Number of groups		215					
LL(0)		-1889.056					
LL(β)		-1467.350					
Chi squared		844.526					
Significance level		0.000					
McFadden's ρ2		0.223					

***, **, * ==> Significance at 1%, 5%, 10% level.

a) Blank indicates €0

The willingness to pay presented in in table 14 is calculated using the price parameter which is computed using the LCA. To compute this variable the actual values of the alternatives were added in the data. This leads to a price parameter describing the marginal utility of price. This marginal utility of the price is used calculate the WTP, using the formula presented in the methodology. The price parameter in both segments are significant meaning the WTP can be calculated. However, a difference can be seen between both segments.

6.1.1 General model performance

It can be seen that 52,1% of all the respondents (n=112) belong to the first segment and that the remaining 47,9% (n=103) belong to the second segment. Overall the log-likelihood values improve significantly from a baseline of -1889.61314 to -1467.35025 when all predictors are included, demonstrating an enhanced fit of the model. These values lead to the McFadden's Rho-squared value of 0.2234653. The chi-squared statistic of 844.52578 with a significance level of 0.000 validates that there is a significant difference between the preferences of the segments. The model, supported by 1720 observations across 215 individuals provides a solid statistical foundation, enabling it to reliably differentiate between the segments.

6.1.2 Segment analysis

The latent class analysis presents two distinct segments, each with unique preference valuations concerning various attributes, as reflected in the significant differences in their coefficients and willingness to pay (WTP). The price parameter included in the table above represents the marginal utility of price. It is expected that that the price parameter would be negative. Because price increasing by 1 unit would lead to a lower perceived utility.

The first segment has a positive price coefficient (1.50E-05). A positive value was not expected, This can be caused by the non-linear relationship of the price parameters. The price parameter is not significant at 5% level. Both of these findings indicate that this segment is price incentive. The WTP for this segments results in extreme values. All of this are reason for exclusion of further analysis.

The second segment has a larger negative willingness to pay coefficient, namely -5.13E-050. This value has proven to be significant, meaning that his group does behave as expected. This confirms that the WTP for segment 2 can be calculated using the price parameter. The unexpected nature and size of this value will lead to trustworthy extreme values which are presented in the graph above

The price parameter did not turn out significant meaning the WTP cannot be determined for Segment 1. However the coefficients do give insights in the preferences of this segment. Segment 1 has with a strong negative constant of -2.976, indicating an inherent aversion to the reference choice. This suggests that this segment is generally less satisfied with the status quo or default options. This segment shows a clear preference for heat pumps over district heating, with a coefficient of 0.662. Additionally, Segment 1 members prefer shorter renovations, with one week showing a strong positive preference (coefficient of 1.139). In contrast, a three-month renovation duration is strongly disliked, as shown by a coefficient of -2.131, highlighting aversion to longer disruptions. There is a willingness to accept some annual energy costs, indicated by significant coefficients for €500/year and €1,500/year. The energy costs of €500/year are slightly preferred over the energy costs of €1,500/year. Noteworthy is that the €0/year attribute is not significant, which aligns with the price incentives of this segment. Lastly, a strong environmental preference is visible with a high positive coefficient of 2.222 for a 55% reduction in CO_2. among all attributes the environmental impact is valued relatively high. Overall segment 1 leans towards preferences that emphasize environmental benefits and quality, with less sensitivity to higher costs.

In stark contrast, segment 2 exhibits a positive constant of 2.251, indicating a baseline favourability towards the new renewable residential heating systems. Another important difference is the behaviour of the price parameter. This parameter indicates that this segment is sensitive to price changes making it possible to calculate the WTP for this segment. Similarly to segment 1, segment 2 prefers heat pumps but the coefficient is slightly lower at 0.622. With this perceived utility there can be determined that segment 1 is willing to pay €12,122.- more for a heat pump than a district heating installation. Preferences in segment 2 are milder with positive coefficients for shorter durations, indicating some acceptance of renovation but concern over costs.

There is a notable aversion to higher energy costs, particularly for €500/year and €1,500/year, with strong negative coefficients along with strong negative WTP for energy costs, indicating that segment 2 is highly sensitive to increases in energy costs, potentially due to tighter budget constraints. The negative willingness to pay compared to the base level indicate that segment do not expects high energy costs after making an investment in their residential heating system. A 15% reduction in CO2 shows a positive coefficient, and WTP of € 27,148.- suggests that while segment 2 recognizes the importance of moderate environmental improvements. Overall segment 2 demonstrates more cost sensitivity, with preferences shaped more by economic considerations and less emphasis on the additional environmental benefits of higher cost options.

Concluding there can be stated that, the differences between segment 1 and segment 2 underscore varying priorities and decision-making criteria. A clear distinction between the segments can be made. To summarize and describe the segments the first segment could be considered 'The Eco-Investors'. This segments exhibits a strong preference for environmentally friendly options such as heat pumps and significant CO2 reductions. They are willing to pay more for these benefits and show a higher tolerance for energy costs, suggesting that they see value in investing in sustainability and efficiency. However they do have a high negative constants indicating that they initial are opposed to a new residential heating system. The second segment can be described as 'Cost-Conscious investors'. This segment is highly sensitive to price and adverse to higher investment and energy costs. They demonstrate practicality in their choices, focusing more on immediate costs than on the potential long-term environmental benefits of more expensive options. This segment prioritizes economic considerations, indicating a pragmatic approach to decision-making.

6.1.3 Personal variables

To gain a better understanding of the segments estimated in the LCA, the segments are examined based on personal variables. This analysis is done using the statistical software of SPSS. In this specific case chi squared test and t-test are used. This analysis of the segments using demographic and household data could enhance the understanding of the population and the segments. Table 16 provides a comprehensive breakdown of demographic and household characteristics across two defined segments along with the bivariate analysis statistics. This detailed segmentation is aimed at identifying whether significant differences exist between the segments using bivariate analyses based on various factors such as gender, education, age, household composition, household size, income, dwelling type and size, age of dwelling, energy label, and annual gas consumption. The table where these statistical results are mentioned, along with the direct output from the statistical software is added in appendix L.

The analysis using personal variables shows that the two segments are very similar across the personal factors, indicating a uniformity in characteristics within these segments. Gender distribution is nearly equal in both segments, although there are minor differences in education levels, with segment 1 having more low/middle educated members and segment 2 having a higher proportion of highly educated individuals. The age distribution is evenly split, and the majority of households in both segments have children. Income levels and dwelling features such as type, size, and age do not significantly differ between the segments. Additionally, energy efficiency levels and annual gas consumption patterns are comparable across the segments.

These findings suggest that demographic and household variables do not strongly differentiate the segments, implying that other factor, perhaps related to personal behaviours, preferences, or external environmental influence, might better account for the distinctions between segment 1 and segment 2.

6.1.4 Mental variables

As previously explained the questions regarding mentality of the responded included in this research will be recoded using a factor- and Cronbach's alpha analysis. The Factor analysis indicated strong correlations between the attitudes towards environmental products and the willingness to pay for them, without any issues of multicollinearity. the factor analysis suggested that one component could explain 70% of the variance, simplifying the interpretation by suggesting a single underlying environmental attitude factor. Here for the segment analysis, a further insight is provided by also considering the statements separately. This provides a complete overview. The bivariate analysis used to compare the means of the segments is a t-test. The output of the bivariate analysis is added in appendix M. This is further summarized in table 16.

Table 16 – Class analysis using mental variables

	Class 1		Class 2		Test statistics		
Factor	mean	St dev.	mean	St dev.	Mean Diff.	t	p
Environmental attitude	2.400	0.734	2.490	0.821	-0.084	-0.786	0.430
Using environmentally friendly products is important	1.960	0.816	2.030	0.834	-0.065	-0.576	0.565
I am willing to pay more for environmental for sustainability products	2.570	0.908	2.680	0.982	-0.108	-0.839	0.402
The government should introduce stricter environmental laws	2.770	0.995	2.990	1.192	-0.222	-1.489	0.138
I feel personally responsible for preserving the environment	2.380	0.871	2.340	0.869	0.035	0.296	0.767

The statistical analysis looked at environmental attitudes (AC) in two segments and found small differences in average scores. segment 2 had slightly more varied scores compared to segment 1. When analysis the combined variable the Levene's test showed that the variances between the segments were significantly different (p = 0.030), meaning there could not be assumed that both segments have equal variances. To still be able to asses if a significant difference can be found an Independent Samples t-Test, considering both equal and unequal variances, was used. When considering the other variables equal variances could be assumed.

None of the factors show a statistically significant difference between segment 1 and segment 2, as all p-values are above 0.05. The differences in means are small and indicate that both segments have similar attitudes and behaviours regarding the environment.

6.3 Discussion

This study provides valuable insights into the preferences and willingness to pay (WTP) for gas-free residential heating systems (RHS) among homeowners in the Netherlands. By identifying distinct market segments and understanding their unique decision-making criteria, this research offers a comprehensive view of the factors influencing the adoption of sustainable heating technologies. However, some limitations need to be considered when interpreting the results.

An important limitation concerns the representativeness of the research population. In this research, the personal characteristics of the research population were compared to the national population of the Netherlands using bivariate analysis. The results showed significant differences between the sample and the national population, limiting the generalizability of the research findings. Households with a Dutch background, higher incomes, children, and those living in relatively large detached houses were overrepresented. This overrepresentation might be due to the use of personal networks as one of the ways to distribute the survey, potentially leading to response biases. The generalizability of results from a discrete choice analysis is already limited due to the experimental nature of the choice context, as opposed to real-world decision-making scenarios.

Further, when analysing the generated segments using personal variables previously identified as influencing decision-making. None of these personal variables yielded significant results when comparing the segments, indicating no substantial differences in personal characteristics between the segments. It was also expected that environmental awareness would provide some explanatory power; however, the t-test results were negative. Even when assessing the included statement factors separately, no significant results were found. Future research could explore these models more deeply by including different personal variables that might result in significant findings, providing better insights into the segments. The lack of significant variables in the bivariate analysis could also be due to sample size biases or insufficient sample size. Expanding the sample size in future research could improve the robustness and generalizability of the findings, offering a more nuanced understanding of variations in preferences and WTP.

When analysing the WTP values of the segments, segment 2 is the most interesting segment. Here there can been seen that the respondents in this segment are willing to pay a base value of €43.869,- for a new more sustainable heating system with all the base attributes. When optimizing the attributes of this heating system the willingness to pay can rise to € 93.197,-. When choosing the least attractive attributes the willingness to pay will decrease to €5.963,-. This indicates the impact of the attributes of the RHS. The first segment did not result in significant price parameter meaning no WTP values can be determined for this segment.

Another noteworthy result is the unexpected behaviour of the MNL regarding the investment costs. It was expected that the effect of the various levels of investment costs would present a linear negative relation, making the generation of a single variable for price more stable. However, an unexpected non-linear relation was found which proved significant, this can be caused by respondents not responding consistently to the price levels. This inconsistency might be due to some choice sets presenting a clear winner, influencing respondents' decisions in a way that deviates from the expected linear pattern. This lead to the inability of determining the WTP for the first segment.

The use of stated choice modelling also imposes some general limitations. This research method assumes that people's decisions are entirely rational and based on the attributes and levels included in the model. In reality, choices can be influenced by variables not included in the model. This limitation suggests that future studies should consider incorporating a broader range of influencing factors to capture the complexity of decision-making processes more accurately. Additionally, the experimental setting of the stated choice model may not fully replicate the conditions of real-world decision-making, further limiting the applicability of the findings.

Overall, while this study provides valuable insights, it is essential to recognize and address these limitations to enhance the validity and applicability of future research in understanding homeowner preferences and will

7. Conclusion

This study aimed to identify distinct market segments based on homeowners' preferences and willingness to pay (WTP) for gas-free residential heating systems (RHS) in the Netherlands. The analysis focused on understanding the heterogeneity in decision-making criteria among different segments of homeowners.

The research utilized a latent class model and a stated choice experiment to gather empirical data, which were analysed using SPSS and NLogit 6. The results highlighted several key factors influencing homeowners' RHS choices, including heating type, duration of renovation, investment costs, energy costs, and CO2 reduction levels.

Homeowners in the Netherlands showed an overall preference for heat pumps over district heating systems, likely due to perceived inefficiencies and lack of control associated with district heating. Shorter renovation periods were preferred, with a significant aversion to renovations lasting three months. This preference aligns with the desire to minimize disruption and inconvenience.

Lower investment costs were significantly preferred, indicating that budget constraints play a critical role in decision-making. Higher investment costs had a negative effect on the choice for sustainable RHS, This all underlines the importance of affordability in adopting new heating systems. Homeowners were willing to accept some increase in annual energy costs, but there was a strong aversion to significantly higher energy expenses. This suggests that while efficiency and sustainability are valued, cost remains a significant barrier. Significant preferences were shown for higher CO2 reduction targets, indicating a strong environmental consciousness among homeowners. The highest reduction target (55%) was particularly favoured, reflecting a commitment to environmental sustainability.

The latent class analysis (LCA) revealed two distinct segments among homeowners. The first group, Eco-Investors, exhibited a strong preference for environmentally friendly options, such as heat pumps and substantial CO2 reductions. They were willing to pay more for these benefits and showed higher tolerance for energy costs, suggesting they value sustainability and efficiency. This segment however has a high negative constant indicating that this segment is less likely to invest in a sustainable RHS in general. The reaction of this segment on price is also considerably lower than the other group. This all makes this segment less attractive for policy makers and investors to target with subsidies because the responses would be minimal due to the general aversion of undergoing a RHS renovation.

The second group, Cost-Conscious Investors, was highly sensitive to price and adverse to higher investment and energy costs. They prioritized economic considerations over environmental benefits, indicating a pragmatic approach to decision-making. This is backed by the high coefficients on either investment costs as annual energy costs. This segment is interesting to target for policymakers and stakeholders because here a significance difference can be made when decreasing the initial investment costs

The findings of this study has implications for policymakers and stakeholders involved in the energy transition. Understanding the distinct preferences and WTP of different market segments can help in designing targeted subsidies and incentives. In this case, Eco-Investors might be more responsive to subsidies that support high CO2 reduction technologies than RHS, while Cost-Conscious Investors might benefit more from financial assistance that lowers upfront investment costs. Tailored communication strategies that address the specific concerns and motivations of each segment can enhance engagement. Highlighting the long-term cost savings and environmental benefits to Cost-Conscious Investors, and emphasizing the environmental impact to Eco-Investors, can foster broader acceptance and participation in the transition to gas-free RHS.

The findings of this study are limited by a slight sample bias, in the sample higher income, Dutch households with large homes are overrepresented. Other limitations are caused by the experimental nature of discrete choice modelling, which may not reflect real-world decisions. Segment analysis found no significant differences in personal variables or environmental awareness, possibly due to the bias sample. and Investment cost responses showed unexpected non-linear patterns, suggesting inconsistent behaviour.

For future research including a larger sample which might me more representable of the Dutch population might lead to new interesting insights in the segments which are found. This might also assist in making the cost variable behave more linear. Further research can also focus on excluded variables and technologies which also might help explain the segmentation. Lastly further research can do longitudinal studies to track possible changes over time.

This comprehensive study illustrates the complex nature of homeowner decision-making regarding gas-free RHS in the Netherlands. By identifying distinct market segments and understanding their unique preferences and WTP, the research provides valuable insights that can inform more effective policies, incentives, and market strategies. The findings highlight the importance of considering both economic and environmental factors in promoting sustainable heating solutions and underscore the potential for targeted approaches to enhance participation and achieve energy transition goals.

7.1 Recommendations

Policymakers should consider the heterogeneity in homeowner preferences when designing and implementing policies. Flexible policies that accommodate different needs and constraints can improve the effectiveness and adoption rates of gas-free heating solutions. The insights into homeowners' WTP can inform the pricing strategies of RHS technologies and services. By aligning product offerings with the financial capabilities and preferences of different segments, providers can enhance market penetration and drive growth in the RHS sector. Some segments in the population might respond to the costs aspects of solutions. And other segments rather focus on the environmental impact. In this case, it can be observed that Cost-Conscious Investors would be influenced by allocating funds to subsidies specifically for RHS. In contrast, Eco-Investors would prefer to see the funds allocated to other impactful environmental subsidies and developments.

The study underscores the need for further research to deepen understanding of homeowner preferences and behaviours. Future studies should aim to include larger sample sizes to improve the robustness and generalizability of the findings. A broader demographic representation can provide more nuanced insights into regional and socio-economic variations. Conducting longitudinal studies can help track changes in preferences and WTP over time, especially as new technologies emerge and market dynamics evolve. This can provide valuable information for adapting policies and strategies to shifting trends. Integrating more personal and mental factors into the analysis can offer a deeper understanding of the segments. These findings could help predict which segment a specific person is likely to belong to, thereby simplifying the implementation of measures in real-world applications. Exploring the role of social norms, peer influences, and cognitive biases can also further enrich the analysis.

8. References

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Appendix A - Overview of included studies

Appendix B - Data extraction table

Appendix C - SAS in- and output

Appendix D - Choice sets

Appendix E - Informed consent form

Appendix F - Survey questions

Appendix G - Survey results

Appendix H – Sample validation - Chi squared test

Appendix I - Factor analysis statements

Appendix J - Corelation matrix

Appendix K - MNL and LCA Nlogit6 in-output

Appendix L - Chi squared class analysis personal variables

Appendix M - T-test class analysis mental variables